

Original Article

The acute muscular response following a novel form of pulsed direct current stimulation (Neubie) or traditional resistance exercise

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Abstract

Objectives: To examine changes in muscle thickness (MT), soreness (SOR), and isometric torque (ISO) following exercise with pulsed direct current (Neubie) or traditional high-load (TRAD) exercise. **Methods:** Thirty-two participants had SOR, MT, and ISO measured before, immediately after, and 24 and 48h following TRAD and Neubie. Rating of perceived exertion (RPE) and discomfort were also measured. Results are displayed as means(SD). **Results:** For MT, there was a condition x time interaction ($p < 0.001$). For Neubie, MT increased pre [3.7(0.7)cm] to post [3.9(0.8) cm, $p < 0.001$] and remained elevated at 24h. For TRAD, MT increased pre [3.7(0.6)cm] to post [4.0 (0.7)cm, $p < 0.001$] and remained up to 48h. Greater values were observed for TRAD post-exercise. For ISO, both conditions decreased up to 48h. TRAD demonstrated a greater change post exercise ($p < 0.001$). For SOR, both conditions increased up to 48h. Neubie demonstrated greater SOR at 48h ($p = 0.007$). RPE was higher for all sets in TRAD [Mean across sets = 16.0(1.9) vs. 13.5(2), $p < 0.001$]. Discomfort was higher in all sets for Neubie [Mean across sets = 5.8(1.5) vs. 4.5(2.0), $p < 0.05$]. **Conclusions:** Both conditions showed increased SOR, and decreased ISO for up to 48h, with MT increased for up to 24h. MT remained elevated in TRAD at 48h. Neubie training might be effective for individuals who are looking to experience lower RPE responses during exercise.

Keywords: Neuromuscular Electrical Stimulation, Pulsed Direct Current, Muscle Swelling, Muscle Thickness

Introduction

Growing evidence suggests that muscle hypertrophy does not rely upon the exercise load^{1,2}. As such, the understanding of muscle growth and the underlying mechanisms has evolved over recent years. For example, recent research has demonstrated that, when performed until failure, low-load resistance training can elicit comparable hypertrophy to that of high-load resistance training^{3,4}. Mitchell et al.³ found that 3 sets of knee extension exercise performed at 80% of one repetition maximum (1RM) or 3 sets of knee extension

exercise performed at 30% 1RM (3x/week) resulted in a similar muscle growth following 10 weeks of resistance exercise. Ozaki et al.² reviewed the importance of exercise load for skeletal muscle growth and concluded that a wide range of training loads will result in similar growth with varying degrees of contribution from mechanical tension and metabolic fatigue. Overall, it seems that maximal muscle growth will occur in the presence of sufficient muscle activation and/or fatigue development⁵. With this realization, scientists have begun to examine various alternatives to traditional high load resistance exercise.

The quest of examining alternatives to traditional resistance training has allowed scientists to demonstrate that an individual can achieve hypertrophy without the use of an external load⁶. Counts et al.⁶ observed that voluntary maximal contractions of the biceps muscles throughout the range of motion (termed "NO LOAD" training) resulted in muscle growth similar to that of traditional high load resistance exercise. Authors demonstrated that an external load is not necessary to produce maximal muscle growth if

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there is a high level of voluntary internal tension and effort⁶. Thus, individuals who are unable to perform traditional resistance training (i.e., lifting a heavy weight around 8-12 reps for 3-4 sets) may achieve muscle growth by simply contracting their muscle as hard as possible throughout a range of motion. This demonstrates that “NO LOAD” training does not require the use of a heavy external load as long as contractions are performed with a high level of voluntary effort⁶. Although this technique may have potential applications for some clinical populations, not all individuals are capable of producing a high level of voluntary effort⁷. This may be due to an injury⁸, following recovery after a surgery⁷, due to diseases such as ALS⁹ and Myasthenia Gravis¹⁰, or neuromuscular complications that are associated with ageing¹¹. In such scenarios, neuromuscular electrical stimulation (NMES) may serve as an alternative to achieve muscle activation¹². This technique of training has been widely used for rehabilitation settings, and several anecdotal case observations have demonstrated improved muscular function and body composition.

