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RESEARCH ARTICLE

Acute neuromuscular and hormonal responses to 20 versus 40% velocity loss in males and females before and after 8 weeks of velocity-loss resistance training

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Abstract

Scientific examination of velocity-based resistance training (VBRT) has increased recently, but how males and females respond to different VBRT protocols or how these acute responses are modified after a period of training is unknown. Habitually resistance-trained males and females followed either a 20 or 40% velocity-loss programme for 8 weeks. Acute squat loading tests (five sets, 70% one-repetition maximum load, 3 min rest) were performed before and after the training period. Tests of maximum neuromuscular performance and blood sampling were conducted before, within 10 min of completion (POST) and 24 h after each acute loading test. Testing included countermovement jump, resting femoral nerve electrical stimulation and bilateral isometric leg press. Blood samples were analysed for whole-blood lactate, serum testosterone, cortisol, growth hormone and creatine kinase concentrations. Countermovement jump height, maximum isometric bilateral leg-press force and the force from a 10 Hz doublet decreased in all groups at POST after 20 and 40% velocity loss. Only males showed reduced force from the 100 Hz doublet and voluntary force over 100 ms at POST before training. The 40% velocity loss led to increased blood lactate and growth hormone responses before training in both males and females. After training, more systematic and equivalent responses in force over 100 ms, force from a 100 Hz doublet and blood lactate were observed regardless of sex/VBRT protocol. Overall, acute responses were greater from 40% VBRT, and males were more susceptible to acute loss in force production capacity before the training period. These VBRT protocol- and sex-related differences were diminished after training.

KEYWORDS
electrical stimulation, fatigue, low frequency, power, sex, strength

1 | INTRODUCTION

Fatigability, the magnitude of acute reduction in force production capacity, owing to isometric muscular contraction is typically lower in females compared with males (Petrofsky & Lind, 1975; Yoon et al., 2007). Some authors have suggested that prolonged time to task failure during submaximal isometric contractions are attributable to differing muscle perfusion (Yoon et al., 2007), potentially owing to greater intramuscular pressure in males, which is evoked by higher absolute force levels. Indeed, this phenomenon is not observed when the sexes are matched for strength (Hunter et al., 2004). Furthermore, recent evidence suggests that sex differences in fatigability are more likely to be attributable to the greater proportion of type I muscle fibres and slower muscle oxygen desaturation in females (Hunter et al., 2009; Keller & Kennedy, 2021; Wüst et al., 2008).

Between-sex investigations of fatigability using dynamic contractions are scarce in comparison to studies on isometric contractions. Nevertheless, it appears that a slow lifting tempo leads to similar observations of fatigue resistance in females (Häkkinen, 1994; Yoon et al., 2015) to those observed from isometric contractions. One area of current contention is when external loads are lifted with maximal velocity. Linnamo et al. (1998) observed that 5 × 10 × 40% one-repetition maximum (1-RM) leg-press power loading led to lower reductions in maximal and rapid force production in females (approximately −10%) compared with males (approximately −25%). Single-joint knee-extensor loadings resulted in a decreased maximal torque of ~18% in males and ~10% in females immediately after 3 × 30 × 20% maximum isometric torque contractions every 3 s (Senefeld et al., 2013). In contrast, elbow flexion contractions in the study by Senefeld et al. (2013) led to similar decreases in maximal isometric torque between sexes (approximately −15% in males vs. −13% in females), potentially suggesting muscle-specific influencing factors. Nevertheless, as discussed in the preceding text, it is justifiable to confirm potential between-sex fatigability after fast contractions and to investigate the acute responses to electrical stimulation in males and females.

From a practical perspective, using generic training protocols (i.e., a number of sets and repetitions for a given percentage of maximum strength) might inherently increase heterogeneity in the acute responses, considering that a different number of repetitions per set with the same relative load can be performed by different individuals (González-Badillo et al., 2017). Following the predictability of a strongly correlated load–velocity relationship, both the intensity and the volume of loading can be programmed using velocity-based resistance training (VBRT). At present, no study has investigated potential between-sex fatigability when intra-set velocity loss is standardized in males and females. It would be reasonable to hypothesize that the previously observed fatigue resistance in females would be diminished when sets are continued until a predetermined fatigue level.

Fatigue, fatigability and the intensity and volume are intrinsically interlinked and result in varying metabolic stress and acute endocrine responses to loading. Acute resistance loadings with higher intensity and volume lead to greater acute increases in blood lactate concentration (Häkkinen & Pakarinen, 1993; Kraemer et al., 1990). This greater metabolic stress is accompanied by larger increases in serum hormone concentrations of testosterone, growth hormone and cortisol (Häkkinen & Pakarinen, 1993; Kraemer et al., 1990; Smilios et al., 2003). In particular, associations between loading-induced increases in blood lactate and serum growth hormone have been observed (Gordon et al., 1994; Häkkinen & Pakarinen, 1993). It would be logical to expect, therefore, that greater acute responses would occur from velocity-loss protocols where greater fatigue occurs from a higher number of repetitions performed per set (e.g., 40 versus 20%), regardless of sex. To date, no data exist on the acute neuromuscular and hormonal responses to different VBRT methods despite the current popularity of the topic, and again, potential sex-related differences have not been studied using standardized velocity-loss protocols to our knowledge. Such investigation is justified, because females have previously demonstrated blunted acute growth hormone responses after power loading, at least using generic protocols (Linnamo et al., 2005).

Finally, given that work from our laboratory has repeatedly shown that fatigability differs after several weeks of resistance training (Ahtiainen et al., 2003; Walker et al., 2013, 2017, 2015), it is also pertinent to assess acute responses before versus after a short-term training programme. Therefore, the purpose of the present study was to investigate acute neuromuscular and hormonal responses to two different velocity-loss protocols (20 and 40% velocity loss) before and after an 8-week resistance training period using the corresponding

New Findings

- **What is the central question of this study?**
  Do males and females differ in fatiguability during dynamic loadings, and what are the acute neuromuscular and hormonal responses to 20 versus 40% velocity-loss resistance loadings? How does an 8-week velocity-loss resistance training period modify acute neuromuscular and hormonal responses in males and females?
- **What is the main finding and its importance?**
  Using resistance training methods that regulated the within-set fatigue limit, males appeared to be more susceptible to fatigue than females before the training period. This between-sex difference was diminished after training. The predominant mechanisms of fatigue from 20 and 40% velocity-based resistance training appear to be within the musculature.

