

Micro-dose of resistance-exercise: effects of sub-maximal thumb exertion on leukocyte redistribution and fatigue in trained male weightlifters

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Abstract:

This study examined the effect of a micro-dose of thumb resistance-exercise on leukocyte redistribution, thumb pinch-strength and reported fatigue. The effect of training status was also studied.

30 male participants (20 weightlifting-trained; 10 untrained) were separated into 3 groups of 10 (WLEXP; UTEXP; WLPLA) & performed 4 x60 second thumb isometric resistance-exercise intervals separated by 60 second rest intervals in a single-blinded placebo-controlled study. Participants were assessed over a 60 minute post-intervention recovery period.

Pinch-strength decreased in WLEXP and UTEXP groups ($p < 0.01$), and recovered to baseline values ($p = 0.01$) in the WLEXP group only. Fatigue increased in WLEXP and UTEXP groups and remained elevated across time ($p < 0.01$). Circulating total leukocyte and lymphocyte counts increased in WLEXP and UTEXP groups across time. Constant elevation was seen in both measures for the UTEXP group ($p < 0.05$) whereas the WLEXP group showed two peaks in leukocyte (baseline – 0 mins post, $p < 0.01$; 20 – 60 mins post, $p = 0.02$) and lymphocyte counts (base-line – 0 mins post, $p < 0.01$; 20 – 60 mins post, $p < 0.01$). Monocyte count increased similarly from baseline ($p = 0.47$) in the WLEXP group ($p = 0.02$) and UTEXP group ($p < 0.01$) at 60 minutes post.

Our results suggest that perception of fatigue does not correlate with physiological recovery from thumb resistance-exercise in resistance-trained individuals which has implications for recovery monitoring. Of particular novelty, we also showed that a micro-dose of thumb resistance-exercise is sufficiently stressful to distort leukocyte trafficking and thus homeostasis.

Key words: resistance-exercise, exercise immunology, pinch-strength, sports science, fatigue.

Introduction

In sports such as Olympic weightlifting, powerlifting and Strongman, resistance-exercise is the primary mode of training. The mechanical stress imposed on weightlifting athletes during resistance-exercise induces skeletal-muscle sarcomere damage with subsequent alterations in biochemical serum profiles (Brancaccio, Lippi, & Maffulli, 2010). Additionally, weightlifting athletes undergo an altered psychological, physiological, biochemical and molecular status (Brancaccio et al., 2010; Hedelin, Bjerle, & Henriksson-Larse'n, 2001; Robson-Ansley & Lakier Smith, 2006; Twist & Eston, 2005). In order to promote adaptive extensive metabolic and molecular remodelling within the skeletal muscle (Clarkson, Nosaka, & Braun, 1992; Egan & Zierath, 2013; Sonnet et al., 2005), characterisation of different dose-responses must be undertaken including low-dose resistance-exercise protocols.

Acute and chronic intervention studies have demonstrated profound leukocyte responses to exercise with demonstrated relevance to athlete health, tissue repair, regeneration and coordination of further recovery responses (Gleeson, 2007; Walsh et al., 2011). Neutrophils for example are chemo-attracted to muscle sites through myokines released from skeletal muscle to aid macrophages with phagocytosis and oxidative burst activity (Tidball & Villalta, 2010). Macrophages perform tissue phagocytosis, indirectly recruit further monocytes and stimulate satellite cell proliferation, all of which is required for recovery and adaptation from resistance-exercise (Chazaud et al., 2003; Mosser & Edwards, 2008; Sonnet et al., 2006; Stupka et al., 2000). A caveat for resistance-exercise science is that exercise immunology research to date has largely focused on endurance exercise (Freidenreich & Volek, 2012; Walsh et al., 2011). The limited literature which has examined resistance-exercise focussed on leukocyte redistribution post high-dose dynamic exercise, often combining multiple muscle groups (Bermon, Philip, Candito, Ferrari, & Dolisi, 2001; Freidenreich & Volek, 2012). As exercise intensity and duration positively regulate the leukocyte responses to resistance-exercise (Bush et al., 1999; Kraemer et al., 1999), low-dose protocols should be studied to determine leukocyte sensitivity and the recovery implications associated with small muscle-group exertion. Knowledge of this cellular sensitivity is

relevant to weightlifting athletes who recruit small muscle groups for gripping and pinch manoeuvres such as isometrically gripping a barbell and thus recruiting the intrinsic thumb muscles (Towles, Hentz, & Murray, 2008). Moreover, weightlifting technique sessions with minimal external load are often incorporated into recovery days or as an additional session due to the notion that gripping unloaded barbells is rest. Recovery research employing hand or thumb resistance-exercise in weightlifters would therefore be pragmatic whilst exploring the sensitivity of leukocytes to this exercise mode. Failure to characterise these cellular responses in the hand and thumb musculature could have adverse implications for tissue remodelling, pinch or grip ability and thus weightlifting performance.

Also, as pinch-strength and reported fatigued can affect athletic performance and are influenced by exercise intensity and duration (Chen et al., 2011), these adjunct performance-indicators should be studied simultaneously with leukocyte changes in low-dose and micro-dose resistance-exercise studies.

In this study, the following hypotheses were made: A micro-dose of thumb resistance-exercise is sufficiently stressful to affect circulating leukocyte counts; Thumb maximum voluntary contraction would decay and perception of thumb fatigue would increase post-exercise; Magnitude of change for all measures would be greatest in the weightlifting experimental group.

Method

Participants

All participants in this study provided written informed-consent. This study received full ethical approval from the Griffith University Human Research Ethics Committee and conformed to standards set out in the Declaration of Helsinki.

