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Ergogenic Effect of Neuromuscular Electrical Stimulation During Rest and Submaximal Exercise

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ABSTRACT

International Journal of Exercise Science 12(3): 203-213, 2019. The primary aim of this investigation was to determine the ergogenic effect of neuromuscular electrical stimulation (NMES) amongst twenty apparently healthy males during submaximal exercise. In Session 1, 20 participants (Age = 35.0 ± 15.0 yrs; Height = 179.9 ± 8.5 cm; Body Mass = 85.4 ± 12.0 kg) were familiarized with all equipment. Sessions 2-4 included the following randomized 5-min trials a) Rest and Rest+NMES, b) Rest, Arms-Only, Arms+NMES, and c) Rest, Arms+Legs, Arms+Legs+NMES. Physiological variables collected during rest and submaximal exercise were volume of oxygen (VO_2), heart rate (HR), systolic and diastolic blood pressure (SBP and DBP), respiratory exchange ratio (RER), and rate pressure product (RPP). Paired sample t-test was used to determine significant mean differences between the NMES and non-NMES trials. Bonferroni post-hoc analysis established alpha at 0.008. From the 18 paired *t*-tests, the only observed significant mean difference ($t(19) = -6.4$, $p < 0.001$) was RER values between the Arms-Only trial compared to the Arms+NMES trial (0.94 and 1.00, respectively). While RER displayed a significant difference, from a practical perspective, however, these differences were deemed non-physiologically significant. Viewed in concert, findings from this study suggests that NMES utilization does not evoke an acute ergogenic effect amongst an apparently healthy male population.

KEY WORDS: Electricity, muscles, apparently healthy, ergogenicity

INTRODUCTION

Neuromuscular electrical stimulation (NMES) has gained wide traction within the clinical realm to enhance muscular strength, muscular endurance, and aerobic capacity. Previous clinically-related studies have shown its effectiveness and utility amongst individuals with spinal cord injuries (8), cardiac transplant (22), chronic obstructive pulmonary disease (16, 21, 23, 24), chronic heart failure (4-6, 10, 12, 17, 19), stroke (13, 20), and critical care patients (18). Specifically, NMES was shown to be effective in enhancing isokinetic and isometric quadriceps muscular strength (4, 10, 16, 19, 24), 6-minute walking test distance (4, 6, 10, 12, 16, 24), and peak workload and aerobic capacities (5, 6, 12, 16, 22).

There are fewer studies on the effects of NMES on apparently healthy individuals (1-3, 7, 9, 11, 14, 15) with documented improvements in submaximal and maximal aerobic capacities (2, 7, 13-15), decreased respiratory exchange ratio (7), caloric expenditure (11), 6-minute walking test distance (14), and blood pressure parameters (14). The consensus amidst the researchers investigating the efficacy of NMES amongst apparently healthy individuals were that NMES may be used as an ancillary tool to supplement a regular, formal exercise program. To the knowledge of the authors, there is a paucity of data documenting the acute, ergogenic effect of NMES on submaximal aerobic exercise. Against this backdrop, the primary aim of this investigation was to determine the ergogenic effect of NMES amongst an apparently healthy population of males during submaximal exercise. It was hypothesized that NMES would decrease volume of oxygen (VO_2), heart rate (HR), systolic and diastolic blood pressure (SBP and DBP), respiratory exchange ratio (RER), and rate pressure product (RPP) associated with submaximal exercise.

METHODS

Participants

The sample included 20 apparently-healthy males between the ages of 21 to 70 years (Table 1). Prior to participation in the research study, volunteers read and signed an informed consent form. The informed consent form contained exclusion criteria, which were: 1) wearing any electronic cardiac monitoring equipment (e.g., Holter monitor, wireless ambulatory electrocardiogram), 2) having any implanted metallic/electronic devices, 3) tendency to bleed internally, 4) suspected or diagnosed coronary heart disease, 5) prior experience(s) with NMES, and/or 6) suspected or diagnosed seizures or epilepsy. If an individual met any of these exclusionary criteria, the volunteer was not permitted to participate in the study. After reading the informed consent form, if participants did not have any questions, the volunteers then signed the form which was approved by the University's Institutional Review Board for human subject use.

Table 1. Descriptive characteristics of participants (*N* = 20).