Electrical stimulation has been shown to increase muscle mass in older adults¹³ and adults with advanced diseases¹⁴, as well as to reverse muscle atrophy caused by inactivity¹⁵. Neuromuscular electrostimulation with no external load in particular has been associated with maintained muscle mass in immobilized limbs¹². Dirks et al.¹² conducted a 5-day study where an intervention group of 12 participants were subjected to a one-legged knee immobilization with daily application of electrostimulation and a control group of 12 participants were subjected to the same immobilization procedure without application of electrostimulation. Following completion of the study, the control group reduced quadriceps CSA by $3.5 \pm 0.5\%$ ($P < 0.0001$) while the intervention group maintained their initial muscle mass¹². Interestingly, immobilization led to an increase in muscle myostatin mRNA expression in the control group while remaining unchanged in the intervention group¹². Myostatin mRNA expression is associated with negative regulation of muscle growth by inhibiting myogenesis¹⁶. Furthermore, muscle protein breakdown in humans is primarily regulated by the ubiquitin ligases MAFbx and MuRF1. Interestingly, MuRF1 mRNA expression increased in the control group while remaining unchanged or slightly declining in the intervention group¹². Thus, Dirks et al.¹² concluded that application of daily (twice a day) supervised electrostimulation on the immobilized leg fully prevented disuse atrophy and maintained initial muscle mass. Overall NMES appears to be a safe and noninvasive therapy that has been utilized to improve skeletal muscle function and morphology.

The present literature examining NMES on skeletal muscle has focused on the use of alternating current (AC) stimulation to achieve muscle activation. However, the use of pulsed direct current (DC) has recently become more popular in the clinical setting. Historically, the use of DC current has not been useful due to the continuous unidirectional flow of ions leading to a build of charge which leads to skin irritation. However, the Neubie (NEUro-Bio-Electric) device

(Neurological Fitness Equipment and Education LLC, Austin TX) has included an additional waveform that dissipates heat and charge buildup, allowing for higher intensity stimulation without skin irritation. In addition, treatments with the Neubie are active, allowing for range of motion, rather than passive lying stimulation as typically performed with many traditional (AC) NMES treatments. The incorporation of movement, even at therapeutic levels of stimulation, allows for eccentric contractions, which may enhance the skeletal muscle response to NMES. Interestingly, there are currently no studies (to our knowledge) examining adaptations or responses to Neubie training.

Given this scarcity of information, a starting point would be to better understand that acute responses to this form of exercise. For example, it has been suggested that the acute swelling response may provide valuable information regarding the anabolic potential of a training protocol. The cell swelling hypothesis¹⁷, suggests that cellular hydration may act as an anabolic proliferative signal, resulting in a shift towards anabolism. In somewhat support of this hypothesis, Yasuda et al.¹⁸ observed that concentric exercise in combination with blood flow restriction (BFR) resulted in a greater acute muscle swelling and greater increases in muscle size over 6-weeks compared to a group performing eccentric exercise in combination with BFR. Authors suggested that the greater growth may be related to the greater degree of acute swelling¹⁸. It is important to note that not all studies have found that a greater degree of swelling is predictive of how much growth one might expect over time;¹⁹ however, it seems that most exercise protocols that result in skeletal muscle growth will result in some level of swelling. In addition, prolonged swelling may provide some indication of the presence of muscle damage. Along with muscle thickness, acute changes in isometric strength are often used to assess fatigue following an exercise stimulus²⁰. This may also provide some indication on the anabolic potential of an exercise protocol, given that fatigue reflects the depletion of substrates and the accumulation of metabolites following an exercise bout²¹. Further, if strength is depressed 24 and 48 hours following the exercise bout, this may suggest the presence of muscle damage²². All of these factors along with perceptual factors such as rating of perceived exertion, discomfort and muscle soreness help to better understand an exercise stimulus.

The purpose of this study is to examine acute changes in muscle thickness, perceptual responses and isometric torque before, immediately following, 24 hours following, and 48 hours following NO LOAD exercise with pulsed direct current (Neubie) and HIGH LOAD exercise without pulsed direct current in the upper body. This may provide insight into the anabolic potential of this emerging training technology. We hypothesize that there will be similar changes in muscle thickness, perception and isometric torque following HIGH LOAD exercise and NO LOAD exercise with Neubie.

Methods

Study Overview

Thirty-four individuals between the ages of 18-35 who had regularly engaged in resistance exercise in the upper body for at least six months were recruited for this study, which was approved by the University's Institutional Review Board. Resistance trained individuals were recruited to avoid confounding influence from the general exposure to muscle contraction in those naïve to exercise. Participants were precluded from the study if it was determined from their Physical Activity Readiness Questionnaire (PARQ) that they were at risk or had muscle or skeletal disorders preventing the completion of biceps curls. All individuals were asked to refrain from upper body exercise 24 hours prior to visit 1 and for the duration of the study.

Visit 1

Participants completed the paperwork, and had their height and body mass measured. Following this, one-repetition maximum strength (1RM) was measured in a randomized arm. The contralateral arm was familiarized with the Neubie device for no load exercise with pulsed direct current. Following this, individuals were familiarized with biceps curls.