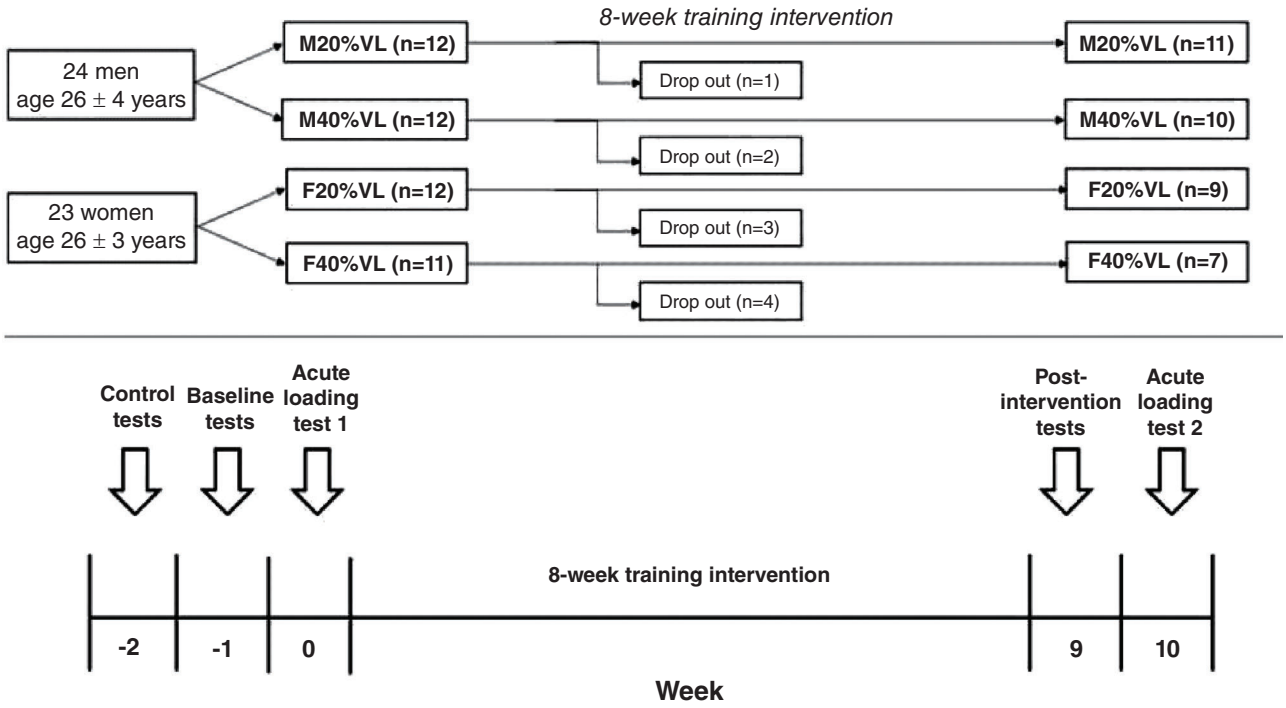

FIGURE 1 Study flow and time line. Outcome measures from the training intervention have been reported previously (Rissanen et al., 2022). Dropouts were attributable to illness ($n = 2$), injury related to the study methods ($n = 2$), injury not related to the study methods ($n = 1$), lack of motivation/interest to continue ($n = 2$) and undisclosed pregnancy ($n = 1$). Two females were also removed from 40%VL analyses owing to atypical hormone concentrations, potentially attributable to their contraceptive medication. The final sample size for each group taken into analyses can be seen in the boxes at the top right corner. Abbreviations: M20%VL, males training to 20% velocity loss per set; M40%VL, males training to 40% velocity loss per set; F20%VL, females training to 20% velocity loss per set; F40%VL, females training to 40% velocity loss per set

velocity-loss threshold in habitually resistance-trained males and females.

2 | METHODS

2.1 | Ethical approval

The study was conducted according to the *Declaration of Helsinki* (2013), except for registration in a database, and was granted ethical clearance by the Ethical Committee of the University of Jyväskylä (23/05/17). Written informed consent was obtained from the subjects before measurements.

2.2 | Study design

This was a sub-study of a larger 8-week training-intervention study that we conducted from August 2017 to December 2017, and the outcome measures from the training intervention (pre- vs. post-training) have been reported previously (Rissanen et al., 2022). Figure 1 shows the study design and time line. Subjects were divided by sex, then males and females were pair matched based on 1-RM performance obtained during the control test. Variance between pairs was 0.3 ± 4.5% for males and 6.2 ± 3.6% for females. Members of each pair were then randomized to either a 20% velocity-loss group (20%VL) or a 40% velocity-loss group (40%VL), with the exception of one woman who did not have a pair and was randomized to 20%VL. During training (two sessions per week) and the acute loading tests, subjects performed concentric repetitions as fast as possible during each set until the mean propulsive velocity (MPV) reached the assigned level for that group (i.e., 20% loss for 20%VL and 40% loss for 40%VL). At this point, the set was terminated and the 3 min allocated inter-set rest period was initiated. Acute loading tests were scheduled throughout the day (range 09.00–20.00 h), but the test time for each subject was standardized (±1 h), and this time was closely matched to their training time throughout the study. Measurements of neuromuscular function and blood samples were taken before the loading protocol (PRE), within 10 min of completing the loading protocol (POST) and 24 h after the completion of the loading protocol (POST24). The order of the measurements before and 24 h after the loading was as follows: (1) fingertip and venous blood sampling; (2) countermovement jump trials; (3) passive electrical stimulation tests; (4) maximal unilateral isometric knee extension with superimposed electrical stimulation trials; (5) maximal bilateral isometric leg-press trials; and (6) maximal concentric velocity trials with a load of 60% 1-RM. The order of the measurements immediately after the loading was as follows: (1) countermovement jump; (2) fingertip blood sampling; (3) passive electrical stimulation; (4) maximal unilateral isometric knee extension with superimposed electrical stimulation; (5) maximal bilateral

TABLE 1 Subject characteristics at baseline

Characteristic	M20%VL ($n = 11$)	M40%VL ($n = 10$)	F20%VL ($n = 9$)	F40%VL ($n = 7$)
Age (years)	26.5 ± 4.6	26.3 ± 3.3	25.8 ± 3.0	25.9 ± 3.3
Height (cm)	178.8 ± 6.2	181.2 ± 6.0	166.6 ± 6.2	165.6 ± 8.0
Body mass (kg)	82.3 ± 14.3	81.5 ± 8.0	61.8 ± 4.3	60.5 ± 9.3
Fat (%)	16.0 ± 6.8	14.2 ± 4.2	21.1 ± 4.6	22.1 ± 7.1
Squat 1-RM (kg)	113.7 ± 28.0	109.1 ± 15.8	66.3 ± 13.1	63.9 ± 14.4

Abbreviations: M20%VL, males training to 20% velocity loss per set; M40%VL, males training to 40% velocity loss per set; F20%VL, females training to 20% velocity loss per set; F40%VL, females training to 40% velocity loss per set; 1-RM, one-repetition maximum.

isometric leg press; (6) maximal concentric velocity trials with a load of 60% 1-RM; and (7) fingertip and venous blood sampling. Exact timings of these measurements are described in detail in subsection 2.5.

2.3 | Subjects

Initially, 24 healthy young males and 23 healthy young females, who were habitually active in resistance training (at least one session per week), agreed to participate in the study. Inclusion criteria were as follows: (1) aged 20–35 years; (2) proficiency in back squat and bench press exercises from ≥1 year of experience in regular resistance training; and (3) motivated and able to commit to a supervised 8-week VBRT intervention. Exclusion criteria were as follows: (1) injury or illness that might influence intense training of the lower and upper limbs; (2) being a competitive athlete in a specific sport; and (3) use of any medication/substance that might influence neural, musculoskeletal or endocrine system function (with the exception of oestrogen/progesterone-containing oral contraception in females). Before study initiation, subjects undertook an evaluation by a medical physician, including a resting ECG test and medical history, to assess suitability. Once cleared for participation, the subjects were fully informed of all study requirements, methodology, possible harms and discomforts and were given the opportunity to discuss the study with the research team. Thereafter, they signed informed consent. Subsequently, 21 males and 16 females (six using oral contraceptives: three in F20%VL and three in F40%VL) completed all study requirements (for characteristics, see Table 1) and were entered into analyses (Figure 1). The final number of subjects in each group was 11 males training to 20% velocity loss (M20%VL), 10 males training to 40% velocity loss (M40%VL), nine females training to 20% velocity loss (F20%VL) and seven females training to 40% velocity loss (F40%VL).

2.4 | Acute loading test protocol

Subjects arrived at the laboratory at their allocated time (range 09.00–20.00 h), which followed 24 h without exercise and 3 h refraining from caffeine. Thereafter, the subjects cycled for 10 min on an ergometer and performed 10 squats without external load as part of their warm-up.

To complete the warm-up, subjects performed the Smith-machine (Kraftwerk, Tuusula, Finland) back squat exercise for two sets: one set of six repetitions at 40% of predetermined 1-RM and one set of four repetitions at 50% of 1-RM. Rest times between warm-up sets were 2 min, and all concentric actions were performed as fast as possible. Subjects were instructed to perform the eccentric action in a controlled manner (i.e., ~2 s). A linear velocity transducer (T-Force system; Ergotech, Murcia, Spain) measured the MPV and relayed the data to accompanying software controlled by a laptop, which was monitored in real time by a researcher, who provided velocity feedback to the subject after each repetition and strong verbal encouragement throughout the loadings (Figure 2). The acute loading protocol consisted of five sets at 70% of 1-RM with 3 min recovery between sets, which lasted ~80 min including all measurements. This loading protocol was designed to match closely the training protocol that the subjects performed in the latter part of the 8-week period and, in particular, the final week (two sessions) of training (Rissanen et al., 2022: their table 2, p. 1271). The sets were terminated once subjects performed a repetition that reached the MPV threshold for their group (VL20% or VL40%), and the number of completed repetitions was recorded. Each concentric action was performed as fast as possible, but the subject was not allowed to jump at full extension. Instead, a slight rise onto the toes was permitted if the subject felt they would otherwise purposefully decelerate the barbell during the lift.

The depth of each squat was controlled by an infrared sensor (Faculty of Sport and Health Sciences, University of Jyväskylä, Finland) that emitted a high-pitched sound once the barbell had descended to the preassigned position (Figure 2). The electrical signal generated by the infrared sensor was also synchronized to EMG data to localize the start/end of each concentric action. Foot placement (foot width and heel position) was reproduced for each subject individually by tape markings on the floor.

