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Peripheral Electrical and Magnetic Stimulation to Augment Resistance Training

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Abstract: Electrical stimulation (ES) and magnetic stimulation (MS), applied peripherally, may be used to elicit muscle contractions to increase muscle hypertrophy, increase muscle strength and reduce knee laxity in rehabilitation following injury. We aimed to examine the effect of a three-week exercise programme designed to induce muscle hypertrophy augmented by peripheral ES and MS. We hypothesised that the use of peripheral stimulation to augment voluntary drive during a resistance-training protocol would induce more repetitions thus leading to increased thigh circumference, muscle layer thickness, and quadriceps strength whilst decreasing knee laxity. Thirty healthy participants were divided randomly into either ES, MS or Control groups. Five resistance training sessions were carried out, consisting of four sets of quadriceps extensions. During the first three sets the participants performed eight repetitions at 85% of their 1-repetition maximum (1-RM). On the last set, the participants were instructed to perform the exercise until failure. The augmentation of peripheral stimuli allowed the MS and ES groups to continue to exercise producing, on average, 4 ± 2 and 7 ± 6 additional repetitions with ES and MS, respectively. Following the training, significant increases were observed for both 1-RM ($p = 0.005$) and muscle layer thickness ($p = 0.031$) whilst no change was observed in thigh circumference ($p = 0.365$). Knee laxity decreased ($p = 0.005$). However, there were no significant differences in the stimulation groups compared with control for any of these measurements. The additional repetitions elicited by stimulation after the point of failure suggests that peripheral electrical and/or magnetic stimulation may be useful as an adjunct for resistance training. However, this effect of resistance training augmented by peripheral stimulation on hypertrophy, strength and knee laxity may be small.

Keywords: k electrical stimulation; magnetic stimulation; strength

1. Introduction

Resistance training is frequently used to promote muscle hypertrophy, strength and knee laxity. Electrical stimulation (ES) and magnetic stimulation (MS) have been used as an adjunct to athletic training [1–3], although it is more commonly used as a rehabilitation therapy to promote quadriceps strength after surgery [4–7], quadriceps hypertrophy [8], to investigate different types of muscle fatigue [9], daily functional activities after stroke [10], and osteoarthritis patients [11,12]. However, the evidence concerning the usefulness of peripheral stimuli as an adjunct to training programmes for enhancing muscle hypertrophy, strength, knee laxity and training healthy people is not conclusive. One reason for the inconsistence effects reported in the literature is the methods by which stimulation is applied.

Kyung-Min et al. [4] systematically reviewed the literature assessing the effect of ES on quadriceps strength and functional performance following knee surgery. They reported significant effect sizes of quadriceps isometric and isotonic torque (ranging from −0.74 to 3.81) at 6 weeks post-operatively, in contrast, the effect sizes of the lateral step-up test and functional reach test were not significant (ranging from 0.07 to 0.64). The authors concluded that ES with exercise may be more effective in enhancing quadriceps strength than exercise alone. In a more recent systematic review, Hewlett et al. [10] examined the ability of ES to improve walking speed, wrist extension and ankle dorsiflexion, and investigated whether it is more effective than training alone. They showed that ES had a mean moderate effect (0.40, 0.09−0.72; 95% CI) on activity compared to no or a placebo intervention. In addition, the stimulation group showed a mean large effect on upper limb activity (0.69, 0.33−1.05; 95% CI) and a small effect on walking speed (0.08 m/s, 0.02−0.15; 95% CI) compared to the control group. Their findings suggest that ES could be used in patients after traumatic injuries where functions have been affected.

The literature lacks a gold standard anteroposterior knee laxity measure to assess anterior cruciate ligament (ACL) injuries [13]. As a result, clinicians rehabilitate the injured knee through a variety of resistance training protocols with the aim of strengthening thigh muscles to overcome knee instability. Beretta-Piccoli et al. [14] reported that patients showed less fatigability after 24 months of ACL rehabilitation compared to a group of patients who underwent less than 12 months rehabilitation. This suggests that long term resistance training strategies after ACL reconstruction should be implemented to reduce knee injury rates. Taradaj et al. [7] assessed if ACL-reconstructed male football players (n = 40) benefited from ES as an adjunct to their regular protocol after knee ACL reconstruction. To the authors' knowledge, this study design had the shortest protocol for their experiment (one month), and both the intervention and control groups received three sessions weekly consisting of the same exercise programme. The intervention group received ES on both right and left quadriceps three times daily, three days a week. The comparison of post-training measures showed a significant difference in favour of the stimulation group in the quadriceps extension (30.1% versus 4.6%, p = 0.002) and thigh circumference (1.4% versus 0.6%, p = 0.04). The authors concluded that there is evidence of the benefit of peripheral ES in restoring quadriceps muscle mass and strength in football players. Barcellona et al. [15] investigated the effect of two sets of 20-RM (LOW group) and 20 sets of 2-RM (HIGH group) quadriceps open kinetic chain resistance training on anterioposterior knee laxity. Unlike the HIGH and control groups, the LOW group demonstrated a mean reduction of 5 cm in anterior knee laxity after a twelve-week training protocol. The authors concluded that knee extensor open kinetic chain resistance training at the corrected dose may lead to a reduction in anterior knee laxity of the ACL-injured knee. To the author's knowledge, this study is the only one that has investigated the effect of quadriceps hypertrophy training on anterioposterior knee laxity.