Thirty men (18-40 yr) volunteered to participate as subjects in the present study and all thirty men completed the study. Twenty men were considered weightlifting athletes who ranged from local to state-level competitors undertaking frequent weekly weightlifting training (see Table 1). The other ten men were untrained (i.e., not participating in any regular exercise and had not performed resistance-exercise for at least 12 months). All subjects had no current history of upper-limb musculoskeletal injury or past history of hand/wrist/forearm injury. Weightlifting athletes were randomly (concealed, third party randomization method described by Schulz and associates (Schulz, Chalmers, Hayes, & Altman, 1995) allocated into one of two groups: i. Weightlifting experimental (WL_{EXP}; n = 10), or ii. Weightlifting placebo (WL_{PLA}; n = 10). The untrained subjects were grouped altogether into the Untrained experimental group (UT_{EXP}; n=10). All subjects were blinded to their group allocation. Subject characteristics are displayed in Table 1.

Table 1. Subject characteristics

Group	WL _{EXP}	UT _{EXP}	WL _{PLA}
Age (yrs)	27 (SD=5)	27 (SD=7)	26 (SD=7)
Height (cm)	183 (SD=8)	179 (SD=8)	181 (SD=7)
Body mass (kg)	87.6 (SD=9.3)	81.6 (SD=10.6)	84.5 (SD=10.9)
Gym sessions (per week)	4 (SD=1)	0 (SD=0)	4 (SD=1)
Hand dominance	R: n=7 L: n=3	R: n=9 L: n=1	R: n=8 L: n=2
Lateral pinch (kg)	9.4 (SD=1.5)	8.6 (SD=1.5)	8.6 (SD=1.5)
Haemoglobin (g/L)	147.6 (SD=7.4)	144.2 (SD=5.1)	144.7 (SD=7.7)
Haematocrit (%)	40 (SD=0)	40 (SD=0)	40 (SD=0)
Mean Cell Volume (fL)	89.9 (SD=4)	90.0 (SD=2.2)	92.4 (SD=3.6)
Red Cell Distribution Width (µm)	12.3 (SD=0.5)	12.6 (SD=0.4)	12.3 (SD=0.6)
Red Blood Cell count (x10 ¹² /L)	4.8 (SD=0.3)	4.7 (SD=0.3)	4.6 (SD=0.3)
Platelet count (x10 ⁹ /L)	223.3 (SD=35)	241.7 (SD=36.8)	204.6 (SD=31.6)

Experimental approach to the problem

The present study used a single-blinded, randomised, placebo-controlled study design. Before being admitted to the study, all participants were given a detailed explanation of the study design, procedures, experimental interventions and assessments employed, were educated about the potential risks involved and signed a written consent form. Every participant was then given an appointment time and instructed to abstain from all forms of exercise for 48 h and fast for 2 h prior to attending their appointment to control for potential effects of prior physical stress and dietary intake respectively on the study (Carlson et al., 2008; Freidenreich & Volek, 2012; Gleeson, 2007). Each participant attended the testing laboratory (temperature monitored at 23 °C) on one single occasion only. The session began with a pre-screening where each participant was interviewed and examined by a Doctor of Physical Therapy to confirm all inclusion criteria (Table 2) were met and to rule out contraindications to resistance-exercise.

Subjects were familiarised with the interventions and assessment procedures used (see Familiarisation Procedure). An Intravenous (IV) catheter was inserted into the median cubital vein of the participant's dominant hand and left in-situ. An IV catheter was selected for blood collection in order to minimise needle-induced tissue damage and to facilitate precise consistent timing of blood sample collection. Blood was collected directly into an EDTA Vacutainer and analysed within 60 minutes. At each collection point, 5ml of blood was drawn and discarded before collecting sample blood and catheter lines were maintained through saline flushing. After the catheter insertion, the participant rested for 10 minutes in the testing chair before base-line measures were collected to negate any potential affect the catheterisation could have on subsequent measures. Base-line measures were then recorded in the following order: i. Lateral (key) pinch (see MVC Assessment), ii. Fatigue perception (see Fatigue Assessment), iii. Blood collection/Leukocyte assessment (see Leukocyte Assessment).

Table 2. Study Inclusion Criteria

Criterion	Description
Age	18 – 40 yrs
Sex	male
No evidence of contraindications to resistance training *	No current history of unstable angina No current history of uncontrolled hypertension (systolic blood pressure ≥ 160 mm Hg and/or diastolic blood pressure ≥ 100 mm Hg) No evidence of uncontrolled dysrhythmias No recent history of congestive heart failure that has not been evaluated and effectively treated No evidence of severe stenotic or regurgitant valvular disease No indication of hypertrophic cardiomyopathy
Apparently healthy	No past or present history of cardiovascular, metabolic, or respiratory illness No musculoskeletal injury
Well-trained in weight-lifting	Competitor at local-level competition or higher Undertakes 2 or more resistance-exercise sessions per week
Or UT_{EXP}	UT_{EXP} . Does not participate in any structured exercise
* Contraindications to resistance training are based on the “ <i>position paper endorsed by the American College of Sports Medicine</i> ” (Pollock et al., 2000).	

After base-line testing, participants undertook either an Exercise Intervention or a Placebo Intervention depending on their group allocation. Those participants in the WL_{EXP} and UT_{EXP} groups undertook the Exercise Intervention, where as participants in the WL_{PLA} group performed the Placebo Intervention.

Once the interventions were completed, all participants immediately underwent repeat testing as per baseline: i. Lateral (key) pinch ii. Fatigue perception, iii. Blood collection/Leukocyte Assessment.

Each measurement occurred immediately post (0 minutes), 10 minutes post, 20 minutes post and 60 minutes post the interventions. All participants remained seated during the experiments duration and were instructed against moving the tested limb to avoid any active recovery affecting the results. Due to the preliminary nature of this study, data collection time points were selected to provide a broad frame of measurement.

After each participant had completed their final measure, the IV catheter was removed.

All blood samples and raw data were subsequently analysed and statistical analysis applied. The Experimental Design is summarised in Fig. 1.

