International Journal of Physical Medicine & Rehabilitation

Canning and Grenie, Int J Phys Med Rehabil 2014, 2:4
DOI: 10.4172/2329-9096.1000207

Research Article Open Access

Does Neuromuscular Electrical Stimulation Improve Muscular Strength Gains of the Vastus Medialis Muscle

Alicia Canning and Sylvain Grenier*

Department of School of Human Kinetics, Laurentian University, Sudbury, Canada

***Corresponding author:** Sylvain Grenier, School of Human Kinetics, Laurentian University Sudbury, Ontario P3E 2C6, Canada, Tel: (705) 675-1151 Ex: 1095, E-mail: sgrenier@laurentian.ca

Received date: 19 April 2014; **Accepted date:** 17 June 2014; **Published date:** 20 June 2014

Abstract

Background: Neuromuscular electrical stimulation is currently being used for treatment in rehabilitation situations. Studies indicate that neuromuscular electrical stimulation increases muscle strength in weakened muscles; however few studies have examined the effect of neuromuscular electrical stimulation and muscle strength on healthy muscles or compared combinations of NMES and exercise.

Objective: To compare the effectiveness of three methods in strengthening the vastus medialis muscle in healthy adults.

Methods: Fifteen healthy male participants between the ages of 18-25 participated in this randomized repeated measures study. The participants were randomly assigned into three (neuromuscular electrical stimulation, neuromuscular electrical stimulation + exercise or exercise only) groups of five. They performed eccentric step-downs for 5 minutes, 3 times a week for 4 weeks. The force of the vastus medialis muscle was measured with an isometric leg extension at 60 degrees, using the Biodex force dynamometer (Model 820-110). This test was performed a total of three times on each participant: pre-testing, mid-testing and final-testing.

Results: A two-way analysis of variance and a post hoc Scheffe's test revealed a significant test interaction difference between group and test time. In the neuromuscular electrical stimulation group the mean force from the pre-test (121.4Nm), to the final-test (165.8Nm) significantly increased compared to the pre and post-tests in the other groups.

Conclusion: Neuromuscular electrical stimulation training was most effective in increasing muscle strength of the vastus medialis muscle in healthy participants after four weeks.

Keywords: Neuromuscular electrical stimulation; Vastus medialis; Exercise

Introduction

Several therapeutic modalities involving energy are used in physiotherapy settings. More specifically, numerous forms of energy including electromagnetic energy, thermal energy, electrical energy, sound energy, and mechanical energy are relevant in terms of therapeutic modalities. Different modalities are used to help treat the individual by strengthening, relaxing and or healing the muscles. For example, in terms of electrical energy, an electrical signal is sent to an injured muscle to help stimulate the muscle. Over the past several years, electrotherapy has become a common practice in physical therapy [1].

There is plenty of research indicating that neuromuscular electrical stimulation (NMES) helps those with injuries, in certain rehabilitation situations [2] and even helps patients with neurological conditions [3]. Electrical stimulation restores motor functions, and similarly to voluntary exercise, NMES can be used to restore muscle strength [4]. For instance, with muscle weakness or denervation of a muscle group "motor functions can be improved by electrical stimulation of muscles or nerves" [4]. NMES has been shown to be successful following a knee replacement in terms of preventing muscle strength decrease [5], to be effective as a treatment for muscular dysfunction [6] and to increase muscle strength in the wrist, knee and ankle extensors in stroke patients [3]. Additionally, NMES has been shown to increase range of motion in the lower limbs of multiple sclerosis patients [4]. As mentioned by Vrbová et al. [4], "electrical stimulation can replace activity in cases of injury to the nervous system". Indeed, "the increased knowledge about the effects of electrical stimulation on various parts of our healthy or damaged body allows us to use stimulation as an efficient therapeutic tool" [4].

The general consensus is that NMES is used to aid individuals in therapeutic environments, specifically in patients who are already injured. However, some researchers have found NMES increased strength in healthy muscles combined with exercise [7], and others found no change in muscle strength [8]. On the other hand, there is some controversy whether NMES is more effective than voluntary exercise [9].

Central Nervous System (CNS)

During voluntary movement, the smaller motor units are activated first followed by the contractions of the larger motor units [4]. That being said, only during maximal effort are the larger motor units active [4]. Due to biophysical properties of muscle, the order of the motor unit activation is reversed with the application of muscle stimulation [4]. When using NMES, the machine will stimulate the nerves at the motor point. The muscle will then expand and contract similarly to a voluntary contraction. This study explores the potential of combining voluntary movement and muscle stimulation.