2.5 | Measurements

2.5.1 | Countermovement jump height

After the completion of the warm-up (PRE and POST24), subjects stood on a custom-built force-plate (Faculty of Sport and Health Sciences, University of Jyväskylä, Finland), with hands on hips. Flight times were determined from ground reaction forces sampled at 1,000 Hz (Signal software v.4.10; Cambridge Electronic Design, Cambridge, UK), filtered by a 10 Hz fourth-order low-pass Butterworth filter, and analysed offline using a customized script. After the command 'jump', the subjects descended to a self-selected depth

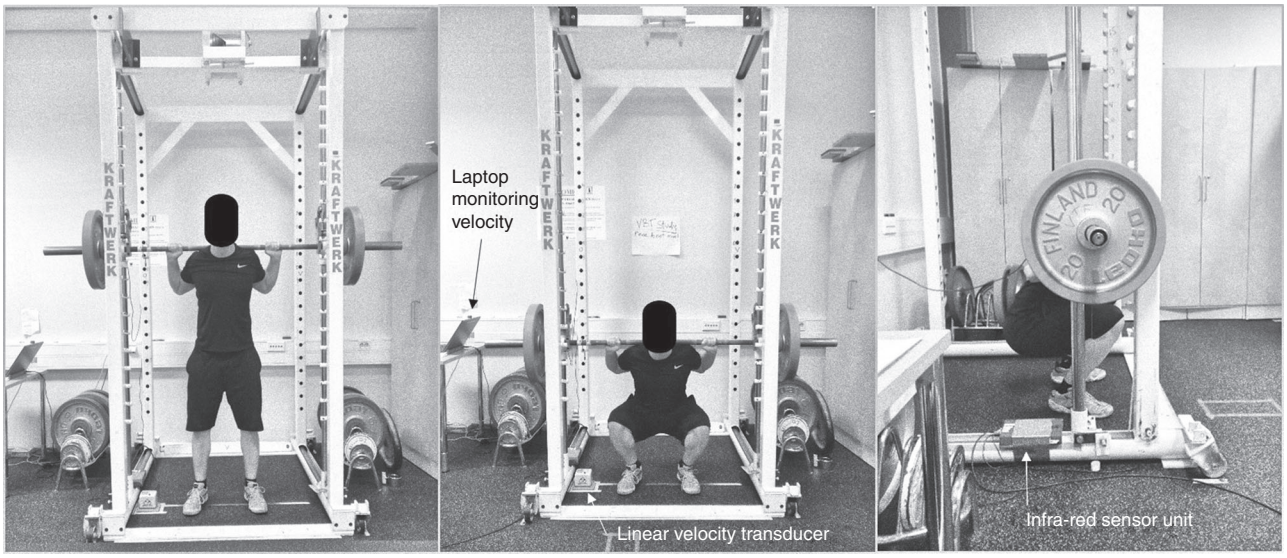

FIGURE 2 Smith-machine back squat set-up, showing the integration of the linear velocity transducer and infrared sensor in monitoring performance. This experimental set-up allowed real-time monitoring and feedback on concentric lifting performance, in addition to standardization of technique throughout the loading. The images show full extension and the base position of the squat

(knee angle of ~90°), then extended the legs and trunk as fast as possible. Subjects were instructed to jump as high as possible and to land on the toes with legs fully extended before cushioning the landing. Subjects were given verbal encouragement during each trial. Jump height was calculated from the flight time using the equation: jump height = $\frac{1}{2}g(t/2)^2$. The trial with the highest jump height (CMJ) was taken forward to further analyses. Three trials were performed before (PRE) and 24 h (POST24) after loading, with 30 s rest between trials, and one trial was performed within 30 s of completing the loading protocol (POST).

2.5.2 | Single-pulse twitch and high- and low-frequency doublet force

Single square-pulse (400 V, 200 μs duration) electrical stimulations were given by a constant-current stimulator (model DS7AH; Digitimer, Welwyn Garden City, UK) to the femoral nerve through 5 cm^2 self-adhesive square electrodes (V-trode electrodes; Mettler Electronics, Anaheim, CA, USA) placed in the femoral triangle either side of the nerve (identified by palpating and locating the femoral artery). The electrodes were replaced slightly until the greatest unilateral knee-extension twitch force response was achieved with a low stimulation intensity. The intensity was then increased until there were no further increases in force response (typically 400–600 mA). The same stimulus intensity was used at POST that was identified and set at PRE. To ensure maximal activation, an additional 20% current was used to induce two maximum single-pulse twitches in resting conditions, with the best taken into further analyses. Thereafter, six double-pulse stimulations were given in resting conditions, first at an interstimulus interval of 100 ms (i.e., 10 Hz, low frequency) then at 10 ms (i.e., 100 Hz, high frequency). Rest periods of 8–12 s were given between stimulations. At POST, the electrical stimulations began 2 min after completion of the loading protocol. The highest twitch force response to 10 Hz (TF10) and 100 Hz (TF100) were taken for further analysis, in addition to the TF10:TF100 ratio (TF10100).

2.5.3 | Voluntary activation level

During maximal unilateral (right leg) isometric knee-extension trials (knee angle of 110°), a 100 Hz doublet was given at the force plateau and 2 s after the cessation of the action (i.e., potentiated doublet). One trial was performed without electrical stimulation, in order to set the target force level for subsequent trials. Two subsequent trials were performed with electrical stimulation procedures at PRE and POST24 (1 min rest between trials), and only one trial at POST, 2 min 30 s after the loading protocol. Voluntary activation level (VA%) was determined by the following equation (Bellemare & Bigland-Ritchie, 1984):

$$\text{VA\%} = \left(1 - \frac{\text{superimposed twitch force} - \text{maximum voluntary force}}{\text{resting twitch force}}\right) \times 100.$$

All electrical stimulation trials were recorded by Signal software (v.4.10; Cambridge Electronic Design) after being passed through an analog-to-digital converter (Micro 1401; Cambridge Electronic

Design), sampled at 2,000 Hz, and analysed offline by manually positioning cursors identifying electrically induced force increases without filtering.

2.5.4 | Bilateral isometric leg press

Subjects sat in a custom-built electromechanical isometric leg-press device (Faculty of Sport and Health Sciences, University of Jyväskylä, Finland), with a hip angle of 110° and knee angle of 107°. After being instructed to push as fast and as hard as possible, subjects were given the commands, 'Ready, set, push!'. The subjects inhaled on 'set' but remained completely relaxed before the instruction, 'Push!'. The subjects maintained a forceful isometric leg-extension action for ~3 s while being given strong verbal encouragement. Force was recorded at 2,000 Hz, filtered by a 20 Hz fourth-order low-pass Butterworth filter, and analysed offline using a customized script (Signal v.4.10; Cambridge Electronic Design). Three trials were performed at PRE and POST24, with 30 s rest between trials. The POST measurements were taken 3 min after the completion of the loading protocol, and only one trial was performed. The maximum force (MVC) was obtained from the highest instantaneous force value minus the pre-existing force attributable to the weight of the legs. Cursor positions used to determine average force over 100 ms (F100) were inspected to ensure accurate identification of the beginning of force production. The best trial according to MVC and F100 was taken for further analysis.

2.5.5 | Mean propulsive power at 60% 1-RM

Subjects completed the battery of tests by performing one set of three squat repetitions at 60% of 1-RM at PRE and POST24. The concentric phase was performed as fast as possible. This test set was repeated 5 min after the completion of the loading (POST). The MPV was measured by a transducer attached to the barbell interfaced to a 14-bit analog-to-digital data-acquisition board and custom software (T-Force System; Ergotech, Murcia, Spain). Velocity was sampled at 1,000 Hz, and a 10 Hz fourth-order low-pass Butterworth filter with no phase shift was used to acquire data in real time. The propulsive phase was defined as the portion of the concentric phase during which barbell acceleration is greater than the acceleration attributable to gravity (Sánchez-Medina et al., 2010). Repeatability of the device and analysis methods have been reported elsewhere (Courel-Ibáñez et al., 2019). The highest MPV from one of the three trials was taken forward to further analyses. Mean propulsive power (MPP) was derived from the product of the external load and MPV.

2.5.6 | Muscle activity during countermovement jump, isometric leg press and squat

Self-adhesive bipolar Ag/AgCl surface EMG electrodes (5 mm diameter, 20 mm inter-electrode distance; Ambu BlueSensor N, Copenhagen, Denmark) were secured to the skin of the vastus lateralis (VL) and vastus medialis (VM) after skin preparation in accordance with Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) project guidelines. Electrode placement was in line with the orientation of the underlying fascicles and marked by indelible ink tattoos (Häkkinen & Komi, 1983) to ensure accurate replacement after the training period. Raw signals were sent from a hip-mounted pack to a receiving box (Telemyo 2400R; Noraxon, Scottsdale, AZ, USA), then relayed to an analog-to-digital converter (Micro 1401; Cambridge Electronic Design) and recorded at 2,000 Hz by Signal v.4.10 software (Cambridge Electronic Design). The EMG signals were amplified at a gain of 500 (bandwidth 10–500 Hz, common mode rejection ratio >100 dB, input impedance >100 MΩ, baseline noise <1 μV root mean square) and sampled. Offline analyses were conducted using customized scripts, in which the signals were filtered using a 20–350 Hz bandpass, and the concentric phase of the countermovement jump (CMJ_{EMG}) and back squat (MPP_{EMG}) tests were identified and isolated for concentric root mean square EMG amplitude assessment. For isometric leg-press trials, root mean square EMG amplitude was taken from 0 to 100 ms ($F100_{EMG}$) and from 500 to 1,500 ms (MVC_{EMG}) after the beginning of force production. The EMG amplitudes of vastus lateralis and medialis were inspected individually, were combined and averaged (VL + VM/2) as a representation of superficial vastii activity.