Visit 2

2-7 days after their first visit, individuals returned to the lab. A coin-flip was performed to determine which arm would perform exercise first. Following this, participants rested for 10 minutes followed by the blood pressure measurement. Following this, muscle thickness (MT), isometric strength, muscle soreness, and perceptual feelings, were taken before performing biceps curls. Immediately following the exercise session (post) isometric torque and blood pressure were taken. Following this muscle thickness was also reassessed. Individuals completed either traditional high load (TRAD) or unloaded bicep curls with the addition of direct pulsed current (Neubie). After the completion of one exercise condition, participants rested for 15 minutes before completing the other exercise condition in the contralateral arm.

Visits 3 and 4

24 hours following visit 2, participants returned to the lab for visit 3. MT was measured in both arms in addition to isometric torque and soreness. Visit 4 took place 48 hours after visit 2 and followed the same procedure as visit 3.

Exercise Protocol

Traditional Condition

For traditional high load training (TRAD) participants performed 4 sets of 8-12 reps using a moderately heavy weight (70% of 1RM). Repetitions were performed at a cadence of 1 second for concentric movement and 1 second

for the eccentric movement set to a metronome. Participants rested for 60s between sets and weights were adjusted to achieve volitional failure in the 8-12 repetitions range.

Neubie Condition

The Neubie condition consisted of contracting the musculature of the upper arms through a full range of motion replicating that of a bicep curl exercise without the use of an external load. Two electrode pads (Neufit NFO6, 5x10cm, Austin TX) were placed at 50% the distance of the upper arm (one on anterior aspect of upper arm and one on the posterior aspect of the upper arm). Although the anterior aspect of the upper arm was of interest in the present study, the activation of the triceps provided additional resistance to the biceps during the elbow flexion movement. Contraction was created using the Neubie device as opposed to voluntary muscle contraction. Thus, participants moved their arm through the range of motion mimicking a dumbbell biceps curl. A foam replica of a dumbbell was provided so participants could better mimic exercise. The Neubie protocol was chosen based the findings of Counts et al.⁶ whom showed that 4 sets of 20 maximal muscle contractions mimicking the movement of a bicep curl without the use of an external load resulted in muscle growth similar to traditional high load resistance training (4 sets of 8-12 repetitions with 90 s of rest between sets at 70% of their 1RM). The Neubie device was set to 55Hz and a current amplitude (intensity) equivalent to 7/10 (presence of discomfort without pain) on the discomfort scale. The intensity was increased if discomfort fell below 7. The intensity on the Neubie device ranges from 1-100 with increments of 1%. The intensity reading correlates 1:1 with voltage. For example, 1% output is 1V peak amplitude of the main direct current pulse, 50% is 50V, and 100% is 100V. The pulse width of the Neubie device is 460 microseconds. The electrode pads remained on the skin for the duration of the protocol including rest periods, but the intensity dropped down to 15% of intensity during rest periods. Participants completed four sets of 20 repetitions with 30s of rest between sets. Repetitions were performed at a cadence of 1 second for concentric movement and 1 second for the eccentric movement set to a metronome.

One Repetition Maximum

Unilateral elbow flexor maximal strength was measured using an adjustable dumbbell in the TRAD condition arm in order to select the exercise load. Individuals stood with their back and heels against a wall during all strength testing. Subjects were instructed to flex their elbow in a full concentric range of motion. 1RM was typically obtained within 3-5 attempts, and 1.5 minutes of rest was allowed between attempts. The smallest possible increment for increase was 0.22 kg.

Ultrasound Images

B-mode ultrasound (Mindray DP50, Shenzhen, China) was used to image the anterior upper arm (biceps brachii).