Variables	Mean ± SD
Age (yrs)	35 ± 15
Height (cm)	179.9 ± 8.5
Body Mass (kg)	85.4 ± 12

Protocol

After signing the informed consent, all participants were required to report to the University's Human Performance Laboratory to complete 4 Sessions, with no more than one Session per day. Participants completed all Sessions within a span of two weeks after completing Session 1 to prevent any training effect knowing that the participants continued a normal exercise routine independent of the research study. Four hours prior to each session, volunteers were asked to refrain from any type of caffeinated food/beverages. Additionally, researchers asked participants to abstain from vigorous physical activity/exercise the night and morning before each Session. The details of each Session are summarized below.

The aim of Session 1 was to allow an accommodation period for each participant. To begin, the participant met the researchers at the University's Human Performance Laboratory at the appointed day and time. Participants sat in the PhysioStep MDX Recumbent Elliptical Cross Trainer (RXT-1000 MDX, USA). A research technician adjusted the Elliptical Cross Trainer according to the participant's arm and leg length. Once the participant was comfortably seated, the research technician documented these specific settings for each participant and used the set values for subsequent Sessions. The technician then placed a Polar® Electro OY heart rate (HR) monitor strap (T31, USA) around the participant's torso. To gain familiarity with the movement of the Elliptical Cross Trainer, participants grasped onto both handles and performed a 3-minute practice session.

Following accommodation, a research technician explained the purpose of and displayed to participants the Rudolph two-way non-rebreathable valve (Series 2700, USA), standard silicone rubber mouthpiece (Series 9060, USA), and reusable noseclip (Series 9105, USA). Then, participants placed the two-way valve mouthpiece into the mouth and noseclip on the nose as per instructed by the research technician. Both two-way valve and mouthpiece were supported by the Rudolph headgear (Series 2726). Participants then performed another 3-minute practice session on the Elliptical Cross Trainer. After the 3-minute practice session, a research technician described the purpose of and displayed to participants the Electrical Myostimulation 2000 Neuromuscular Stimulator (NMES) (BioMedical Life Systems, USA). The research technician verbally and visually specified the locations and placement of the two 5.1 cm x 5.1 cm (25.81 cm^2) adhesive electrodes on each quadriceps. One electrode was placed on the distal motor point of the vastus medialis, whereas, the other electrode was placed on the proximal motor point of the vastus lateralis. These specified locations are congruent with other electrode placements in previous studies (7, 15). When the accommodation period was completed, participants randomly-selected three folded pieces of paper which displayed the subsequent interventions for Sessions 2-4.

The aim of Session 2 was to determine the effects of NMES during a rested state. Similar to Session 1, participants met the researchers at the University's Human Performance Laboratory. The chair and arm settings on the Elliptical Cross Trainer were set to the participant's settings**.** After being seated, a research technician placed a HR monitor, two-way valve mouthpiece, and noseclip onto the participant. Participant then performed Trial 1, which was a 5-minute Rest Trial on Elliptical Cross Trainer while researchers collected data. During the 5-min trial, at the 3:30- and 4:30-minute mark, oxygen consumption (VO_2) and respiratory exchange ratio (RER) were collected and recorded on a Parvo Medic TrueOne 2400 Metabolic Measurement System (USA). The researchers then averaged the 3:30 and 4:30-minute mark values to obtain a singular value for VO_2 and RER. Participant's systolic and diastolic blood pressure (SBP and DBP, respectively) were quantified at the beginning of and at the end of each rest and exercise trials via Omron® Digital Blood Pressure Monitor (HEM-907XL, Japan). The researchers then averaged the SBP and DBP values collected at the beginning and end of each trial to obtain a singular value for SBP and DBP. After the 5-minute Rest Trial was completed, participants were afforded a 3-minute period. During this rest period, the primary investigator cleansed the participant's left and right quadriceps with alcohol-soaked preparation pads, then placed the

NMES electrodes onto those areas. With respect to the individualized NMES settings, the magnitude of intensity was based upon participant's subjective comfort level. For all participants, the device was set to cycled stimulation, 2 seconds on-ramp, 2 seconds off-ramp, 1 second on-time, and 1 second off-time. More specifically, while at rest, the primary investigator slowly increased NMES amplitude one notch at a time and checked every 5-7 seconds with participants to ensure that participants were subjectively comfortable. When participants notified the primary investigator that the increase in amplitude was comfortable, the primary investigator proceeded to augment the intensity. Once a comfortably-tolerated amplitude was achieved, NMES frequency was achieved in the same said manner. If participants were uncomfortable due to the increased stimulation, the primary investigator decreased the intensity until a comfortable state was achieved. When both frequency and amplitude were comfortably established, the primary investigator documented these individualized settings for each participant. Collectively, the NMES amplitude ranged from 2-5 milliamperes (mA) and frequency ranged from 2-5 Hertz (Hz).