2.5.7 | Serum hormone concentrations

Venous blood samples (5 ml blood into Venosafe serum tubes; Terumo Medical, Leuven, Belgium) were collected from the antecubital vein. Samples were collected before EMG preparation and warm-up (PRE) and 10 min after (POST) the loading protocol. Basal samples, after overnight fast, were also collected between 07.00 and 08.00 h on the morning of the acute loading test (PRE_{basal}) and again after fasting between 07.00 and 08.00 h on the morning after the loading ($POST_{basal}$). Samples were centrifuged for 10 min at 4°C, 2,000×*g* (Megafuge 1.0R; Heraeus, Germany) to separate the serum and stored at −80°C until analyses. Immunometric chemiluminescence techniques were used (Immulite 1000; Siemens, IL, USA) with hormone-specific immunoassay kits to determine total testosterone (T), cortisol (COR) and human growth hormone (GH) concentrations. In addition to hormones, the creatine kinase (cK) concentration was obtained from the same serum sample and using the same methods. Data presented are uncorrected for changes in plasma volume. In our laboratory, analytical sensitivity is T = 0.5 nmol L^{-1}, GH = 0.01 μg L^{-1}, COR = 5.5 nmol L^{-1} and cK = 3.9 pg mL^{-1}, and the intra-assay coefficient of variation is T = 13%, GH = 5.8%, COR = 7.9% and cK = 5.9%.

2.5.8 | Blood lactate

Fingertip samples were taken before EMG preparation and warm-up (PRE), 1 min 30 s after (POST1) and 10 min after (POST10) the loading protocol. Samples (20 μl) were collected into capillary tubes, which

TABLE 2 Performance (mean ± SD) during acute loading tests 1 (before the training period) and 2 (after the training period)

Training	Test	Load (kg)	Average number of repetitions	Average concentric velocity (m s^{-1})	Average velocity loss (%)	Total mechanical work (J)
M20%VL	1	79.5 ± 20.5	5.1 ± 1.5	0.66 ± 0.06	19.5 ± 1.0	1,519 ± 502
	2	84.5 ± 23.7*	4.4 ± 0.8	0.72 ± 0.07	21.7 ± 1.1*	1,220 ± 164
M40%VL	1	78.9 ± 9.6	7.1 ± 1.3	0.56 ± 0.03	42.1 ± 3.3	2,108 ± 457
	2	85.6 ± 11.7*	6.0 ± 1.9	0.60 ± 0.04*	40.5 ± 1.1	1,826 ± 642
F20%VL	1	45.9 ± 9.1†	4.6 ± 1.4	0.60 ± 0.08	20.5 ± 1.3	760 ± 279†
	2	50.4 ± 10.0*†	4.4 ± 1.0	0.67 ± 0.08*	20.1 ± 1.8	735 ± 223
F40%VL	1	44.3 ± 9.7†	7.9 ± 2.6	0.53 ± 0.07	41.3 ± 4.2	1,323 ± 512†
	2	50.4 ± 10.2*†	6.3 ± 2.3	0.56 ± 0.09	41.3 ± 2.1	1,072 ± 446†

Abbreviations: M20%VL, males training to 20% velocity loss per set; M40%VL, males training to 40% velocity loss per set; F20%VL, females training to 20% velocity loss per set; F40%VL, females training to 40% velocity loss per set.

*$P < 0.05$ compared with acute loading test 1.

†$P < 0.05$ compared with the male group with the same assigned velocity loss (i.e., M20%VL vs. F20%VL and M40%VL vs. F40%VL).

were placed into a 1 ml haemolysing solution and analysed according to the manufacturer's instructions (EKF diagnostic, C-line system, Biosen, Germany) on the day of sample collection.

2.6 | Statistical analyses

All statistical procedures were performed using SPSS v.26 software (IBM statistics, IBM, Armonk, NY, USA). Standard procedures were used to determine descriptive statistics, and all data are reported as the mean ± SD, unless otherwise stated. Before analyses, tests of normality (Shapiro–Wilk) were run to ensure that the assumptions for parametric statistics were upheld. Hormone and EMG amplitude data were not normally distributed and were $\log_{10}$-transformed before performing statistical analyses (data are presented in their original form).

Repeated-measures ANOVA (three times × four groups × two loadings) was used to evaluate the effects of the loading between sexes and velocity-loss protocols for all except serum hormone variables. In this case, comparisons were made for two time points, either PRE versus POST or PRE_{basal} versus $POST_{basal}$ (repeated-measures ANOVA: two times × four groups × two loadings). In the majority of analyses, sphericity was not observed, hence Greenhouse–Geisser adjusted degrees of freedom for within-group comparisons were applied when calculating main effects for time, time × group, time × loading and time × group × loading. When a significant *F*-value was observed, post hoc tests were performed with Bonferroni adjustments to locate the source of the difference. The value of α was set at 0.05.

3 | RESULTS

3.1 | Performance during acute loading test 1 and 2

Table 2 shows the performance during each loading test for the four groups. Significant main effects for loading and group were observed in load ($F_1 = 70.4$, $P < 0.001$ and $F_3 = 16.5$, $P < 0.001$, respectively), average number of repetitions per set ($F_1 = 10.2$, $P = 0.003$ and $F_3 = 7.7$, $P < 0.001$, respectively), average concentric velocity of all repetitions ($F_1 = 22.7$, $P < 0.001$ and $F_3 = 10.3$, $P < 0.001$, respectively) and total mechanical work ($F_1 = 8.4$, $P = 0.007$ and $F_3 = 17.8$, $P < 0.001$, respectively). Average velocity loss per set showed a main effect for loading × group ($F_3 = 3.7$, $P = 0.022$).

Post hoc tests revealed that load and, in turn, mechanical work, was greater for males than for females (Table 2). Furthermore, there were significant differences in total mechanical work between M20VL and M40VL during acute loading test 1 ($P = 0.03$) and 2 ($P = 0.011$), but there were no differences in total mechanical work between F20%VL and F40%VL.

3.2 | Maximal voluntary dynamic and isometric performance

The MPP showed significant main effects for time ($F_{2,1.89} = 13.6$, $P < 0.001$), time × group ($F_{6,5.46} = 2.7$, $P = 0.021$), group ($F_3 = 28.2$, $P < 0.001$) and loading ($F_1 = 8.1$, $P = 0.006$). Post hoc tests revealed that M40%VL decreased MPP at POST compared with PRE ($P = 0.037$) during acute loading test 1. This reduced MPP was recovered at POST24 (Figure 3a). Conversely, MPP decreased in M20%VL at POST compared with PRE ($P = 0.009$) during acute loading test 2. No changes in MPP were observed in females.

The CMJ showed significant main effects for time ($F_{2,1.95} = 207.5$, $P < 0.001$), time × group ($F_{6,5.84} = 4.0$, $P = 0.001$), group ($F_3 = 35.1$, $P < 0.001$) and loading ($F_1 = 4.6$, $P = 0.036$). Post hoc tests revealed that all groups decreased CMJ at POST compared with PRE ($P < 0.05$; Figure 3b) during both acute loading test 1 and test 2. The CMJ had recovered at POST24 in all groups after both loading tests.