Muscle Stimulation Protocol

The variety in the treatment parameters, such as: the frequency, program duration, pulse width/duration etc. make it difficult to determine the most effective type of muscle stimulation. In addition, a considerable number of researchers have examined which parameters combined will produce optimal contraction, and to date none have been shown to be most effective [9].

To produce muscular contraction, sufficiently high intensities are commonly used and can be applied to the muscle during movement or without movement occurring [9]. Although in some research [10] NMES showed significant muscle strength increases with a frequency of 80Hz, a starting frequency of 60Hz with an on off ratio of 1:3 is suggested [5]. Several researchers studied the effect of NMES on the abdominal muscles [11] and on the back musculature [12]. However, the quadriceps femoris is the most common stimulated muscle [13].

It seems intuitive that by increasing muscle strength with electrical stimulation; a higher frequency of current is required to provide a stronger muscle contraction. Evidence suggests, “The stronger the induced contraction force in the muscle the greater are the strength gains” [14]. However, in Lake’s [5] study “the same parameters can be used for re-education as for strengthening, but there is no evidence that high-stimulus intensities are required”.

As for the frequency of treatment, multiple researchers have used three to seven sessions per week over three to six weeks of training [2,5,9,10,13,15]. In Porcari’s study [2] no significant effect of quadriceps isometric and isokinetic strength was shown when participants underwent stimulation training three times per week. Yet, Parker et al. [15] explored the strength training effect of two versus three training sessions per week over a four-week period of NMES on the quadriceps femoris muscle. As a result, the participants having the NMES three times per week, showed a significant increase in the strength of the quadriceps femoris muscle [15].

Evidence for NMES and Muscle Strength

Early research has been proven that NMES increases muscle strength. Robinson [16] indicates that NMES is “significantly more effective at strengthening quadriceps than voluntary exercise”. In a more recent study, however voluntary exercise and NMES showed no differences [8].

In physical therapy environments, physiotherapist will prescribe exercise, NMES and NMES combined with exercise to a patient. In a study by Selkowitz [7] the effects of muscle strength in the quadriceps femoris training isometrically with electrical stimulation were investigated and a significant increase ($p<0.1$) was revealed to the group training isometrically with electrical stimulation. In a more recent review, evidence concludes that electrical stimulation of atrophied quadriceps muscles can improve its isometric strength with the combination of NMES and volitional exercise [17]. Additionally, researchers designed a systematic review to determine if NMES increases the quadriceps femoris muscle strength [13]. They used post-injury and post-operative subjects and measured the isometric and isokinetic contractions. Their data suggested that when comparing NMES to volitional exercise, volitional exercise seems to be more effective [13]. Nevertheless, in healthy subjects, several researchers discovered in abdominal training, that NMES combined with voluntary exercise could be more effective than exercise alone [18,19]. Furthermore, most studies regarding the quadriceps femoris muscle with NMES in combination with exercise have focused entirely on abnormal muscles (injured, atrophied, post-operation ect). In the current study, we evaluated exercise, NMES and NMES combined with exercise on healthy quadriceps femoris muscles.

Another important characteristic of the current study is that only the eccentric step down exercise will be prescribed to the participants; compared to the numerous studies that have targeted isometric exercises. Given that NMES causes a maximal effort by activating the larger motor units first through the nerves located at the motor point of the muscle, and voluntary movement first activates the smaller motor unites from the CNS sending signal to the muscle [4], we predict that healthy muscles will have better strength gains with NMES combined with exercise.

Materials and Methods

Ethics approval was granted from the Research board prior to participant recruitment and testing.

Participants

Fifteen healthy male athletes between the ages of 18-25 years old were recruited by convenience sampling within the university population. The participants were divided into three groups of five. Between each group, the participant's mean age, height and weight were similar. Table 1 demonstrates the means for each group.

Group	Age	Height (cm)	Weight (kg)
NMES	20.2	177.8	79.9
NMES + EX	19.8	178.8	79.2
EX	20.6	176.9	75.7

Table 1: Group means.

Participation was voluntary with no incentives. All subjects were cleared by the Physical Activity Readiness Questionnaire (PAR-Q) questionnaire, which enabled them to participate in the study without concern. The participants were not taking any body building supplements or protein supplements during time of testing and research period. Also, the participants were not aware of any known disease or conditions that would preclude participation, had no current injuries (more specifically knee injuries), no pacemakers, no open wounds, no previous knee/leg injuries or surgeries within the last year, no history of cancer, no neuromuscular conditions and no neurological conditions. Lastly, all participants provided their informed written consent to participate in the study.