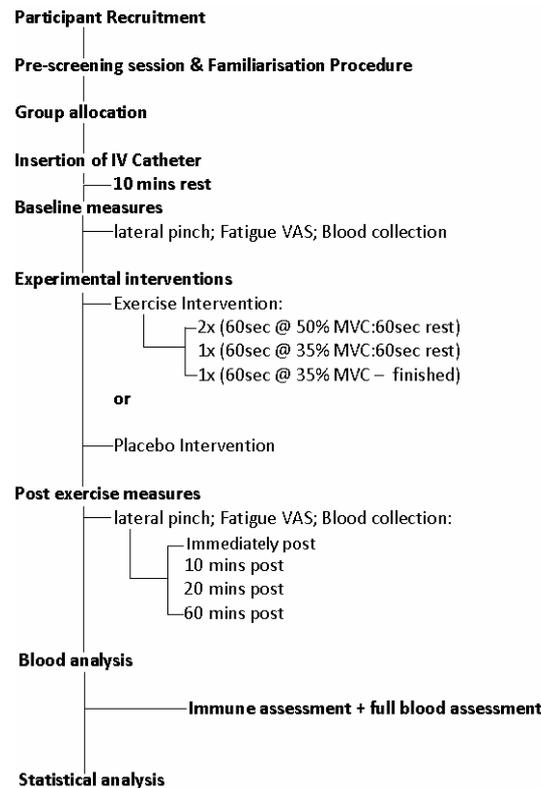


Fig. 1. Schematic of the experimental design

Procedures

Familiarisation Procedure

Participants were familiarised with the B&L Pinch Gauge (PG-60) dynamometer and the testing procedure. Participants were then seated in a standardised testing position as recommended by the American Society of Hand Therapists (Fess & Moran, 1981) to optimally recruit the muscles specific to the test and control for contribution from accessory muscles; an important consideration for this present project which investigated the sensitivity of leukocyte redistribution to micro-dose resistance-exercise. Only the dominant hand was utilised in this project to ensure maximal efforts were achievable. The participants were instructed that downward pressure onto the pinch-gauge was only to be applied with the thumb interphalangeal joint in neutral (lateral-pinch or key-pinch posture). Lateral-pinch was chosen due to its strong association with recruitment of the intrinsic thumb muscles, specifically flexor pollicis brevis, opponens pollicis and adductor pollicis (Towles et al., 2008). In specific biomechanical situations (such as gripping a barbell during weightlifting), the thumb web-space is closed, the thumb is abducted, flexed and opposed, thus requiring significant contribution from the muscles engaged during the lateral-pinch action (Punsola-Izard, Salas-Gómez, Sirvent-Rivalda, & Esquirol-Caussà, 2012; Roman-Liu, 2003). It is for this reason that the lateral-pinch action was chosen for this research project. Once participants were in the correct testing posture, they were instructed to perform 5 sub-maximal pinch efforts separated by 30 seconds rest before immediately completing a maximal-effort practice session identical to the testing session (see MVC Assessment). This thorough familiarisation process ensured each participant was sufficiently familiar with the pinch gauge whilst preventing excessive fatigue and; ensured any pre-fatiguing effect associated with this familiarisation procedure was consistent across all research participants. Participants were also shown a copy of the Visual Analogue Scale (VAS) used for assessing perception of fatigue and were instructed on how to complete it.

Exercise Intervention

All participants in the WL_{EXP} and UT_{EXP} groups performed a micro-dose resistance-exercise protocol. A B&L Engineering pinch gauge (PG-60) was utilised to ensure that applied resistance was consistent and at the same relative intensity for each individual (different absolute values). This involved performing 4 min total isometric resistance-exercise with the thumb of the dominant hand. The 4 min of exercise was divided into four, 60-s work-intervals each separated by one, 60-s rest interval. The total time for the exercise intervention was 7 min. Each work-rest interval was followed immediately by the subsequent work-interval until all four work-intervals were completed. Each work-interval was performed at a relative intensity calculated from each participant's base-line thumb MVC result which was determined during the MVC Assessment. The first two

work intervals were performed at 50% MVC and the remaining two work intervals at 35% MVC. Each participant was informed of their intensities. The exercise intervention was developed from pilot study testing with participants (data not presented) to develop a protocol that was achievable below the level of volitional-fatigue to limit recruitment of accessory musculature, thus maintaining a low exercise dose. Due to the preliminary nature of the present study, multiple exercise doses/protocols were not performed.

The participant performed the work-intervals of the exercise intervention in the standardised testing position (see Familiarisation Procedure). In order to exercise at the required intensity, the participant was instructed to continuously look at the pinch gauge during the work-intervals to ensure they were consistently producing the required amount of force (kilograms). This process was closely monitored by a member of the research team and verbally corrected if necessary by using the standardised command “keep the needle at your weight”. Participants were allowed to relax their upper limb and rest their testing hand on their lap during the rest interval. Each participant was advised to avoid any voluntary contraction of the upper limb and testing hand during the rest-interval to avoid any form of active recovery which could influence the results. Participants were closely supervised to guarantee this did not occur. The details of the exercise intervention are displayed Table III.

Table 3. Exercise intervention overview

Repetition	Work-Interval (s)	Work-Interval Intensity (% of MVC)	Rest-Interval (s)
1	60	50	60
2	60	50	60
3	60	35	60
4	60	35	Protocol complete

Placebo Intervention

WL_{PLA} participants undertook the placebo intervention. The placebo intervention involved 4 work-intervals lasting 60-s separated by 60-s rest-intervals. In contrast to the exercise intervention, WL_{PLA} subjects held the pinch gauge without applying any downward pressure. This holding action of the pinch gauge was considered a placebo intervention as subjects held the mass of the pinch gauge which they could have perceived as low-dose resistance-exercise. Body positioning in the placebo intervention was identical to the exercise intervention. Participants rested during the rest-interval as described in the exercise intervention. 7 minutes total time elapsed during the placebo intervention to ensure body positioning and intervention duration were consistent between interventions.