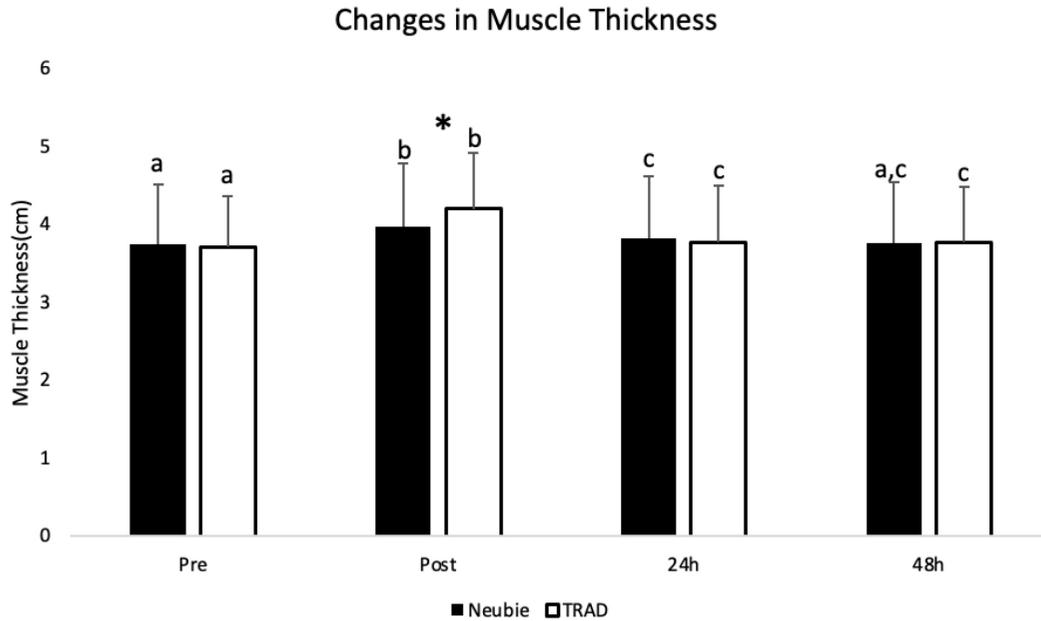


Figure 1. Changes in muscle thickness across time. An asterisks* denotes a difference between exercise conditions. Within each condition across time, different letters indicate differences at a given time point. For example, the Neubie condition has a “b” immediately post exercise which indicates that it is different than all other time points for that condition. The pre time point has an “a” indicating that it is similar to the 48h time point. The “c” would indicate the time points with a “c” are similar to other time points with a “c” within a given condition.

Measurements were taken at 70% the distance between the acromion process and lateral epicondyle. The probe was coated with gel and held lightly against the skin. Two consecutive images were taken by the same trained technician. Images were saved and analyzed in a blinded fashion.

Isometric Strength

For upper body strength testing, participants were asked to flex their arm against an immovable object as hard as possible to determine their isometric strength. Participants were seated in a preacher curl bench with their elbow flexed at 90° and asked to flex their arm as hard as possible against an immovable object. Isometric strength was measured using a load cell (Omega DP8EPT Load Cell, Norwalk, CT). Two contractions were performed per arm and each contraction lasted approximately 5 seconds. Each attempt was separated by 60 seconds rest interval. This test was performed seated in a preacher curl machine with the elbow at a fixed angle. Participants were verbally encouraged during each attempt.

Muscle Soreness

A visual analog scale was used to assess elbow flexor muscle soreness in both arms²³. The individuals were asked to mark off how much biceps muscle soreness they felt on a 100-mm line ranging from “no soreness” to “severe

soreness”. The marks were measured using a standard ruler.

Perceptual Response

The Borg scale of rating of perceived exertion (RPE)²⁴ was used to measure the participants perceived effort following each set of exercise. Immediately following each set participants were asked to rate their RPE on a scale of 6 (none at all) to 20 (maximal effort). In addition, 20-s after each set, participants were asked to rate their discomfort using the Borg discomfort scale (CR10+)²⁵. Discomfort was rated on a scale of 0 (no discomfort at all) to 10 (maximal discomfort).

Exercise-Induced Feelings

The Exercise-Induced Feeling Inventory is a 12-item questionnaire designed to assess the affective responses to a bout of exercise²⁶. Questions are on a 5-point scale ranging from 0: do not feel to 4: feel very strongly. The questionnaire asks feelings of “refreshed”, “calm”, “fatigued”, “enthusiastic”, “relaxed”, “energetic”, “happy”, “tired”, “revived”, “peaceful”, “worn out”, and “upbeat” in order to evaluate three positive feeling states (positive engagement, revitalization, and tranquility), as well as one negative feeling state (physical exhaustion). Exercise-induced feelings were measured before and after both exercise protocols. Reliability and validity have been shown to be adequate²⁶.

Table 1. Demographics and Baseline Characteristics.

	(n=32)
Height (cm)	172.3 (9.1)
Body Mass (kg)	69.9 (22.2)
Age (yrs)	23 (3)
Females (n)	13
1RM (kg)	18.5 (8.0)
Neubie 7/10	32 (10)

Data is displayed as means (SD).
1RM = one-repetition maximum strength
Neubie 7/10 = Current amplitude intensity level of Neubie device out of 100.