The MVC showed significant main effects for time ($F_{2,1.92} = 205.9$, $P < 0.001$), group ($F_3 = 18.1$, $P < 0.001$) and time × group ($F_{6,5.76} = 7.4$, $P < 0.001$). Post hoc tests revealed that all groups decreased MVC at POST compared with PRE ($P < 0.05$; Figure 3c) during both acute

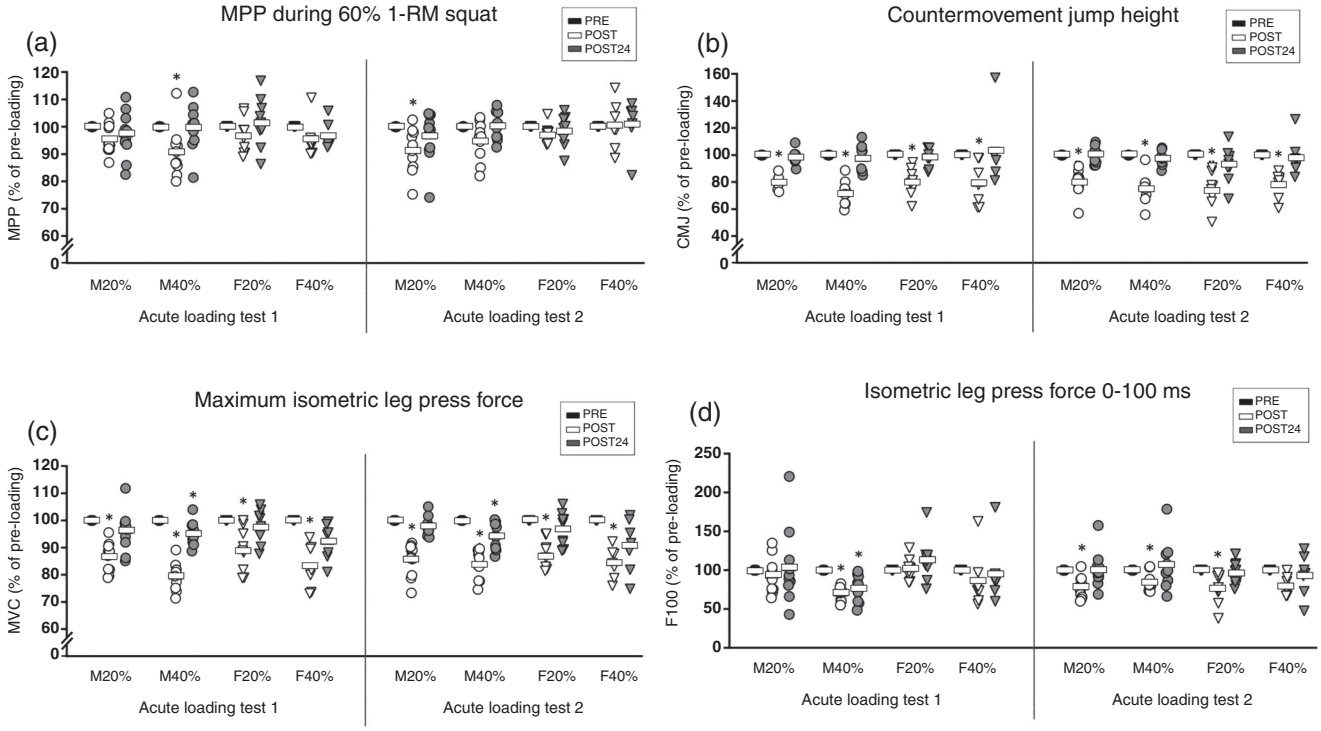

FIGURE 3 Mean (white bars) and individual data for voluntary neuromuscular performance, relative to pre-loading levels, during acute loading tests 1 (before the training period) and 2 (after the training period) in mean propulsive power (MPP) in back squat (a), countermovement jump height (CMJ; b), maximum bilateral isometric force (MVC; c) and isometric force over the initial 100 ms (F100; d) in the leg press. *$P < 0.05$ compared with pre-loading. Abbreviations: 1-RM, one-repetition maximum; POST24, 24 h after loading

loading test 1 and test 2. However, M40%VL had not recovered MVC at POST24 after acute loading test 1 ($P = 0.022$) or test 2 ($P = 0.009$). A similar trend was also observed for F40%VL at POST24 after acute loading test 1 ($P = 0.073$).

The F100 showed significant main effects for time ($F_{2,1.85} = 27.1$, $P < 0.001$), group ($F_3 = 5.3$, $P = 0.003$) and time × group × loading ($F_{6,5.56} = 2.2$, $P = 0.05$). Post hoc tests revealed that only M40%VL reduced F100 at POST compared with PRE ($P = 0.001$) during acute loading test 1, which remained decreased at POST24 ($P = 0.001$; Figure 3d). After acute loading test 2, both M20%VL and M40%VL decreased F100 at Post compared with PRE ($P < 0.05$), and also F20%VL showed decreased F100 at POST compared with PRE ($P = 0.048$), with F40%VL trending to decrease ($P = 0.066$). All had recovered at POST24.

3.3 | Voluntary muscle activity

The MPP_{EMG} showed significant main effects for time × loading ($F_{2,1.85} = 27.1$, $P < 0.001$) and time × group × loading ($F_{6,5.56} = 2.2$, $P = 0.05$). Post hoc tests did not reveal significant within-group changes in MPP_{EMG} at any time point during acute loading tests (Table 3). Also, there were no significant main effects observed for CMJ_{EMG}.

The MVC_{EMG} showed significant main effects for time ($F_{2,1.34} = 27.1$, $P < 0.001$) and group ($F_3 = 7.7$, $P < 0.001$). Post hoc tests revealed that only M20%VL decreased MVC_{EMG} at POST compared with PRE ($P = 0.002$) during acute loading test 1. However, all groups demonstrated decreased MVC_{EMG} at POST compared with PRE during acute loading test 2 ($P < 0.01$; Table 3).

The $F100_{EMG}$ showed significant main effects for time ($F_{2,1.97} = 5.8$, $P = 0.004$) and time × group ($F_{6,5.92} = 3.6$, $P = 0.003$). Post hoc tests did not reveal significant within-group changes in $F100_{EMG}$ at any time point during acute loading tests (Table 3).

3.4 | Twitch responses and voluntary activation level

The TF10 showed significant main effects for time ($F_{2,1.66} = 216.8$, $P < 0.001$), group ($F_3 = 6.7$, $P = 0.001$) and time × group ($F_{6,4.98} = 6.9$, $P < 0.001$). Post hoc tests revealed that all groups decreased TF10 at POST compared with PRE ($P < 0.05$; Figure 4a), but only F40%VL showed reduced TF10 at POST24 ($P = 0.01$) after acute loading test 1. After acute loading test 2, all groups decreased TF10 at POST compared with PRE ($P < 0.01$), but both male groups showed reduced TF10 at POST24 ($P < 0.01$).

The TF100 showed significant main effects for time ($F_{2,1.62} = 66.7$, $P < 0.001$), group ($F_3 = 15.0$, $P < 0.001$) and time × group ($F_{6,4.86} = 3.3$, $P = 0.009$). Post hoc tests revealed that both male groups decreased TF100 at POST compared with PRE ($P < 0.01$; Figure 4b) after acute loading test 1. After acute loading test 2, all groups decreased TF100 at

TABLE 3 Voluntary root-mean squared EMG amplitudes (mean ± SD) of the vastus lateralis (VL) and vastus medialis (VM) muscles (VL + VM/2) during acute loading tests 1 (before the training period) and 2 (after the training period)

		Acute loading test 1			Acute loading test 2		
Electrical activity	Training	PRE	POST	POST24	PRE	POST	POST24
MPP_{EMG} (mV)	M20%VL	0.560 ± 0.209	0.540 ± 0.158	0.767 ± 0.397	0.550 ± 0.165	0.476 ± 0.145	0.387 ± 0.155
	M40%VL	0.548 ± 0.145	0.517 ± 0.216	0.587 ± 0.198	0.606 ± 0.157	0.566 ± 0.125	0.526 ± 0.182
	F20%VL	0.532 ± 0.135	0.493 ± 0.097	0.592 ± 0.238	0.616 ± 0.229	0.595 ± 0.283	0.685 ± 0.315
	F40%VL	0.503 ± 0.230	0.578 ± 0.248	0.517 ± 0.222	0.545 ± 0.202	0.476 ± 0.152	0.544 ± 0.295
CMJ_{EMG} (mV)	M20%VL	0.795 ± 0.294	0.713 ± 0.223	0.745 ± 0.284	0.850 ± 0.242	0.819 ± 0.228	0.827 ± 0.324
	M40%VL	0.765 ± 0.288	0.718 ± 0.319	0.732 ± 0.421	0.826 ± 0.247	0.769 ± 0.160	0.824 ± 0.191
	F20%VL	0.548 ± 0.216	0.529 ± 0.133	0.469 ± 0.223	0.489 ± 0.167	0.517 ± 0.112	0.574 ± 0.289
	F40%VL	0.560 ± 0.234	0.357 ± 0.253	0.610 ± 0.311	0.490 ± 0.211	0.473 ± 0.136	0.491 ± 0.231
MVC_{EMG} (mV)	M20%VL	0.609 ± 0.236	0.558 ± 0.176*	0.606 ± 0.227	0.560 ± 0.177	0.464 ± 0.128**	0.567 ± 0.167
	M40%VL	0.547 ± 0.232	0.516 ± 0.327	0.524 ± 0.181	0.611 ± 0.174	0.489 ± 0.155**	0.548 ± 0.141
	F20%VL	0.470 ± 0.169	0.451 ± 0.170	0.428 ± 0.091	0.510 ± 0.145	0.401 ± 0.105**	0.401 ± 0.129
	F40%VL	0.344 ± 0.171	0.324 ± 0.164	0.380 ± 0.126	0.373 ± 0.126	0.317 ± 0.115**	0.345 ± 0.132
$F100_{EMG}$ (mV)	M20%VL	0.055 ± 0.022	0.050 ± 0.015	0.055 ± 0.024	0.052 ± 0.023	0.042 ± 0.014	0.055 ± 0.027
	M40%VL	0.045 ± 0.022	0.040 ± 0.023	0.041 ± 0.018	0.053 ± 0.022	0.045 ± 0.015	0.051 ± 0.026
	F20%VL	0.0013 ± 0.0006	0.0009 ± 0.0007	0.0007 ± 0.0003	0.0014 ± 0.0013	0.0016 ± 0.0009	0.0009 ± 0.0006
	F40%VL	0.0012 ± 0.0005	0.0008 ± 0.0005	0.0013 ± 0.0004	0.0010 ± 0.0009	0.0012 ± 0.0016	0.0014 ± 0.0014