Repeatability Study

The MVC Assessment in this project utilised a minimally modified version of the testing protocol described by Mathiowetz and colleagues (Mathiowetz et al., 1985). The original protocol utilised 3 MVC efforts per test, conversely the present project aimed to investigate the sensitivity of specific biological responses to a micro-dose of resistance-exercise. It was therefore identified that the lateral-pinch testing could potentially affect the data due to the physical nature of the test requiring maximal voluntary muscle contraction. To address this, a repeatability study was undertaken. 12 male participants were recruited as described previously. Participants were pre-screened and familiarised as described previously, before undertaking 3 consecutive lateral-pinch MVC efforts. Testing was performed using the MVC Assessment procedure described in the present study, however with 3 instead of 2 maximal efforts, and without rest intervals between efforts. Results of a one-way ANOVA showed that no statistical differences were found for age ($F=0.08$, $p=0.93$), height ($F=0.54$, $p=0.59$) and body mass ($F=0.86$, $p=0.44$) variables. Furthermore, participants were not different for pinch ($9.0\text{kg} \pm 0.75$) at baseline and no differences were seen across time (efforts 1 – 2, 2 – 3 or 1 – 3) for any participant ($p>0.05$). This revealed no learning effect or fatiguing effect occurred as a result of the procedure and consequently lateral-pinch testing could be performed with only 2 consecutive efforts, and without rest between efforts.

MVC Assessment

All participants undertook the MVC Assessment to determine their maximum lateral-pinch-strength using their dominant hand only. A B&L Engineering pinch gauge (PG-60) was used to measure MVC as it has been extensively proven to be both reliable and valid in the literature and is considered the ‘Gold Standard’ for pinch-strength assessment (Mathiowetz et al., 1985; Mathiowetz, Vizenor, & Melander, 2000; Mathiowetz, Weber, Volland, & Kashman, 1984). Additionally, in consideration of normative data (Mathiowetz et al., 1985), the 60Lb model was selected to accommodate the expected upper strength range of the weightlifting participants. To eliminate testing bias, one tester gave instructions and reset the dynamometer and a separate person viewed and recorded each test result. To ensure that subject encouragement during testing was consistent, standardised instructions were used as described previously (Mathiowetz et al., 1984). The examiner demonstrated the correct technique then gave the dynamometer to the participant. The participant was then positioned in the standardised

testing position (Fess & Moran, 1981; Mathiowetz et al., 1985) to optimally recruit the muscles specific to the test and to control for contribution from accessory musculature. Participants were then tested using the protocol described by Mathiowetz and colleagues (1985). Based on the results of the repeatability study, only 2 testing efforts were used for each MVC assessment. Participants were seated with their shoulder adducted to neutral and neutrally rotated, elbow flexed at 90°, forearm in the neutral position, and wrist between 0° and 30° dorsiflexion and between 0° and 15° ulnar deviation. After the participant was positioned appropriately, the participant was instructed to give a maximal effort. Immediately after the first effort was completed, the dynamometer was reset and a second (and final) effort was performed. Values were recorded and later averaged.

Fatigue Assessment

Perception of thumb fatigue (reported fatigue) was assessed using a VAS based on previous studies (Reid, Gleeson, Williams, & Clancy, 2004; Takamoto et al., 2009). A 4cm (40mm) unmarked horizontal line with the terminal descriptors “profound, could not train” (score of 1) and “absent, no fatigue” (score of 5). The scale was scored by using a ruler to measure the distance (mm) between the “absent, no fatigue” anchor and the respondent’s mark. A score of 5 indicated the absence of fatigue, where as a score of 1 indicated maximal fatigue.

Leukocyte Assessment

Blood collected in a 10ml EDTA Vacutainer was analysed using a 5-point discrimination function on an automated haematology analyser (Beckman Coulter *Coulter HmX Hematology analyser*) with reported accuracy and reliability (Beckman Coulter, 2010; Hijiya et al., 2004). Circulating total leukocyte, lymphocyte, neutrophil, basophil, eosinophil and monocyte concentrations were calculated. Additionally, base-line blood was analysed for standard full-blood parameters to ensure participants were physiologically healthy, using the same automated haematology analyser.

Statistical Analysis

All results are presented as group means \pm standard deviation. Fully factorial ANOVA with repeated measures for *sample time* was used to examine *group* differences in pinch-strength, reported fatigue (VAS) and circulating leukocyte counts. Where statistically significant F values were detected, least square difference post hoc tests and pairwise comparisons were performed to determine differences among groups and sample time (time points). Statistical Package for the Social Sciences (SPSS Inc., Release 22.0) was used for the data analyses and significance was accepted at $p \leq 0.05$.

Results

Subject characteristics are displayed in Table I. The results of a one-way ANOVA revealed that no statistical differences were found for age ($F= 0.08$, $p=0.93$), height ($F=0.54$, $p=0.59$) and body mass ($F=0.86$, $p=0.44$) variables. Participants at baseline were also within healthy full blood count limits.

MVC Lateral Pinch: pinch-strength (kg)

There was no difference in pinch-strength (PS [kg]) among the three groups at baseline ($p>0.05$). A significant interaction for time and groups was found for PS (kg) ($F=13.16$, $p<0.01$). Pairwise Comparisons demonstrated that the Placebo group showed no significant change from base-line at any post intervention time point ($p>0.05$).

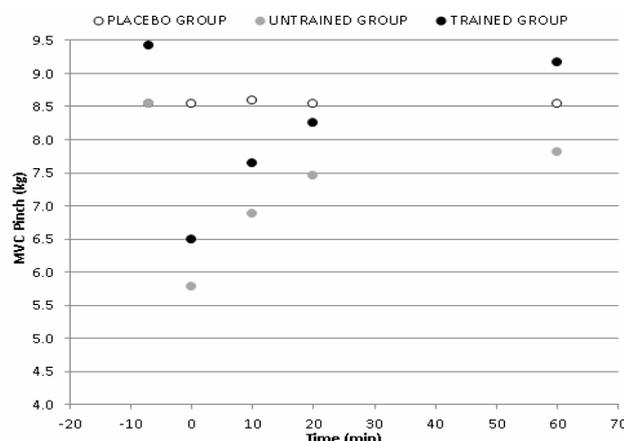


Fig. 2. MVC pinch strength (kg) over time

INTERACTION: $F = 13.16, p < 0.01$

There was no difference in pinch strength (PS) among the three groups at baseline (-7 min; $p > 0.05$). Furthermore, there was no change in PS in the WL_{PLA} across time ($p > 0.05$). PS decreased similarly ($p = 0.27$) in the WL_{EXP} ($p < 0.01$) and UT_{EXP} ($p < 0.01$) groups from baseline to immediately post (0 min). PS increased from 0 to 10 min and 10 to 20 min in both WL_{EXP} and UT_{EXP} groups ($p < 0.01$) but remained lower than values recorded at baseline (i.e., -7 min; $p < 0.01$). No further increase in PS from 20 to 60 min post ($p = 0.06$) was observed in the UT_{EXP} group whereas the WL_{EXP} group returned to a PS value at 60 min that was not different from baseline ($p = 0.10$).