Study design

This study compared muscle strength increase of the vastus medialis (VMO) muscle between the three groups where the leg and task were randomly assigned. The frequency of sessions was chosen based on recommendations regarding the usage of NMES [1]. The participants in each group performed three sessions per week, over a period of four weeks [4,5,13].

A battery powered muscle stimulation (S48 Stimulator) device was used for the stimulation of the VMO muscle (the batteries were replaced after every fifth participant). In all three groups, participants wore shorts and performed a five-minute warm up including, jogging and stretching.

In the first and second group, the surface of the skin where the electrodes were placed was properly washed with soap and water to promote better contact and to prevent electrical resistance of the interface [1]. After this, two carbon electrodes with electrode gel were connected to the NMES device. The carbon electrodes, created better contact with the skin because of their malleability [9]. The electrode size is determined by the muscle being stimulated [1,20] and in order to get a motor response, a small square electrode is placed on the motor point and the larger rectangular electrode is placed somewhere over the muscle belly [21]. Participants contracted their leg to provide a reference, thus confirming the location of the muscle belly [4].

Participants in the first group were exposed to the NMES signal on their VMO muscle for five minutes in a relaxed supine position. In the second group, the participants were exposed to the NMES on their VMO muscle for five minutes and performed the eccentric step down exercise where the leg with the NMES was standing on a 15cm (6 inch) stool or bench. In the third group the participants performed the eccentric step down exercise for five minutes on a 15 cm (6 inch) stool or bench.

The NMES was set at the same parameters for each participant in groups one and two. The settings for the parameters were guided by McDonough's recommendations [9] and included: amplitude set at a maximum tolerable by the individual, frequency of current of 60 Hz with an on: off ratio of 5s: 15s and the number of contractions per session between 30 and 45 [9]. The participant's in-group 3 were timed each 15s and performed the eccentric step down exercise for 5s, thus an on:off ratio of 5s:15s for a total of 5 minutes. Following each session, the participants completed a five minute cool down, which consisted of a fast walk/light jog and stretch. Each session lasted approximately twenty minutes.

Functional testing

The following test was performed a total of three times on each participant: before beginning session 1 of week one, before beginning session 6 of week two, and one day after the final session 12 in week four.

Force dynamometer: The force of the VMO muscle was measured using the Biodex force dynamometer (Model 820-110). The knee was fixed at 60o of flexion because the isometric knee extensor torque is found to be greatest at this angle [22]. The participants performed a maximum voluntary contraction for 5 seconds.

Data analysis

Statistical analysis program for Mac OS (StatPlus: mac; version: 2009, AnalystSoft Inc) was used to analyze data. The mean values of the VMO muscle strengths from the force dynamometer in each group were calculated for the pre-test, mid-test and final-test. Analysis of variance (ANOVA) was used to compare the differences in mean force (DV) between the tests (pre, mid and final) for each group (NMES, EX +NMES, EX). A Post Hoc Scheffe's test was used to determine the specific significant differences between each pair. Significance was accepted as $p<0.05$.

Results

A comparison between tests within each exercise group using the Fisher LSD test showed that within NMES group there was a significant difference between the pre test and final test ($p=0.012$). Figure 1 demonstrates this relationship. No other group showed this difference. A significant difference was found overall (main effect) between exercise groups (NMES group, NMES + Exercise group and Exercise group) ($p=0.027$). Refer to Table 2. Each group combination using the Post Hoc Scheffe's test was analysed. That difference was between the NMES group and the Exercise group ($p<0.05$) but no other group comparisons showed a significant difference. These differences can be seen in Table 3.

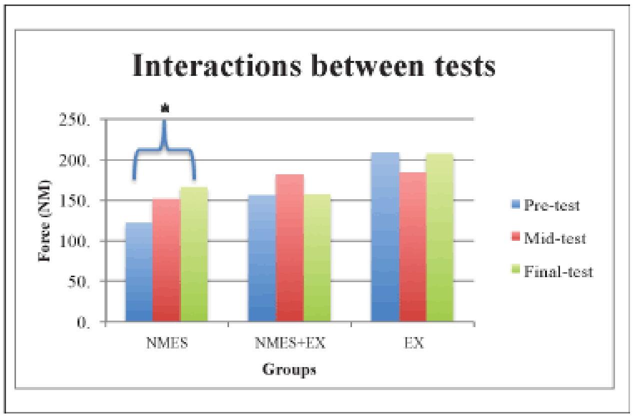

Figure 1: Mean force measured for each test in each group; the pre-test (blue), the mid-test (red) and the final test (green). Force was measured in NM. The asterisk (*) denotes a significant difference between pre and final test of NMES group ($p< 0.05$).