In addition to its clinical use, the effect of peripheral stimulation as an adjunct to weight training has been investigated in healthy people. Kubiak et al. [3] compared quadriceps strength torque in control (n = 9), isometric exercise (n = 10) and ES (n = 10) groups before and after a five-week training protocol consisting of three sessions per week. The quadriceps of the stimulation group received 15-s long stimulation contractions with a 50-s rest period between each contraction. All the participants tolerated a stimulation intensity which ranged between 75% and 134% of the MVIC, and significant strength increases ($p < 0.05$) were seen for all in both the electrical and isometric exercise groups. Szecsi et al. [1] evaluated the mechanical power generated by healthy participants during MS or ES induced ergometer training conditions; MS produced more mechanical power (23.8 ± 9.1 W) and longer cycling exercise compared to ES (11.3 ± 11.3 W). Bax et al. [16] systematically reviewed the literature that investigated the effect of ES as an adjunct to training on the quadriceps femoris muscle strength for both healthy and ACL-reconstructed participants. A number of important conclusions were highlighted in this review. They suggested that the application of ES for both injured and non-injured participants is likely to be more appropriate as an adjunct to rather than a replacement of resistance training. They also suggest voluntary activity together with ES likely results in greater efficacy. Their meta-analysis indicated that publication bias may be present in the literature regarding whether the included studies represent the full spectrum of trials performed in actual research practice. Finally, they highlighted the observation that the literature in this field lacks high quality studies and that further research is necessary.

Recently, peripheral MS has been trialled as an alternative to ES [9,17]. As this technique is novel, there is a dearth of literature examining its efficacy as an adjunct to training programmes for quadriceps circumference, muscle layer thickness, strength and knee laxity. Previously, peripheral MS has been restricted to the study of fatigue [18] and it has been reported that peripheral stimulation might minimise the effect of muscle fatigue and shorten the time spent in recovery [1,7,18]. In addition, peripheral stimulation alongside weight training may be preferred by patients and athletes as it is characterised by portability (ES) and less pain (MS) compared to alternative methods, such as stretching, massage and cold water immersion [11,19]. Moreover, the application of peripheral ES and MS will bypass central nervous system (CNS) fatigue, and, therefore, it may be more efficacious if applied at the point of voluntary muscle failure in order to induce additional repetitions. Nevertheless, studies that showed a positive effect of peripheral stimulation used subjective outcome measures (e.g., pain), which increase the chances of false positive results [20,21].

We aimed to determine whether peripheral ES and MS applied at the point of muscle failure following voluntary exercise could induce greater hypertrophy, strength and less anterior knee laxity than voluntary muscle activity alone. We hypothesised that a three-week training protocol using peripheral ES or MS applied at the point of voluntary muscle failure would induce more repetitions, and increase thigh circumference, muscle layer thickness, quadriceps strength, whilst decreasing anterior knee laxity compared to the controls.

2. Materials and Methods

2.1. Participants

Thirty healthy participants (16 females, mean age 20 ± 4 SD years, range = 18–37; and 14 males, mean age 19 years ± 1 SD, range = 18–20) were recruited. All the participants were undergraduate university students who performed active regular exercise of not less than 30 min of physical activity at least five times per week. Participants were screened for previous knee injuries and neuromuscular conditions, and agreed not to undergo any additional leg strength training during the three weeks of this study. All participants provided written informed consent prior to participating in the study. The experimental procedures were conducted in accordance to the Declaration of Helsinki and were approved by the ethical committee of the University of Birmingham Science, Technology, Engineering and Mathematics (STEM) committee (ethics approval code: ERN-14-0188).