The WL_{EXP} group PS (kg) decreased significantly from baseline at immediately post (0 min; $p < 0.01$) which equated to a 30.86% change. This group showed a relative increase towards baseline (11.7% change from baseline) at 20 minutes post intervention which remained significantly different ($p < 0.01$). PS (kg) at 20 minutes post was significantly lower than PS (kg) at 60 minutes post ($p < 0.01$), and no significant differences were found between base-line and 60 minutes post values ($P = 0.10$).

UT_{EXP} participants showed a significant decrease in PS (kg) from baseline at immediately post ($p < 0.01$) which equated to a 32.56% change. This change was similar to the WL_{EXP} group ($p = 0.27$). The UT_{EXP} group remained significantly below base-line values across all post intervention time points ($p < 0.01$) and 60 minutes post scores were 9.3% below baseline. No significant differences were found between time points 20 minutes post and 60 minutes post ($P > 0.05$). See Fig. 2.

Fatigue VAS

There was no difference in Fatigue VAS scores among the three groups at baseline ($p > 0.05$). A significant interaction for time and groups was found for Fatigue VAS ($F = 28.41, P < 0.01$). Pairwise Comparisons revealed the WL_{PLA} group showed no significant change from base-line at any post intervention time point ($p > 0.05$).

Scores for the WL_{EXP} group changed significantly from baseline at immediately post ($p < 0.01$) equating to a 60% relative change, and values remained significantly different across all time points ($p < 0.01$). Pinch values at 10 minutes post and 20 minutes post began to shift towards baseline (40% and 20% change from baseline respectively) but the differences from baseline remained significant ($p < 0.01$). No significant changes were seen between time points 20 minutes post and 60 minutes post ($p > 0.05$).

UT_{EXP} group Fatigue VAS changed significantly from baseline at immediately post ($p < 0.01$; 80% difference from baseline) which was greater than WL_{EXP} Fatigue VAS at this time point ($p = 0.02$). UT_{EXP} values remained changed up to 60 minutes post ($P < 0.01$). Pinch values at 10 minutes post began to increase towards baseline (40% change from baseline) but the difference remained significant ($p < 0.01$). Significant changes were also seen between time points immediately post and 10 minutes post, 10 minutes post to 20 minutes post, and 20 minutes post to 60 minutes post ($p < 0.01$) where 60 minutes post values represented 20% difference from baseline. WL_{EXP} and UT_{EXP} group values were similar at 60 minutes post ($p = 0.75$). See Fig. 3.

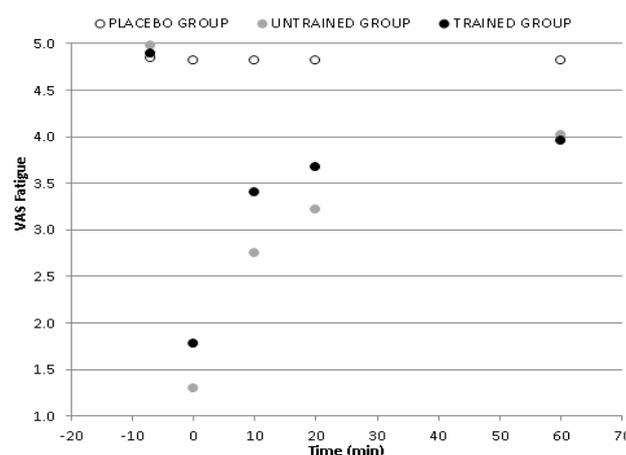


Fig. 3. Reported thumb fatigue (VAS) over time

INTERACTION: $F = 28.41, P < 0.01$

5 = absent fatigue; 1 = maximal fatigue

There was no difference in Fatigue VAS scores among the three groups at baseline (-7 min; $p > 0.05$). Furthermore, there was no change in fatigue for the WL_{PLA} across time ($p > 0.05$). Both the WL_{EXP} and UT_{EXP} groups significantly increased reported fatigue from baseline at immediately post (0 min) ($p < 0.01$) but to a

different extent between groups ($p=0.02$). Reported fatigue decreased from 0 – 10 minutes post and 10 – 20 minutes post ($p<0.01$) in the WL_{EXP} and UT_{EXP} groups but fatigue remained higher than baseline across time ($p<0.01$). The WL_{EXP} group did not change from 20 – 60 minutes post ($p>0.05$), whereas the UT_{EXP} group did ($p<0.01$). WL_{EXP} and UT_{EXP} values were similar at 60 minutes post ($p=0.75$).

Total Leukocyte Count

There was no difference in total leukocyte count among the three groups at baseline ($p>0.05$). A significant interaction for time and groups was found for leukocyte count ($F=2.93$; $p=0.01$). Pairwise Comparisons revealed the WL_{PLA} showed no significant change from base-line at any post intervention time point ($p>0.05$).

The WL_{EXP} group showed a significant increase in leukocyte count from baseline at all post intervention time points ($p<0.05$). At immediately post the intervention, a highly significant increase was found ($p<0.01$) which equated to an 8.7% change from baseline. At 10 minutes post, leukocyte count decreased from immediately post values ($p<0.01$), however this value remained above baseline ($p<0.01$). No change was found from 10 to 20 minutes post ($p=0.53$), conversely a significant difference was seen between 20 minutes and 60 minutes post ($p=0.02$). At 60 minutes post, leukocyte had returned to 8.7% above baseline.