Discussion

As mentioned in the results, significant strength increase between tests was found in the NMES group. More specifically a significant difference was found between the pre and final test ($p=0.012$). This is in agreement with literature, which showed that NMES is effective to increase muscle strength in the quadriceps [13,16]. Conversely, previous research revealed that voluntary exercise compared to NMES showed no differences in muscle strength [8]. Differences in these studies may be due to the duration of the muscle stimulation provided. Although, 5 minutes of stimulation (as we have done) is currently being used in a physical therapy setting, several researchers used >10 minutes of stimulation in their studies [2,10]. Five minutes of stimulation in this study showed an increase of 44.4NM, from the pre-test (121.4NM) and final test (165.8NM) in the NMES group. It is possible that greater strength increases could be found with longer muscle stimulation (>10 minutes).

Factor #1 (Group) **p-value = 0.0269***	
Group	Mean
1	146.2
2	165.0
3	199.9
Factor #2 (Test) **p-value = 0.729**	
Test	Mean
1	161.8
2	172.6
3	176.8
Factor #1 + #2 (Group x Test) **p-value = 0.6186**	
Group x Test	Mean
1x1	121.4
1x2	151.5
1x3	165.8
2x1	155.9
2x2	182.1
2x3	157.1
3x1	208.3
3x2	184.1
3x3	207.4

Table 2: p-values and factor means. *p<0.05 using two-way ANOVA.

Group vs Group (Contrast)	**Difference**	**Test Statistics**	**Critical value (5%)**	**Accepted?**
NMES vs NMES +EX	-18.814	0.976	2.533	Rejected
NMES vs EX	-53.733	2.789	2.533	Accepted
NMES+EX vs EX	-34.919	1.812	2.533	Rejected

Table 3: Scheffe contrasts among pairs of means.

Although no difference between tests was found with the NMES + Exercise group, this type of training was previously found to increase muscle strength in the quadriceps femoris in a study by Selkowitz [7]. The findings by Selkowitz [7] may be attributed to the study design in which the training was done isometrically. Consequently, in our experimental design the training was done eccentrically, therefore, the comparison may not be valid. The findings also reveal that NMES combined with voluntary exercise is not more effective than exercise alone. Although researchers Alon et al [18] and Alon & Taylor [19] studied the effects of electrical stimulation and exercise on healthy abdominal musculature, they indicated that NMES combined with voluntary exercise could be more effective than exercise alone. Given that the study trained healthy quadriceps musculature, (more specifically the VMO musculature) and the previous studies researched healthy abdominal musculature, the comparison is inadequate.

Another difference between the experimental design of the study, and the study of Paillard et al. [10] is the stimulation frequency during treatment. As previously stated, Paillard et al. [10] used a frequency of 80Hz, rather than using a frequency of 60Hz to increase muscle strength. The NMES training group with a frequency of 80Hz showed significant muscle strength increases [10] whereas this study did not for the NMES + Exercise group with a frequency of 60Hz. However, the 60Hz frequency of treatment did show significant muscle strength increase in the NMES group. Therefore, the frequency of treatment may have been to low for the NMES + Exercise group and could be a possible reason why there was lack of significance for that particular group in the current study. Moreover, this leads us to question the NMES treatment parameters that likely played a role in this finding. The duration of stimulation (5 minutes, 3 time for 4 weeks) and frequency of stimulation (60Hz) used in this study, may not have been appropriate to stimulate healthy muscles with the incorporation of exercise. It is known that muscles will adapt to a training stimulus over time causing a plateau where the individual no longer seems to improve in their training [23]. Thus, healthy active adults may require different frequencies with the NMES + Exercise training.

Certain limitations should be acknowledged in the study. First, a small sample size was used with only 15 participants. However, since there was a significant difference detected among groups, future research should consider the finding that muscle strength increased from NMES. Furthermore, participants were asked to refrain from taking any body building supplements or protein supplements during time of testing and research period. Since it is unknown if participants followed these requirements, results can be influenced. Finally, all of the participants were healthy active athletes, however some of which may have been involved in exercise, specifically weight training exercise more than others. Therefore, the participant's involvement in physical activity and exercise may have also affected the study's results.

Conclusion

The study revealed that NMES alone increases muscle strength. Although the muscle strength with NMES + Exercise training did not increase, the frequency and duration of stimulation could have contributed to the lack of significance.