2.2. Study Design

The study was carried out over 21 days and had a between-participant design with four dependent variables: girth measurement of the thigh muscle, quadriceps muscle layer thickness, knee anterioposterior laxity measure, and maximum weight lift of the quadriceps extension. Participants were randomly assigned to one of the three study groups: strength training only (control), strength training with electrical stimulation (ES), or strength training with magnetic nerve stimulation (MS). The study had two independent variables: time (pre vs. post) and group (electrical vs. magnetic vs. control). The study protocol started with baseline testing and a weight training session on day one, followed by two rest days, which were also provided between each subsequent training session. After the final training session all the participants rested for a week to ensure no peripheral fatigue existed as a result of the training protocol. Finally, on day 21, post-experimental testing was conducted (Figure 1). All measurements were carried out on the participant's dominant leg in a non-fatigued state.

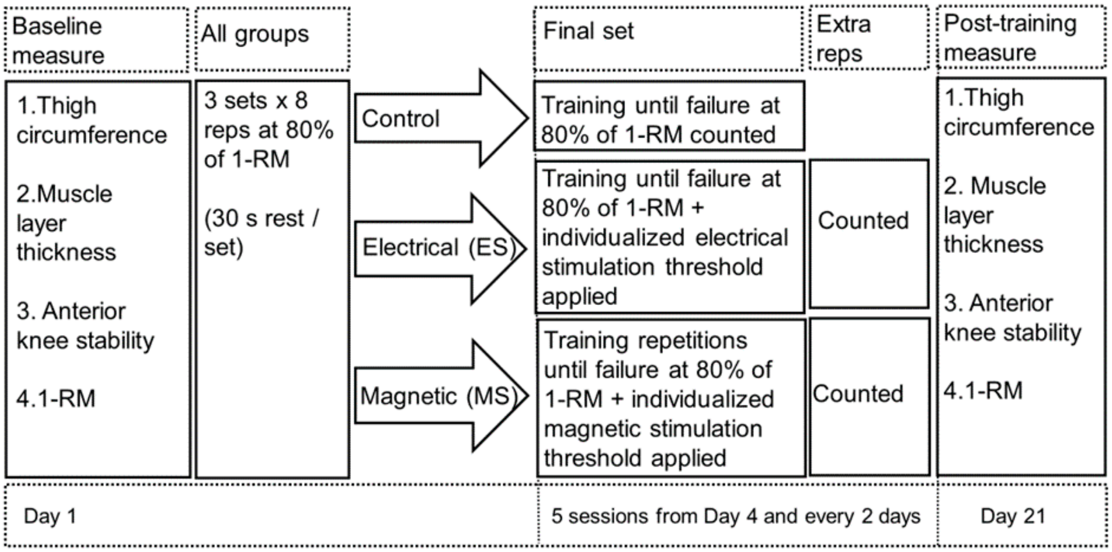

Figure 1. Flow diagram of the weight training protocol for the three groups. All performed a baseline measure before any weight training followed by four sets of resistance quadriceps weight training. The first three were standardised to eight repetitions only at 80% of 1-RM. The fourth set was aimed to reach the maximum number of repetition a participant can could perform. For the intervention groups both received either stimulation to assess whether extra repetitions could be induced or not at point of muscle failure. ES = electrical stimulation; MS = magnetic stimulation; reps = repetitions; 1-RM = 1-repetition maximum.

2.3. Procedures

Baseline and post-exercise measures for thigh circumference (Section 2.4.1), muscle layer thickness (Section 2.4.2) and knee laxity (Section 2.4.4) were recorded with the participant laying supine on a plinth. The baseline and post-exercise 1-RM assessment (Section 2.4.3) and fatiguing exercises were conducted with the participant seated in Cybex chair (Cybex VR3, International Inc., Owatonna, MA, USA).