Statistical analysis

All data were analyzed using SPSS 26.0 (SPSS Inc., Chicago, IL, USA). Three 2 x 4 [condition (Neubie vs. TRAD) x time (pre, Post, 24, 48 hours)] repeated measures ANOVAs were used to examine changes in MT and isometric torque. A 2x3 [condition (Neubie vs. TRAD) x time (baseline, 24, 48 hours)] repeated measures ANOVA was used to examine differences in muscle soreness between the conditions. A 2x2 [condition (Neubie vs. TRAD) x time (pre, Post)] repeated measures ANOVA was used to examine exercise-induced feelings. If there was a significant interaction (condition x time), a follow-up one-way repeated-measures ANOVA was performed across time (pre-post) within each condition and paired samples t tests were used to compare whether the changes from baseline differed across conditions (Neubie vs. TRAD). Paired samples t-tests were used to examine differences in RPE and discomfort between conditions (Neubie vs. TRAD) for each exercise set. Data are presented as mean (SD).

Results

Demographics and Baseline Characteristics

Descriptive data are presented as mean (SD) and displayed in Table 1. 34 individuals were recruited for the present study. Two individuals dropped out due to unrelated scheduling issues.

Muscle Thickness

For muscle thickness (MT), there was a condition (Neubie vs. TRAD) x time (pre, post, 24h, 48h) interaction ($p < 0.001$, Figure 1). For the Neubie condition, MT increased from pre to post exercise ($p < 0.001$) and remained elevated 24 hours post ($p = 0.020$), reaching baseline levels at 48 hours ($p = 0.51$). The TRAD condition followed a similar pattern, with MT increasing from pre to post exercise ($p < 0.001$) and remained elevated 24 and 48 hours post ($p < 0.05$). Greater MT values were observed for the TRAD condition immediately following exercise [mean difference = $0.23(0.25)$ cm, $p < 0.001$].

Isometric Torque

For isometric torque, the Neubie condition decreased 18% from pre [$70.8(22.6)$ Nm, $p < 0.001$] to post exercise [$58.2(18.2)$ Nm, $p < 0.001$], remaining depressed 8.7% and 7.5% respectively 24 [$64.7(20.8)$ Nm, $p < 0.001$, 6.4%] and 48 [$65.5(22.3)$ Nm, $p < 0.001$] hours post exercise. The TRAD condition followed a similar pattern, with torque decreasing 26.7% from pre [$70.9(23.5)$ Nm, $p < 0.001$] to post exercise [$52.0(18.7)$ Nm, $p < 0.001$], remaining depressed 6.4% and 5.1% respectively 24 [$66.4(22.9)$ Nm, $p < 0.001$] and 48 [$67.3(24.4)$ Nm, $p < 0.001$] hours post exercise. The TRAD training condition demonstrated a greater decrease in torque immediately following exercise [mean difference = 6.19 Nm, $p < 0.001$].

Table 2. Table 2 displays the mean (SD) values pre and post exercise for all affect responses examined.

	Condition	Pre Exercise	Post Exercise
Positive Engagement	Neubie	3.18 (0.67)	3.12 (0.79)
	TRAD	3.16 (0.63)	3.09 (0.69)
Revitalization	Neubie	2.62 (0.74)	2.51 (0.76)
	TRAD	2.53 (0.67)	2.41 (0.65)
Physical Exhaustion	Neubie [†]	1.40 (0.75)	1.81 (0.98)*
	TRAD	1.48 (0.89)	1.90 (1.00)*
Tranquillity	Neubie [#]	2.87 (0.99)	2.48 (0.98)*
	TRAD	2.96 (0.82)	2.34 (1.01)*

An interaction is noted by the pound symbol[#] and main effect for time is indicated by the dagger symbol[†]. An asterisks* indicated significantly different from pre value ($p < 0.05$). Questions are on a 5-point scale ranging from 0: do not feel to 4: feel very strongly. Data displayed as mean (SD).

Table 3. Table 3 displays RPE and discomfort scores for Neubie and TRAD condition across sets.

		RPE	p-value	Discomfort	p-value
Set 1	Neubie	12.3(2.0)	p<0.001	5.2(1.6)	p<0.001
	TRAD	15.2(1.9)		3.5(1.6)	
Set 2	Neubie	13.3(1.8)	p<0.001	5.8(1.3)	p=0.004
	TRAD	16.1(1.8)		4.5(2.0)	
Set 3	Neubie	14.0(1.7)	p<0.001	6.1(1.3)	p=0.008
	TRAD	16.2(2.0)		4.9(2.0)	
Set 4	Neubie	14.2(2.0)	p<0.001	6.3(1.5)	p=0.019
	TRAD	16.6(1.8)		5.1(2.2)	

Data are displayed as mean (SD).