References

1. Watson T (2008) Current concepts and clinical decision making in electrotherapy. Electrotherapy: Evidence-based practice. Edinburgh: Churchill Livingstone, 3.
2. Porcari JP, McLean KP, Foster C, Kernozek T, Crenshaw B, et al. (2002) Effects of electrical muscle stimulation on body composition, muscle strength, and physical appearance. J Strength Cond Res 16: 165-172.
3. Glanz M, Klawansky S, Stason W, Berkey C, Chalmers TC (1996) Functional electrostimulation in poststroke rehabilitation: a meta-

analysis of the randomized controlled trials. Arch Phys Med Rehabil 77: 549-553.

4. Vrbová G, Hudlická O, Centofanti KS (2008) Application of muscle/nerve stimulation in health and disease. Springer 2-58.
5. Lake DA (1992) Neuromuscular electrical stimulation. An overview and its application in the treatment of sports injuries. Sports Med 13: 320-336.
6. Downey RJ, Bellman M, Sharma N, Wang Q, Gregory CM, et al. (2011) A novel modulation strategy to increase stimulation duration in neuromuscular electrical stimulation. Muscle Nerve 44: 382-387.
7. Selkowitz DM (1985) Improvement in isometric strength of the quadriceps femoris muscle after training with electrical stimulation. Phys Ther 65: 186-196.
8. Paternostro-Sluga T, Fialka C, Alacamliogliu Y, Saradeth T, Fialka-Moser V (1999) Neuromuscular electrical stimulation after anterior cruciate ligament surgery. Clin Orthop Relat Res : 166-175.
9. McDonough S (2008) Neuromuscular and muscular electrical stimulation. Electrotherapy: Evidence-based practice. Edinburgh: Churchill Livingstone 233-247.
10. Paillard T, Noe F, Bernard N, Dupui P, Hazard C (2008) Effects of two types of neuromuscular electrical stimulation training on vertical jump performance. J Strength Cond Res 22: 1273-1278.
11. Lake DA, Gillespie WJ (1988) Electrical stimulation (NMES) does not decrease body fat. Med Sci Sports Exerc 20: S 22.
12. Kahanovitz N, Nordin M, Verderame R, Yabut S, Parnianpour M, et al. (1987) Normal trunk muscle strength and endurance in women and the effect of exercises and electrical stimulation. Part 2: Comparative analysis of electrical stimulation and exercises to increase trunk muscle strength and endurance. Spine 12: 112-118.
13. Bax L, Staes F, Verhagen A (2005) Does neuromuscular electrical stimulation strengthen the quadriceps femoris? A systematic review of randomised controlled trials. Sports Med 35: 191-212.
14. Snyder-Mackler L, Ladin Z, Schepsis A, Young JC (1991) Electrical stimulation of the thigh muscles after reconstruction of the anterior cruciate ligament. Effect of electrically elicited contractions of the quadriceps femoris and hamstring muscles on gat and strength of the thigh muscles. J Bone Joint Surg Am 73: 1025-1036.
15. Parker MG, Bennett MJ, Hieb MA, Hollar AC, Roe AA (2003) Strength response in human femoris muscle during 2 neuromuscular electrical stimulation programs. J Orthop Sports Phys Ther 33: 719-726.
16. Robinson AJ (1995) Electrotherapy and Electrophysiological Testing., Williams & Wilkins, Baltimore, MD, USA.
17. Arna Risberg M, Lewek M, Snyder-Mackler L (2004) A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? Phys Ther Sport 5: 125-145.
18. Alon G, McCombe SA, Koutsantonis S, Stumphauzer LJ, Burgwin KC, et al. (1987) Comparison of the effects of electrical stimulation and exercise on abdominal musculature. J Orthop Sports Phys Ther 8: 567-573.
19. Alon G, Taylor DJ (1997) Electrically elicited minimal visible tetanic contraction and its effect on abdominal muscles strength and endurance. Eur J Phys Med Rehab 7: 2-6.
20. Starkey C (2013) Therapeutic Modalities. FA Devis Company.
21. Behren BJ, Michlovitz SL (2006) Electrical Stimulation. Physical Agents, Theory and Practice. (2nd edn). Philadelphia., USA.
22. Williams M, Stutzman L (1959) Strength variation through the range of joint motion. Phys Ther Rev 39: 145-152.
23. Heyward VH (2010) Advanced fitness assessment and exercise prescription. United States of America: Burgess Publishing Company.