UT_{EXP} group leukocyte count increased significantly from baseline at immediately post ($p<0.01$; 5.98% change) which was similar to the WL_{EXP} group ($p=0.86$). Values remained significantly elevated across time ($p<0.01$) and no difference was found between post intervention time points ($p>0.05$). See Fig. 4

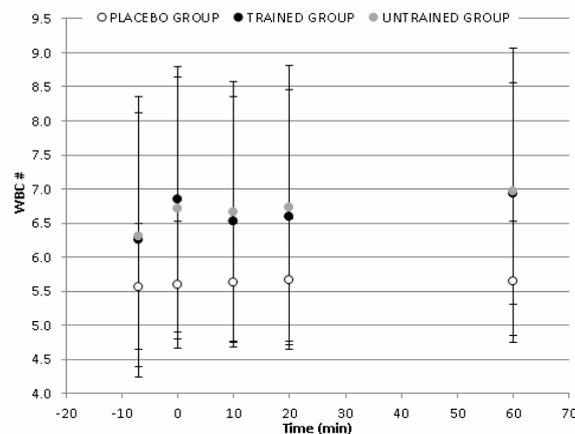


Fig. 4. Total leukocyte count over time

INTERACTION: $F=2.93$; $p=0.01$

There was no difference in total leukocyte (WBC) count (cells $\times 10^9/L$) among the three groups at baseline (-7 min; $p>0.05$). Furthermore, there was no change in leukocyte count for the WL_{PLA} across time ($p > 0.05$). Leukocyte count increased similarly ($p=0.86$) from baseline to immediately post (0 min) in WL_{EXP} and UT_{EXP} groups ($p<0.01$). In the UT_{EXP} group, this elevation continued across time ($p<0.01$) and did not change from 10 – 20 and 20 – 60 minutes post ($p>0.05$). In the WL_{EXP} group, leukocyte count decreased from 0 – 10 minutes post ($p<0.01$) yet stayed above baseline ($p<0.01$). No change was seen from 10 – 20 minutes post ($p=0.53$), but from 20 – 60 minutes post a second increase was seen ($p=0.02$).

Lymphocyte Count

There was no difference in lymphocyte count among the three groups at baseline ($p>0.05$). A significant interaction for time and groups was found for lymphocyte count ($F=3.34$; $p<0.01$). Pairwise Comparisons demonstrated that the WL_{PLA} group did not significantly change from base-line at any post intervention time point ($p>0.05$).

WL_{EXP} participants showed a significant increase from baseline values at immediately post ($p<0.01$) by 13.64%. A significant decrease in Lymphocyte count was seen from immediately post to 10 minutes post values ($p<0.01$) however 10 minutes and 20 minutes post values were not significantly different from baseline ($p>0.05$). At 60 minutes post, Lymphocyte count was again significantly elevated from baseline ($p<0.01$; 9.52% change). UT_{EXP} participants demonstrated a significant increase above baseline values at immediately post ($p<0.01$) by 13.04%. This was similar to the WL_{EXP} group ($p=0.55$). UT_{EXP} group values remained elevated across all post intervention time points ($p<0.05$) without significant change between time points ($p>0.05$). Additionally, UT_{EXP} changes were different to WL_{EXP} changes at 20 minutes post ($p=0.04$) but not at 60 minutes post ($p=0.47$). See Fig. 5.

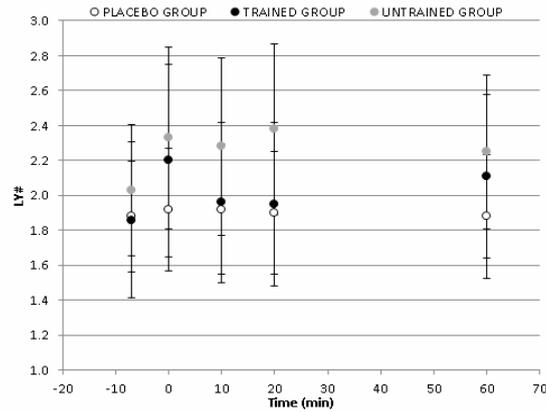


Fig. 5. Lymphocyte count over time

INTERACTION: F=3.34; p<0.01

There was no difference in lymphocyte count (cells $\times 10^9/L$) among the three groups at baseline (-7 min; $p>0.05$).

Furthermore, the WL_{PLA} group did not significantly change from base-line across time ($p>0.05$).

A similar increase ($p=0.55$) in lymphocyte count from baseline occurred in the WL_{EXP} and UT_{EXP} groups ($p<0.01$) at immediately post (0 min). UT_{EXP} group count remained elevated ($p<0.05$) across time without change ($p>0.05$). However, the WL_{EXP} lymphocyte count decreased from 0 - 10 minutes post ($p<0.01$) to values similar to baseline ($p=0.18$) and remained unchanged from 10 – 20 minutes post ($p=0.86$). Lymphocyte count then increased again to values above baseline ($p<0.01$) from 20 – 60 minutes post.

Monocyte Count

There was no difference in monocyte count among the three groups at baseline ($p>0.05$). A significant interaction for time and groups was found for monocyte count ($F=2.57$; $p=0.01$). Pairwise Comparisons revealed the WL_{PLA} showed no significant change from base-line at any post intervention time point ($p>0.05$).

Monocyte count increased similarly from baseline ($p=0.47$) in the WL_{EXP} group ($p=0.02$) and UT_{EXP} group ($p<0.01$) at 60 minutes post. See Fig. 6.

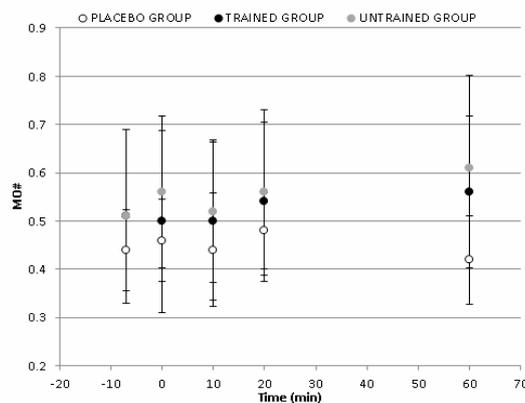


Fig. 6. Monocyte count over time

INTERACTION: F=2.57; p=0.01

There was no difference in monocyte count (cells $\times 10^9/L$) among the three groups at baseline (-7 min; $p>0.05$). Furthermore, the WL_{PLA} group showed no significant change from base-line across time ($p>0.05$).