Soreness

For soreness, the Neubie condition increased from baseline [3(6) mm] to 24h [21(20) mm, $p<0.001$] and remained elevated at 48h [28(23) mm, $p<0.001$]. The TRAD condition increased from baseline [3(6) mm] to 24 h [21(20) mm, $p<0.001$] and remained elevated at 48 h [17(16) mm, $p<0.001$]. The direct pulsed current condition demonstrated greater SOR at 48 h ($p=0.007$).

Blood Pressure

For systolic blood pressure (SBP) there was no condition (Neubie vs. TRAD) by time (pre vs. post) interaction ($p=0.37$). In addition, there was no main effect for condition ($p=0.21$). However, there was a main effect for time ($p<0.001$). SBP increased from pre [124(15) mmHg] to post exercise [139(18) mmHg]. For diastolic blood pressure (DBP) there was no condition (Neubie vs. TRAD) by time (pre vs. post) interaction ($p=0.50$). In addition, there was no main effect for condition ($p=0.07$). However, there was a main effect for time ($p<0.001$). DBP increased from pre [74(10) mmHg] to post exercise [82(14) mmHg].

Exercised Induced Feelings

For tranquility, there was a condition (Neubie vs. TRAD) by time (pre vs. post) interaction ($p=0.04$). Follow up tests revealed that tranquility decreased for the Neubie ($p=0.001$) and TRAD ($p<0.001$) condition from pre to post exercise (Table 2). Paired samples t-tests revealed no differences between conditions pre ($p=0.31$) or post exercise ($p=0.08$). For physical exhaustion, there was a main effect for time ($p<0.05$), with physical exhaustion increasing from pre to post exercise (Table 2).

RPE and Discomfort

RPE and discomfort values are displayed in Table 3. For each exercise set RPE values were higher in the TRAD condition compared to the Neubie condition ($p<0.001$). For each exercise set, discomfort values were higher in the Neubie condition compared to the TRAD condition ($p<0.05$).

Discussion

The primary findings of the present study are that both TRAD and Neubie training showed increases in MT, soreness, and decreases in isometric strength for up to 24h. In both conditions, changes in soreness and isometric strength remained at 48h, but increases in MT remained only in the TRAD condition. TRAD training was associated with greater levels of perceived exertion; whereas Neubie training was associated with higher levels of discomfort.

Acute changes in Muscle thickness and Torque

Although it is unclear whether muscle swelling is a mechanism for muscle growth, similar acute swelling has been previously observed across several different resistance training protocols and conditions in the upper body^{6,27,28}. Acute swelling is viewed as a positive response to training¹⁸, and may act as an anabolic signal, resulting in a shift towards anabolism^{29,30}. Even though acute protein synthesis response does not perfectly predict muscle growth³, there is indirect evidence suggesting that acute measurements of muscle protein synthesis following exercise are related to muscle growth^{31,32}. In the present study we observed an increase in muscle thickness post exercise in both conditions with the TRAD condition experiencing higher swelling compared to the Neubie condition [mean difference=0.23(0.25) cm, $p<0.001$]. Although tempting to suggest, the greater swelling response immediately post exercise does not necessarily indicate that a greater magnitude of growth will be observed over time. For example, Fahs et al.¹⁹ demonstrated similar acute swelling between low load BFR and low load non-BFR conditions, with the BFR condition demonstrating a greater increase in muscle size following 6 weeks of resistance training. Furthermore, Buckner et al.²⁰ observed greater muscle swelling in the low-load condition (15% 1RM with and without BFR) compared to the high-load condition (70% 1RM) following an acute bout of resistance exercise. In the follow up training study they demonstrated greater change in muscle thickness for the high-load condition (0.16 cm at the 50% site; 0.15 cm at the 60% site; 0.09 cm at the

70% site) compared to the low-load condition³³ despite initially observing a greater magnitude of acute swelling in the low-load condition²⁰. It seems that muscle swelling does not perfectly predict the magnitude of growth and greatly varies across conditions^{19,20}. Therefore, swelling appears to accompany training modalities that lead to growth; however the magnitude of swelling may not necessarily predict the magnitude of growth.