The study training protocol was designed to focus on hypertrophy rather than strength. Previous research has suggested that optimum hypertrophy gains in healthy individuals are best obtained when performing the 1-repetition maximum (1-RM) technique (see [22] for review), although it has also been shown that training with higher intensities can also lead to strength gains in addition to hypertrophy (e.g., [23,24]). Each participant performed three sets of 8 repetitions at 80% of their 1-RM (as defined in Section 2.4.3) with 30 s rest between each set (Figure 1). This was followed by a fourth set, also performed at 80% of the 1-RM, where the participant exercised to the point of muscle failure. Failure was defined as the point at which a participant could no longer voluntarily contract the quadriceps to fully extend the leg. At this point either electrical (ES group) or magnetic (MS group) stimuli were provided to augment the voluntary effort thus allowing the participants to perform additional repetitions beyond the point of failure. In both cases, stimuli were delivered to the motor point of the rectus femoris muscle. Electrical stimuli were delivered through self-adhesive surface stimulating electrodes (Compex Easy Snap, Compex Global, Surrey, UK) using the Mi Compex 3, Professional (Compex Global), with a pulse duration of 400 µs and a pulse frequency of 50 Hz. To determine the magnitude of the stimuli, the intensity of stimulation was increased to the point where the greatest contraction was produced within the individual tolerance level of the participant. This intensity was recorded as their maximum threshold. The magnitude for magnetic stimuli (MagPro ×100, MagVenture, Farum, Denmark) was determined in a similar manner increasing the stimulation from 5% intensity until reaching their maximum threshold.

2.4. Assessment Methods

All testing and weight training sessions were supervised by a certified strength and conditioning coach. Post-testing was carried out by an experimenter who had remained blinded throughout the data collection sessions to avoid bias when reading the follow up results. Post-training measurements were carried out at roughly the same time of day (±2 h) to reduce the effect of circadian fluctuations [25,26]. All measures were taken from the participant dominant leg.

2.4.1. Thigh Circumference

Thigh circumference was measured with the participant lying supine position on a plinth. The measurement was taken at the midpoint between the anterior superior iliac spine (ASIS) and the lateral epicondyle of the femur, and the position was marked with a permanent marker. Three measures of thigh circumference were made with a medical tape recording to the nearest millimetre, from which a median value was calculated for use in the statistical analysis.

2.4.2. Muscle Layer Thickness

With the participant in the same position as for the circumference measure, rectus femoris (RF) muscle layer thickness (MLT) was obtained using a Phillip Sonos D2 5500 ultrasound (US) with an 11-3L probe at an image depth of 7 cm. Measurements were made using the ultrasound's calliper function. Rectus femoris MLT measures were repeated three times to the nearest millimetre, from which a median value was calculated for use in the statistical analysis (Figure 2).

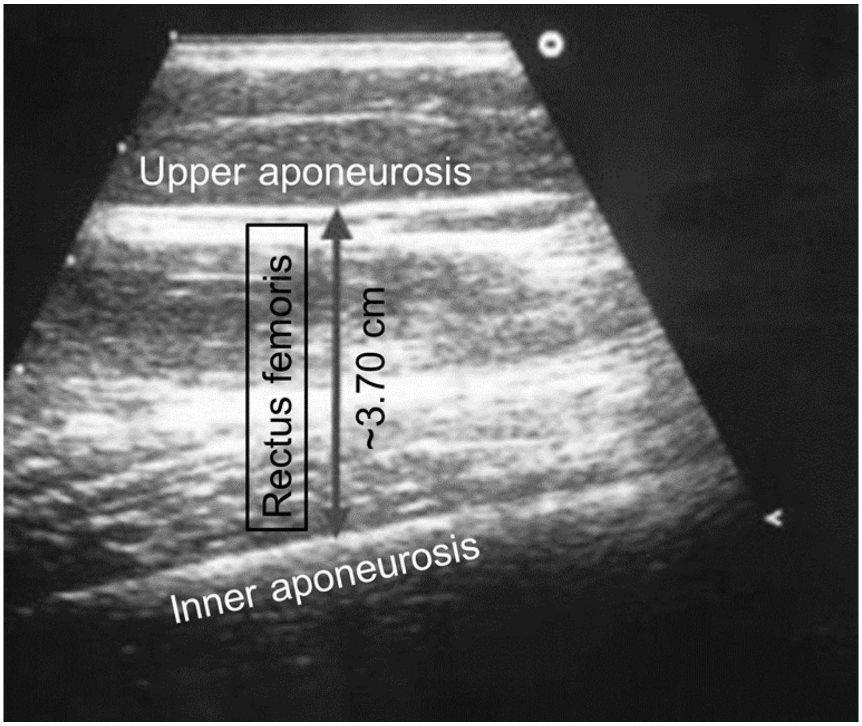

Figure 2. Illustration of how the muscle layer thickens was measured using the ultrasound image for every participant. The distance between the upper layer and lower layer of the rectus femoris muscle image was measured using the integrated US arrow. The US gives the exact distance between the two heads of the arrow which corresponds to the thickness of the measured muscle.

2.4.3. Maximal Leg Extension

Knee extension strength was measured with a Cybex VR3 (Figure 3). The participant was seated with the back support and tibia pad adjusted to fit the individual's height, and these seating

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