Monocyte count increased similarly from baseline ($p=0.47$) in the WL_{EXP} group ($p=0.02$) and UT_{EXP} group ($p<0.01$) at 60 minutes post.

Granulocytes: Neutrophils, Eosinophils & Basophils

There was no difference in among groups at baseline for Neutrophil count; Eosinophil count; Basophil count ($p>0.05$). No significant interactions were found for time and groups for neutrophil ($F=1$; $p=0.44$) or eosinophil counts ($F=0.48$; $p=0.87$). Basophil count remained completely unchanged across all time points ($p>0.05$). See Fig. 7-8.

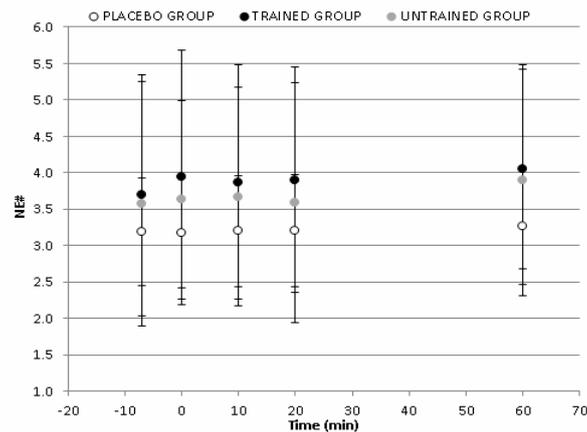


Fig. 7. Neutrophil count over time

NO INTERACTION: $F=1$; $p=0.44$

There was no difference among groups at baseline (-7 min; $p>0.05$) for neutrophil count (cells $\times 10^9/L$)

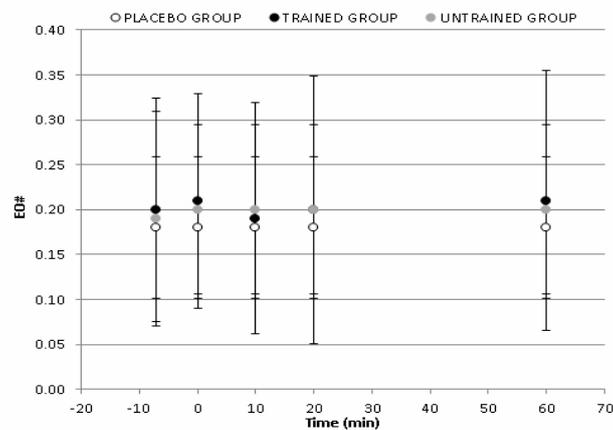


Fig.8. Eosinophil count over time

NO INTERACTION: $F=0.48$; $p=0.87$

There was no difference among groups at baseline (-7 min; $p>0.05$) for eosinophil count (cells $\times 10^9/L$)

Discussion

To the best of the authors' knowledge, the present study is the first to investigate leukocyte responses to any low-dose resistance-exercise protocol, specifically a micro-dose involving the thumb of weightlifters and untrained individuals. These findings were assessed in combination with local muscular performance (thumb MVC pinch) and reported fatigue to gain insight into potential practical implications of performing micro-dose resistance exercise.

The primary findings of the present study were that a micro-dose of thumb isometric resistance-exercise was sufficiently stressful to disrupt leukocyte trafficking. This indicates a disruption to homeostasis (Mayhew, Thyfault, & Koch, 2005) in a system central to tissue repair and remodelling. This finding also indicates greater leukocyte sensitivity to resistance-exercise than previously documented and should be examined further in relation to weightlifters who perform frequent barbell pinching/gripping. As the present study's intervention was short in duration (7 minutes total-work time), the observed disruption to leukocyte trafficking was shown to be significantly more rapid than previously documented. Additionally, trained weightlifting participants only recovered fully in pinch-strength post exercise, yet reported residual fatigue. This observation suggests that perception of fatigue does not correlate with physiological recovery from resistance-exercise in resistance-trained individuals. No changes were seen for the WLPLA group in any measure, demonstrating that the baseline MVC Assessment and catheterization did not affect results.

In relation to MVC pinch-strength, groups were not significantly different at baseline which was an unexpected finding considering the distinctions in training status. It is feasible that the occupational roles of the UTEXP subjects provided a training stimulus for maximal pinch-strength development. Occupations were recorded (data not presented) yet were heterogenous in their requirement for pinching and gripping tasks thus specific conclusions cannot be drawn. Only the WLEXP group recovered fully in MVC pinch-strength, suggesting training status affects rate of recovery in the intrinsic thumb muscles. This may reflect the need for

weightlifting athletes to perform prolonged pinching and gripping during training and competition. Conversely, full recovery did not occur until 60 minutes post, suggesting that low-intensity thumb resistance-exercise could adversely affect acute performance of the intrinsic thumb muscles which are required in situations where the thumb is abducted, flexed and opposed (Punsola-Izard et al., 2012; Roman-Liu, 2003) such as gripping a barbell. This novel finding may have implications for performance in weightlifting sports and should be investigated further.

Rate of recovery for Fatigue VAS (reported fatigue) was greatest in the WLEXP group, however neither the WLEXP or UTEXP groups recovered fully for this affective parameter. Difference in recovery rate paralleled with MVC pinch-strength findings. Conversely, the UTEXP group reported experiencing residual fatigue at the final time point and this was objectively shown by reduced pinch-strength. The WLEXP group however reported continuing fatigue yet recorded pinch-strength scores no different from their pre-exercise (intervention) maximal efforts. This finding suggests that perception of fatigue does not correlate with physiological recovery from resistance-exercise in resistance-trained individuals. Alterations in fatigue perception are known to be associated with sport related stress (Kellmann, 2010; Kellmann & Günther, 2000; Robson-Ansley & Lakier Smith, 2006) however the present study employed but a micro-dose of resistance-exercise, thus the observed discrepancy between reported and physiological fatigue are likely a result of training status. This warrants further investigation for the purpose of maintaining validity in stress-monitoring for weightlifters.