The measures of isometric torque were used as a surrogate for fatigue (immediately following exercise) and muscle damage (24 and 48h following exercise). We observed decreases in isometric torque in both conditions with TRAD condition demonstrating a greater decrease in torque immediately following exercise [mean difference=6.19 Nm]. Torque remained depressed 24- and 48-hours following exercise with no differences between conditions. Present findings indicate that TRAD protocol was more fatiguing immediately after exercise compared to the Neubie protocol with no differences in the speed of recovery following 24- and 48-hours post exercise. Previous studies have demonstrated that differences in acute fatigue vary between high load and low load protocols. For example, Farrow et al.³⁴ suggested that low-load exercise (15% 1RM with and without blood flow restriction) has been associated with greater acute fatigue (greater short-term decrease in peak force/maximum voluntary contraction; MVC) and greater muscle swelling compared to heavier-load exercise (70% 1RM)³⁴. Yet, the long-term adaptations appear similar if exercise is performed to voluntary failure. Although future research is necessary to confirm, if long-term training with Neubie leads to growth, it may do so with minimal acute fatigue following exercise. In addition to acute changes, depressed torque in both conditions following 24- and 48- hours post exercise might suggest some level of muscle damage or prolonged fatigue in both conditions^{35,36}. However, it is important to note that sustained decreases in torque were small (~4-9%) compared to what has been observed in untrained individuals across a similar time period (17-21%³⁵). Thus, additional studies may be necessary to confirm the presence of muscle damage.

Muscle Soreness

Both TRAD and Neubie conditions increased soreness from baseline to 24 and 48 hours post exercise. Interestingly, Neubie condition exhibited greater soreness 48 hours post exercise ($p=0.007$) compared to the TRAD group. Jones & Round³⁷ have previously suggested that DOMS (delayed onset of muscle soreness) is due to an inflammation of the connective tissue around the muscle. Nosaka et al.³⁸ has suggested that the use of DOMS to judge the magnitude of muscle damage should be avoided since muscle damage and loss of muscle function may exist in the absence of DOMS. However, it is possible that connective tissue damage was present in the TRAD group due to the mechanical stress of the external load³⁷. Similarly, during the Neubie exercise condition, the elbow flexors are activated during the lengthening portion of the exercise, which may mimic an eccentric muscle

action. Specificity of motor unit recruitment during muscle contractions under electrical stimulation (non-selective, synchronous and spatially fixed manner³⁹) can lead to muscle damage which results in increased circulating creatine kinase activity, myofibrillar disruptions, Z-disc streaming, etc⁴⁰. Additionally, training with electrical stimulation has been associated with lactate formation and increased acidification compared to voluntary contraction^{41,42} which, in turn, might result in greater metabolic stress which may also play a role with exercise-induced muscle damage⁴³. Altogether, both protocols produced a similar level of soreness over time, with levels comparable to previous studies in the upper body³⁶. For example Buckner et al.³⁶ observed peak soreness levels of 16 mm out of 100 mm following traditional resistance training in resistance trained individuals. The levels observed in the present study peaked at 24 mm for TRAD and 28 mm for Neubie. This is in contrast to what might be observed following heavy eccentric exercise in individuals completely naïve to exercise. Krentz and Farthing⁴⁴ observed soreness scores of 5.3 out of 9 (0 being “no soreness” and 9 being “intense soreness”) in untrained individuals performing intense unilateral eccentric training. Although muscle soreness is not a requisite for muscle growth⁴⁵, it might provide some indication that the Neubie provided a robust novel stimulus to the muscle which was comparable to that of traditional resistance exercise.

RPE and Discomfort

RPE values were higher in the TRAD condition ($p<0.001$) while discomfort values were higher in the Neubie condition ($p<0.05$). Thus, individuals experienced higher level of perceived exertion in the TRAD condition while having lower level of discomfort. It seems that Neubie condition didn't feel like they were working as hard as the TRAD condition while experiencing more discomfort. Head et al.⁴⁶ examined acute responses following each set of lower limb neuromuscular electrical stimulation and observed an average RPE between 11.0 and 11.1 (RPE scale of 6-20) and an average discomfort values between 3.5 and 3.6 (pain scale of 0-10). Additionally, Crognale et al.⁴⁷ observed RPE values of 13.8 following first session and RPE of 14.4 following second session of lower body neuromuscular electrical stimulation. Our RPE values of 12.3-14.2 and discomfort values of 5.2-6.3 seem similar or slightly lower than the values previously observed when using electrical stimulation. Mattocks et al.⁴⁸ examined changes in perceptual responses following lifting a very low load (15% 1RM) with and without different blood flow restriction pressures (40% (15/40) and 80% (15/80) arterial occlusion pressure) and compared them to RPE and discomfort values following lifting traditional load (70% 1RM) (52). RPE values in the 70% 1RM condition in the upper body following visit 1 were 14.1 while 15/0, 15/40, and 15/80 conditions observed RPE values of 11.6, 13.2, and 15.5 respectively. Our TRAD condition had higher values than what Mattocks et al.⁴⁸ observed that were equal to the RPE of 15.2 following set 1, and RPE of 16.1, 16.2, and 16.2 following sets 2, 3,

and 4 respectively. Higher values in our TRAD condition could be attributed to the training status of the participants. Trained participants may have a better ability to gauge how much effort they are exerting compared to the non-trained participants⁴⁹. Regarding the lower RPE values in the Neubie condition, despite a high level of discomfort during exercise, participants did not have to focus on the external weight throughout the range of motion. In addition, the Neubie device may remove much of the voluntary effort related to contraction given the fact that effort is essentially offloaded to the device.