Abbreviations: CMJ_{EMG}, electrical activity during countermovement jump; $F100_{EMG}$, electrical activity during bilateral isometric leg-press force production over the first 100 ms; MPP_{EMG}, electrical activity during back squat with 60% 1-RM load; MVC_{EMG}, electrical activity during maximal bilateral isometric leg-press force production; M20%VL, males training to 20% velocity loss per set; M40%VL, males training to 40% velocity loss per set; POST24, 24 h after loading; F20%VL, females training to 20% velocity loss per set; F40%VL, females training to 40% velocity loss per set; 1-RM, one-repetition maximum.
*$P < 0.05$, **$P < 0.01$ compared with pre-loading.

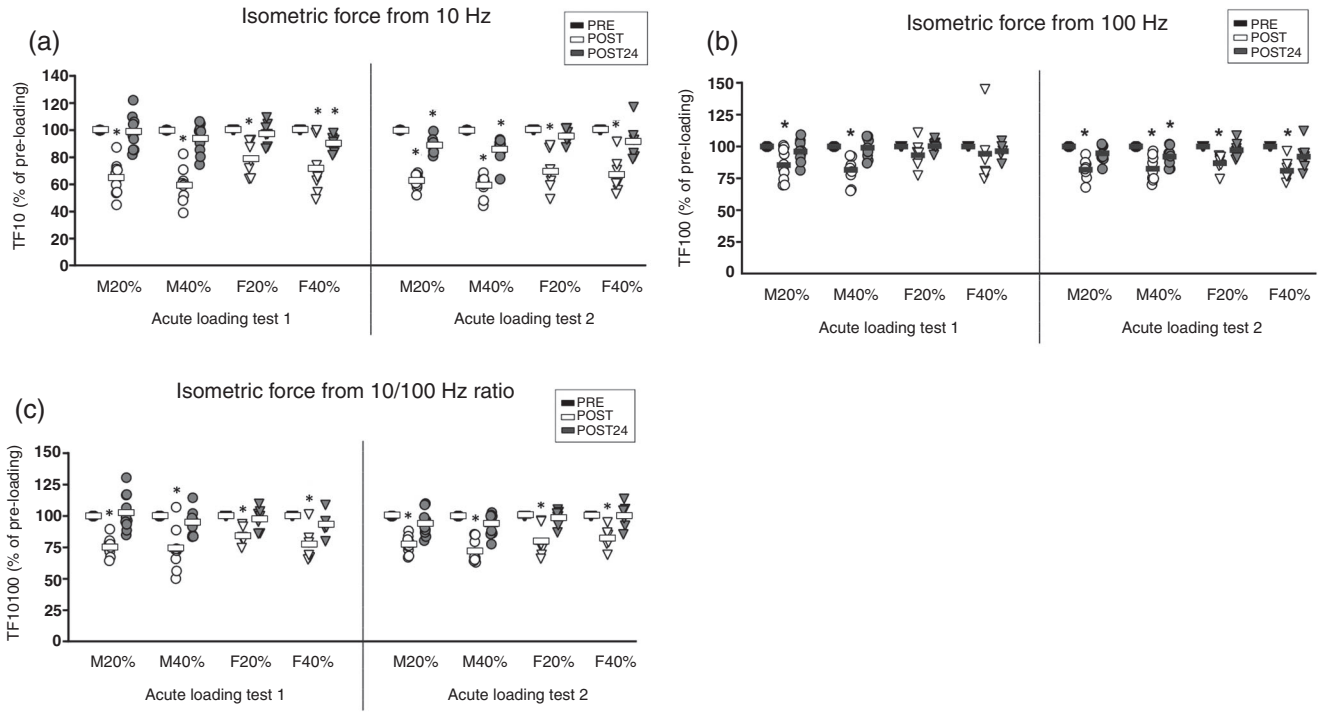

FIGURE 4 Mean (white bars) and individual data for involuntary twitch force responses after electrical stimulation, relative to pre-loading levels, from 10 Hz doublet (TF10; a), from 100 Hz doublet (TF100; b), and their ratio (TF10100; c) during acute loading tests 1 (before the training period) and 2 (after the training period). *$P < 0.05$ compared with pre-loading. Abbreviation: POST24, 24 h after loading

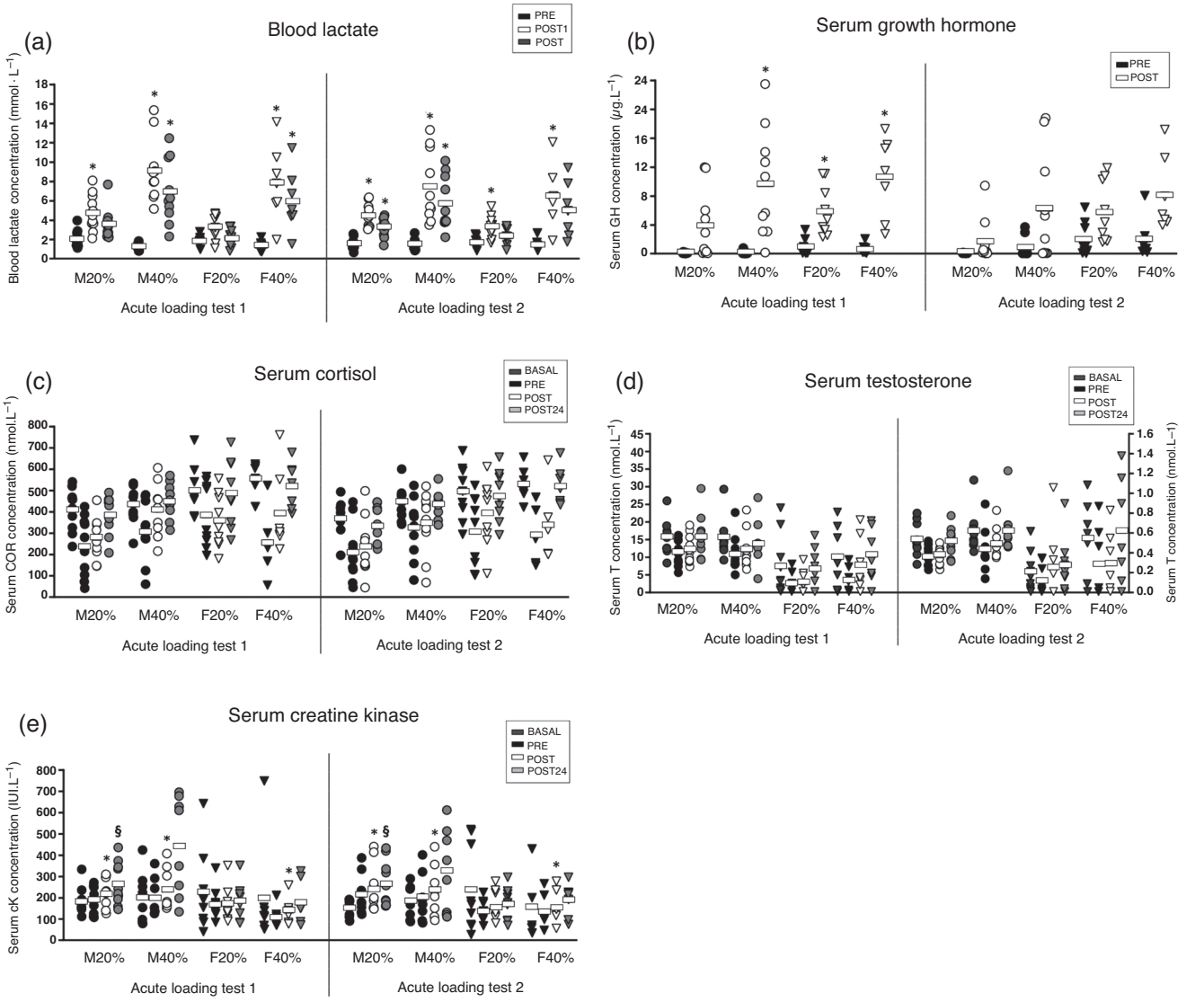

FIGURE 5 Mean (white bars) and individual data for blood lactate (a), serum growth hormone (GH; b), serum cortisol (COR; c), serum testosterone (T; d) and serum creatine kinase (cK; e) concentrations during acute loading tests 1 (before the training period) and 2 (after the training period). *$P < 0.05$ compared with pre-loading. §$P < 0.05$ compared with basal concentrations before loading. Abbreviations: POST1, 1.5 min after loading; POST, 10 min after loading; POST24, 24 h after loading

POST ($P < 0.01$), and TF100 remained lowered at POST24 in M40%VL ($P = 0.036$).