The general increase in leukocyte count seen for both WLEXP and UTEXP groups was consistent with previous studies which utilised high-dose protocols over comparably protracted time courses (Freidenreich & Volek, 2012). This likely indicates a redistribution of cells from the marginated pool (Benschop, Schedlowski, Wienecke, Jacobs, & Schmidt, 1997; McCarthy et al., 1992). These findings were smaller in magnitude compared to previous studies, and are therefore consistent with the current research consensus that leukocyte redistribution is influenced by duration and intensity of exercise (Mayhew et al., 2005; Walsh et al., 2011). The present findings do however demonstrate that the leukocyte response to exercise is more rapid and more sensitive than shown previously (Freidenreich & Volek, 2012; Walsh et al., 2011). Additionally, this study revealed two leukocyte peaks over the course of 60 minutes post exercise which was characteristic of the WLEXP group only. This temporal response was also seen in lymphocyte counts, and was again characteristic of the WLEXP group only. The trough seen between peaks in this temporal pattern may reflect extravasation of leukocytes out of the primary vasculature or into the local tissue or capillary bed (Smith, Kruger, Smith, & Myburgh, 2008) of the thumb before additional cells were recruited (2nd peak). This dual peak response may therefore represent more efficient exercise-induced leukocyte trafficking as a consequence of training status. Future studies should confirm the post-exercise localisation of leukocytes and examine their functionality to determine if a hyper-sensitive response is advantageous or deleterious. This is particularly valuable for weightlifting athletes who perform regular low-dose resistance-exercise (technique training).

Considering that lymphocytes were the strongest responders in the present study, future examination of the lymphocyte subpopulations would assist in elucidating the functional result of this exercise-induced change in trafficking. It is possible that the mechanism of action was partly catecholaminergic as catecholamines are released strongly in response to resistance-exercise (Bush et al., 1999) and are known to redistribute leukocytes from the marginated pool (Benschop et al., 1997; McCarthy et al., 1992). Moreover, lymphocytes have the highest cell surface expression β_2 Adrenergic receptors (G-protein Coupled Receptor) of the leukocyte populations (Landmann, 1992) allowing them to respond most rapidly and substantially to catecholamine's including Adrenalin. This may also explain in part why the WLEXP group responded to the exercise intervention with 2 peaks, whereas the UTEXP group did not. Whilst catecholamines were not measured in the present study, inclusion of this parameter would assist future research in determining the mechanisms of action underlying the present study's findings.

The present study also found a monocytosis which occurred at a similar rate and magnitude for the WLEXP and UTEXP groups. This elevation occurred from 20 - 60 minutes post exercise which was delayed compared to existing literature (Ramel, Wagner, & Elmadfa, 2003) however may be explained by the longer duration, greater exercise dose and intensity of previous studies (Mayhew et al., 2005; Ramel et al., 2003). The elevation of blood monocytes suggests a coordinated leukocyte recovery response and provides strong evidence that elements of the immune system are highly sensitive to resistance-exercise. Considering that mature monocytes (tissue macrophages) are responsible for stimulating myosatellite cell proliferation and differentiation (Chazaud et al., 2003; Mosser & Edwards, 2008; Sonnet et al., 2006; Stupka et al., 2000), further research should investigate the subacute or delayed effects of low-dose thumb exercise of leukocyte redistribution and function as they relate to tissue repair and regeneration.

No significant changes were seen in the present study for circulating granulocytes (neutrophils, Eosinophils and basophils). The negative basophil and eosinophil findings were consistent with existing literature (Freidenreich & Volek, 2012). Several studies reported an increase in neutrophils count post resistance-exercise however peak times varied up to 120 minutes post (Mayhew et al., 2005; Ramel et al., 2003). This is likely explained by the great heterogeneity among study designs and exercise protocols used. Therefore, it is

possible that due to the low-dose and short duration of the present study, either no neutrophil response occurred or a delayed neutrophilia could have occurred after 60 minutes post.

There are some minor limitations. Leukocyte redistribution was measured however cell localisation and functionality during recovery was not examined; Metabolic and hormonal measures were not recorded along with leukocyte redistribution. Conversely, the aim of this preliminary study was to determine if a micro-dose of resistance-exercise could affect leukocyte distribution, reported fatigue and pinch strength in trained vs untrained individuals.

Conclusions

Weightlifting sports require frequent pinching and gripping from small muscle groups, providing a strong rationale to study the effects of low-dose resistance-exercise on reported fatigue, strength and facilitators of tissue adaptation (leukocytes). Our findings suggest that perception of fatigue does not correlate with physiological recovery from thumb resistance-exercise in resistance-trained individuals. This has implications for athletes who grip weightlifting implements as the ability to recognise grip-strength decay and recovery can influence the weight which an athlete will attempt to lift, and therefore performance. Furthermore, novel leukocyte sensitivity in relation to resistance-exercise was observed, particularly in the lymphocytes. From another perspective, our results show that a micro-dose of isometric resistance exercise is sufficiently stressful to disrupt leukocyte trafficking. Whilst the health and performance consequences of this finding require further investigation, it does represent a systemic disruption to homeostasis and should be contemplated by coaches and researchers when considering resistance-exercise protocols. Research into the mechanisms underlying these responses should now be undertaken to confirm if heightened leukocyte sensitivity to resistance-exercise is advantageous. Finally, our findings collectively demonstrate a distinction in physiological and affective responses of individuals to resistance-exercise based on training status. This should be considered when selecting subjects for future research and in relation to athlete's returning from protracted rest.

Conflicts of Interest

There are no conflicts of interest to declare.

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