It has been observed that discomfort associated with electrical stimulation has high individual variability⁵⁰, but discomfort levels are similar across different types of electrical stimulation current waveforms⁵¹. Thus, Neubie training may elicit a similar discomfort response as neuromuscular electrical stimulation. Head et al.⁴⁶ observed discomfort values between 3.5 and 3.6 (pain scale of 0-10) following lower limb electrical stimulation, while we observed discomfort values between 5.2 and 6.3. We specifically asked our participants to train at or close to the discomfort level of 7, while Head et al.⁴⁶ simply measured participants' discomfort level following each set of neuromuscular electrical stimulation. Hence, discomfort levels following our protocol are higher.

Acute Changes in Blood Pressure

Changes in BP were not different between conditions. The average increase from pre to post exercise was 14.25 (12) mmHg for SBP and 7.3 (12.7) mmHg for DBP. The changes in BP observed are similar to those of Mouser et al.⁵² whom observed an 10 (11) mmHg increase in SBP following high load or low load (with and without blood flow restriction) biceps curl resistance training. However, Mouser et al.⁵² did not observe a significant increase in DBP following their traditional resistance exercise condition [mean change 2 (11) mmHg]. This difference may be due to the shorter rest periods utilized in the present study (30 or 60s vs. 90s). Nevertheless, the differences in blood pressure responses are relatively small and in line with what one might expect following a resistance training bout in the upper body^{52,53}.

Exercise-Induced Feelings

When examining exercised-induced feelings, there were no differences between conditions. Overall, the results suggest that individuals felt less tranquil and more physically exhausted following both Neubie and TRAD exercise. For the remaining affective measures examined (positive engagement, revitalization) there were no changes from pre to post exercise. Thus, both Neubie and the TRAD conditions experienced similar changes in feelings post exercise suggesting that both exercise protocols affect feelings in the similar manner. Buckner et al.⁵⁴ observed that one's feelings in response to exercise do not change across time suggesting

that in case of a long training intervention we might expect patterns in exercise-induced feelings over time. Parfitt et al.⁵⁵ suggested that shift in affective responses from pleasure to displeasure following exercise is correlated with increases in exercise intensity suggesting that affective responses post exercise are intensity dependent. However, literature shows that affective responses post exercise might be driven by fatigue rather than external load^{54,56}. Interestingly, fatigue might not always explain the changes in affective responses. Richardson et al.⁵⁷ observed similar affective responses between conditions (high load at low velocity and low load at high velocity) despite high load group demonstrating higher rating of fatigue. Buckner et al.⁵⁴ suggested that affective responses may depend on the volume of work completed and can be influenced by fatigability. They also speculated that the perceived discomfort may contribute to the more negative affective response⁵⁴. Contrary to the suggestions of Buckner et al.⁵⁴, we observed similar changes between conditions from pre to post exercise despite TRAD condition experiencing higher RPE values and greater swelling response post exercise. Arguably, it is possible that despite TRAD condition having higher volume, the fatigability between conditions was similar due to increased discomfort of the Neubie condition.

The present study is not without limitations. For example, the present results may be specific to the Neubie device. Thus these findings may be non-generalizable to other electrical stimulation machines. Further, using ultrasound, we were not able to determine if fluid shifted into the actual muscle cell. Therefore, it can only be hypothesized that muscle cell swelling occurred in the present study. In addition, we performed Neubie training at an intensity equivalent to 7/10 (presence of discomfort without pain) on the discomfort scale. It is possible that other intensity settings may provide different results. It is also possible that a different number of repetitions, rest periods and sets would result in different outcomes. Finally, the present study examined acute responses to Neubie and TRAD training. Although these findings help to characterize the exercise stimulus, training interventions are necessary to better understand the anabolic potential of Neubie training.

Conclusion

Results of the present study suggest that a similar acute skeletal muscle response was observed between Neubie training and TRAD with some subtle differences observed in the time course of muscle swelling, changes in isometric torque, and muscle soreness. In addition, individuals experienced similar exercise-induced feelings following both conditions. Overall, Neubie training might be effective for individuals who are looking to experience lower RPE responses during exercise. However, this might occur with increased discomfort levels. Further research is necessary to examine neuromuscular responses to Neubie training over longer periods of time (8-12 weeks).

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