The TF10100 showed a significant main effect for time ($F_{2,1.97} = 155.1$, $P < 0.001$). Post hoc tests revealed that TF10100 decreased at POST compared with PRE ($P < 0.05$; Figure 4c) in all groups after both acute loading test 1 and test 2, with full recovery in all groups at POST24.

No main effects were observed for VA%.

3.5 | Serum hormones and blood lactate

Blood lactate showed significant main effects for time ($F_{2,1.47} = 225.7$, $P < 0.001$), group ($F_3 = 11.5$, $P < 0.001$) and time × group ($F_{6,4.42} = 14.3$, $P < 0.001$). Post hoc tests revealed that blood lactate increased at POST1 compared with PRE ($P < 0.05$; Figure 5a) in all but F20%VL, where changes were at the level of a trend ($P = 0.059$) during acute loading test 1. The loading-induced increases ($P < 0.05$) were observed in all groups at POST1 during acute loading test 2. Blood lactate remained elevated at POST in M40%VL and F40%VL during acute loading test 1, and in M20%VL and M40%VL during acute loading test 2 (Figure 5a).

There were no differences observed for basal hormone comparisons before (PRE_{basal}) versus after ($POST_{basal}$) the loadings. When running ANOVA for the immediate effects of the loadings (PRE and POST), GH showed significant main effects for time ($F_{1,1.00} = 135.6$, $P < 0.001$), group ($F_3 = 17.7$, $P < 0.001$) and time × loading ($F_{1,1.00} = 6.9$, $P = 0.011$). Growth hormone increased from PRE to POST ($P < 0.05$; Figure 5b) in M40%VL, F20%VL and F40%VL after acute loading test 1 but not after acute loading test 2. Cortisol showed significant main effects for time

($F_{1,1.00} = 14.1$, $P < 0.001$) and group ($F_3 = 3.6$, $P = 0.017$), and T showed a significant main effect for time ($F_{1,1.00} = 7.4$, $P = 0.009$). Nevertheless, there were no significant changes observed from PRE to POST in either COR or T (Figure 5c,d).

Creatine kinase showed significant main effects for time ($F_{1,1.00} = 109.6$, $P < 0.001$), group ($F_3 = 5.4$, $P = 0.002$) and time × group ($F_{3,3.00} = 4.8$, $P = 0.005$). Post hoc tests revealed that cK increased from PRE to POST ($P < 0.05$; Figure 5d) in M20%VL, M40%VL and F40%VL during both acute loading test 1 and test 2. Basal cK at POST24 was increased compared with basal cK in M20%VL after acute loading test 1 ($P = 0.048$) and test 2 ($P = 0.028$).

4 | DISCUSSION

Our study showed that after acute loading test 1, males appeared to be more susceptible to acute neuromuscular fatigue than females, and the difference in fatigability between 20 and 40% velocity loss was more pronounced in males. Furthermore, acute blood lactate and serum GH responses were more robust from 40% compared with 20% velocity-loss protocols in both males and females after acute loading test 1. Interestingly, these observed VBRT protocol- and sex-related differences were diminished after the present 8-week training period. The more systematic neuromuscular fatigue observable in females and after the 20% velocity-loss protocol after the training period (e.g., F100, TF100 and MVC_{EMG}) supports previous findings (Walker et al., 2013, 2015, 2017), whereby fatiguability is greater after a short-term training programme in non-athletic populations. Thus, the findings of the present study showed that females and males seemed to respond in a similar manner after the 8-week training period, and also re-enforces the notion that examination of acute exercise responses should be conducted in both the untrained and the trained state; and responses are not generalizable from one-shot study designs.

4.1 | Performance during the acute loadings

Theoretically, assigning a load of ~70% 1-RM should allow 10 repetitions to be performed on average, at least in males (Brzycki, 1993). The assigned velocity-loss magnitudes of 20 and 40% should have allowed four to five repetitions in the former and approximately eight repetitions in the latter with an intensity of 70% 1-RM (Sánchez-Medina & González-Badillo, 2011). In the present study, both males and females in the 20% velocity-loss groups performed approximately five repetitions in each set (range 3–8). Thus, the methods achieved their desired volume. However, the 40% velocity-loss groups performed an average of six to seven repetitions per set (range 4–11) and, as such, the training volume might be considered to be one to two repetitions per set lower than anticipated. This might be attributable to the fatigue induced in the first sets, which might decrease the maximal number of repetitions able to be completed in the last sets. Therefore, it is likely that the subjects could not perform 10 repetitions with such a load over the five sets.

This small difference in the number of repetitions performed resulted in only the male groups showing statistically significant differences in mechanical work between 20 and 40% velocity-loss protocols. Thus, the 20% velocity-loss protocol followed the anticipated so-called maximum strength/power protocol. However, it could be argued that the 40% velocity-loss protocol did not match the so-called hypertrophic protocol (American College of Sports Medicine, 2009) expected, which has previously been shown to result in differing long-term adaptations (Pareja-Blanco et al., 2017; Pareja-Blanco, Alcazar et al., 2020). Overall, the magnitude of responses, along with the lack of change in cortisol and limited cK responses, suggest that the loadings were not particularly stressful metabolically nor damaging to the muscle tissue; for example, more closely matching previously observed acute responses following multiple sets of five repetitions rather than ≥10 repetitions per set (Kraemer et al., 1990; Linnamo et al., 2005; Smilios et al., 2003). Hence, there might not have been the expected large differences in acute response between maximum strength/power and hypertrophic loadings, and all comparisons between velocity-loss protocols should be considered while bearing in mind these methodological considerations.

4.2 | Indicators of muscular fatigue

Voluntary contraction performance is governed by both central (i.e., neural) and peripheral (i.e., musculotendinous) factors, although it has been suggested that maximum force capacity and its change are closely related to intramuscular factors (Maughan et al., 1984; Walker & Häkkinen, 2014). Here, there appears to be some evidence (MPP and MVC) that the M40%VL group experienced greater fatigue during acute loading test 1 compared with the other groups. The magnitude of fatigue in the voluntary contraction tests during acute loading test 2 was more systematic and consistent between all groups, as hypothesized based on previous studies (Walker et al., 2013, 2015, 2017).

More direct examination of the ability of the musculotendinous tissue to produce force in isolation can be obtained through peripheral electrical stimulation. Low-frequency fatigue is purported to reflect changes in excitation–contraction coupling, particularly calcium kinetics, or muscle damage (Jones, 1996; Keeton & Binder-Macleod, 2006). In the present study, more prominent low-frequency (10 Hz) fatigue compared with high-frequency (100 Hz) fatigue was observed in all groups immediately after both loadings, reflected by the reduced 10 Hz:100 Hz ratio. Although cK concentrations increased significantly post-loading in most groups and some groups showed sporadic increased 24 h post-loading, the low magnitude of increases (300–500 IU L^{-1}) indicates it is unlikely that mechanical damage primarily influenced the low-frequency fatigue, leaving altered calcium kinetics as the suggested cause.

One interesting observation was that the males in the present study appeared to be particularly affected by high-frequency fatigue, because only the M20%VL and M40%VL groups demonstrated reduced force (i.e., TF100) immediately after acute loading test 1.

Such losses in force production during high-frequency stimulation are purported to be attributable to alterations in extracellular K^+ concentrations affecting action potential propagation along the sarcolemma and/or t-tubules (Jones, 1996). In terms of influencing voluntary activation, a reduction in high-frequency force production would be likely to affect rapid force production primarily. This was observed in the M40%VL group in MPP and force over the initial 100 ms in the present study. After the training period, all groups showed significant reductions in force when stimulated at 100 Hz, and three out of four groups also showed reduced isometric force production during the initial 100 ms (i.e., F100), which appears to support the accepted theory. This also supports the proposal that fatiguability was greater after the training period and that the between-sex difference in fatiguability was reduced. Furthermore, reduced MVC_{EMG} was also observed in all groups after acute loading test 2, which might indicate that alterations in action potential propagation led to modification in either motor unit firing frequency (Jones, 1996) or recruitment.

Given that high-frequency force decrement reverses quickly after cessation of exercise (Jones, 1996; Tomazin et al., 2008), it is difficult to determine why the males training to 40% velocity loss also demonstrated high-frequency fatigue 24 h after acute loading test 2. Nevertheless, these data, along with other specific observations within this group, such as reduced MVC in M40%VL 24 h after loading test 2, might indicate that greater acute fatigue occurred in the males who used a higher training volume.

4.3 | Indicators of neural fatigue

The voluntary activation level provides a widely used estimate of the neural drive to the muscle (Taylor, 2009), but it lacks sensitivity (Herbert & Gandevia, 1999). In the present study, we observed no reductions in voluntary activation level after the VBRT loadings, and previous studies have shown conflicting results (González-Hernández et al., 2021; Peltonen et al., 2014; Walker et al., 2013). The exact reason for the conflicting findings is unclear, but observing such fatigue using the twitch interpolation technique might require higher resistance/force contractions (Peltonen et al., 2014; Walker et al., 2013) and/or higher mechanical work with accompanying peripheral fatigue (Ruotsalainen et al., 2014; Walker et al., 2013). It should also be remembered that the loading used during the present study was bilateral (dynamic) squat exercise, and the twitch interpolation technique is performed during unilateral isometric knee extensions. Although some evidence has suggested that males and females might experience differing neural fatigue (Latella et al., 2018), the lack of sensitive measures, along with limited overall magnitude of neuromuscular fatigue, have probably influenced the ability of the present study to evaluate potential sex differences.

Rapid muscle activation, in particular motor unit discharge rate, during the early stage of contraction is a key determinant of the rate of force development (Del Vecchio et al., 2019). Therefore, reductions in both force and muscle activity (as measured by surface EMG) over the initial 100 ms of isometric contraction might provide indirect evidence for central fatigue. In the present study, we observed limited reductions in F100 (only the M40%VL group demonstrated reductions in acute loading test 1, whereas all groups showed ~20% reductions in test 2) and no changes in surface EMG amplitude over the same time window in any group during either test (Table 2). The magnitudes of these changes are lower than previous observations of ~25% reduction in force and ~15–35% reduction in EMG amplitude over 100 ms after maximal strength and power loadings (Linnamo et al., 1998; Peltonen et al., 2014). The results of the present study are also lower than previously observed reductions in force (~55% in males and ~44% in females) and EMG amplitude (~47% in males and ~25% in females) over the initial 100 ms after 10 × 10-RM hypertrophic loadings (Häkkinen, 1994). Perhaps the greater number of repetitions per set (Häkkinen, 1994; Linnamo et al., 1998) and/or specific loading of the quadriceps muscles via knee-extension exercise (Peltonen et al., 2014) led to additional neuromuscular fatigue that was observable in EMG amplitude compared with the present study. Overall, our findings suggest limited central fatigue attributable to the present loading protocols and no differences between males and females either before or after the training period.

4.4 | Acute metabolic and hormonal responses

During acute loading test 1, blood lactate concentration increased significantly in the M20%VL, M40%VL and F40%VL groups 1.5 min after the loading. The raised blood lactate concentrations persisted over 10 min in the groups training to 40% velocity loss but had returned to baseline in the groups training to 20% velocity loss. A similar pattern of response was observed after acute loading test 2. However, this time also the F20%VL group showed a statistically significant increase 1.5 min post-loading, and concentrations of lactate remained elevated for 10 min in both male groups (i.e., M20%VL and M40%VL). Previous studies have shown that males tend to display greater increases in blood lactate than females after the same loading protocol (Häkkinen, 1994; Linnamo et al., 2005). Furthermore, the blood lactate concentrations after 20% velocity-loss loadings in the present study (~3–5 mmol L^{-1}) match those reported for submaximal-load power loading and maximal strength loadings consisting of 5–10 repetitions per set (Kraemer et al., 1990; Linnamo et al., 2005; McCaulley et al., 2009). Thus, the blood lactate concentrations after 40% velocity-loss loadings (~8 mmol L^{-1}) are somewhat in between typical power loading values and concentrations reported after hypertrophic loadings (~10–16 mmol L^{-1}; Häkkinen & Pakarinen, 1993; Kraemer et al., 1990; Linnamo et al., 2005; McCaulley et al., 2009). However, in females, some studies have reported blood lactate concentrations as low as ~6 mmol L^{-1} after hypertrophic loadings (Häkkinen, 1994) and, as such, our findings in the F40%VL group are similar.

The (high) metabolic cost of (hypertrophic) resistance loading is accompanied by increases in GH and cortisol concentrations (Häkkinen, 1994; Häkkinen & Pakarinen, 1993; Kraemer et al., 1990;

McCaulley et al., 2009; Smilios et al., 2003). Positive associations between acute blood lactate and GH responses have been observed previously (Häkkinen & Pakarinen, 1993). Thus, based on the blood lactate results of the present study, it could be expected that GH concentrations would respond most robustly to 40% velocity-loss loadings. This 20 versus 40% velocity-loss difference was clearly observed in males, but both female groups significantly increased serum GH concentrations after acute loading test 1, without between-group differences, although the mean concentration after 20% velocity loss was lower. Acute GH responses are also influenced by neural factors (Ju, 1999), and previous studies have observed significant increases in the GH concentration after power loading in the absence of large increases in the blood lactate concentration (Walker et al., 2010). Therefore, if the 20% velocity-loss protocol was sufficiently stimulating for females, this could have driven the acute GH response after test 1. It is noteworthy that the acute GH response was blunted after the training period. We have proposed that the acute GH response to a resistance loading protocol reflects the state of adaptability to such a training protocol (Walker et al., 2015, 2017); therefore, it might be that the subjects in the present study had already adapted to the training stimulus, and maintaining the same training protocol would lead to depletion or no further adaptation. The training period in the present study was 8 weeks, and the durations typically used for power training are 4–8 weeks. Furthermore, prolonged power training for 10 weeks has been shown to lead to a reversal of gains in fast force production (Peltonen et al., 2018). Thus, the blunted acute GH response could well be indicative of the need to alter the training programme to induce further adaptation.

Serum cortisol responds most robustly during resistance training when the number of sets and repetitions are moderate to high. It has been shown that four to six sets of 10–15 repetitions lead to higher serum cortisol concentrations than, for example, two set of 10 repetitions (Smilios et al., 2003). After power loadings, serum cortisol concentration has been found to continue to decrease along the expected circadian rhythmic pattern (McCaulley et al., 2009; Walker et al., 2010). Therefore, it seems that a robust cortisol response to resistance training occurs only when there is a high training volume, probably owing to high energy requirements (Simmons et al., 1984), with maximal loads (Izquierdo et al., 2009) leading to some appreciable muscle damage. Given that the loading protocols in the present study led to performance of four to eight repetitions per set and that inter-set rest intervals were 3 min, there might not have been sufficient metabolic or psychophysiological stress to induce acute responses. This finding matches a previous VBRT study, in which subjects performed half of the possible number of repetitions at different loads (Pareja-Blanco, Rodriguez-Rosell et al., 2020). Thus, given the lack of cortisol and cK response to velocity-loss loadings in the present study, there would probably be little inflammatory response or mechanical damage as a consequence of the loadings in the subjects of the present study, who were recreationally active in resistance training.

5 | CONCLUSION

The present back squat loading protocols (five sets, with 3 min recovery) led to typical reductions in voluntary force production (by 10–20%) in physically active males and females. As expected, acute neuromuscular fatigue and the blood lactate and hormonal responses were greater when training to 40% velocity loss per set compared with 20% velocity loss, at least before the training period, and this was more observable in the males. Nevertheless, there were not large differences in the number of repetitions performed per set (approximately two more during the 40% velocity-loss protocol) and no difference in mechanical work in females between 20 and 40% velocity-loss protocols. Males appeared to be more susceptible to acute fatigue before the training period, but there were no obvious signs of females being less fatigable after the training period. This study also provides further evidence that acute fatigue after resistance exercise might be enhanced after a short-term training period.

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COMPETING INTERESTS

None declared.

AUTHOR CONTRIBUTIONS

Simon Walker, Keijo Häkkinen and Fernando Pareja-Blanco designed the study. All authors collected and analysed the data. Simon Walker, Keijo Häkkinen and Fernando Pareja-Blanco drafted the manuscript. All authors provided comments, approved the final version of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed.

DATA AVAILABILITY STATEMENT

All data included in this study are available at: https://doi.org/10.5281/zenodo.6801211

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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