While one research technician was establishing the individualized NMES settings, another research technician was calculating the exercise target heart rate zones utilizing the Karvonen Formula. The research technician multiplied the age-predicted HRmax by 0.30 and 0.40, which corresponded to submaximal exercise intensities between 30%-40% of the participant's age predicted HRmax. When the 3-minute rest period was completed, participants performed Trial 2, which was a 5-minute Rest period with NMES activated (Rest+NMES) while sitting on the Elliptical Cross Trainer. Similar to Trial 1, all physiological metrics were collected into the Parvo Medic TrueOne 2400 Metabolic Measurement System.

The aim of Session 3 was to determine the effects of NMES during an exercise routine employing only the arms. With respect to Trial 1, participants performed a 5-minute Arms only exercise session at an intensity that elicited 30-40% of age-predicted HRmax while researchers collected physiological data. Upon completion of the Arms only exercise session, during the 3-minute rest period, researchers placed the NMES electrodes on participant's lower limbs and activated the NMES based upon the previously-recorded settings established in Session 2. In Trial 2, participants performed a 5-minute Arms only plus NMES (Arms+NMES) exercise session while researchers collected physiological data.

The aim of Session 4 was to determine the effects of NMES during an exercise routine employing both arms and legs. After feet/shoes were comfortably strapped and secured researchers instructed participants to refrain from voluntarily contracting the legs during this Session and to allow the Elliptical Cross Trainer to passively move the legs for the participants. The rationale with this was to inhibit the influence of the Frank-Starling mechanism via voluntary muscular contractions from the lower limbs. When participants understood the task, they grasped onto both handles of the Elliptical Cross Trainer and performed a 5-minute arms with passive legs (Arms+Legs) exercise session at an intensity that elicited 30-40% of age-predicted HRmax while researchers collected physiological data. Upon completion of the Arms+Legs exercise session, during the 3-minute rest period, researchers placed the NMES electrodes on participant's lower limbs and activated the NMES. For Trial 2, participants grasped onto both handles of the

Elliptical Cross Trainer and performed a 5-minute Arms+Legs with NMES (Arms+Legs+NMES) exercise session while researchers collected physiological data.

Statistical Analysis

Mean and standard deviations for descriptive characteristics of participants were calculated. Physiological variables collected during rest and submaximal exercise were VO_2, HR, SBP, DBP, RER, and RPP. Eighteen paired sample *t*-tests were used to determine if there were significant mean differences between the NMES and non-NMES trials. All analyses were conducted using IBM SPSS Statistics 23. Lastly, the Bonferroni correction was employed due to the multiple tests, therefore, the alpha level was established at 0.008.

RESULTS

From the 18 paired *t*-tests, the only observed significant mean difference was the RER values between the Arms only trial compared to the Arms+NMES trial (0.94 and 1.00, respectively). Tables 2, 3, and 4 display the paired sample t-test results for each respective trial.

Table 2. Paired *t*-test between Resting Non-NMES versus NMES trials.

	Non- NMES	**NMES**
Resting VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	4.1 ± 0.91	4.2 ± 0.50
Respiratory Exchange Ratio (RER)	0.89 ± 0.06	0.84 ± 0.06
Heart Rate (bpm)	71.0 ± 14.0	71.0 ± 13.0
Systolic Blood Pressure (mmHg)	128.0 ± 13.0	130.0 ± 14.0
Diastolic Blood Pressure (mmHg)	73.0 ± 13.0	73.0 ± 12.0
Rate Pressure Product (RPP)	89.0 ± 21.0	93.0 ± 25.0

Table 3. Paired *t*-test between Arms-Only Non-NMES versus NMES trials.

	Non- NMES	**NMES**
Submaximal VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	14.4 ± 3.1	14.1 ± 3.0
Respiratory Exchange Ratio (RER)	1.0 ± 0.04	0.94 ± 0.04*
Heart Rate (bpm)	104.0 ± 12.0	105.0 ± 11.0
Systolic Blood Pressure (mmHg)	152.0 ± 15.0	146.0 ± 17.0
Diastolic Blood Pressure (mmHg)	64.0 ± 13.0	62.0 ± 10.0
Rate Pressure Product (RPP)	158.0 ± 15.0	155.0 ± 20.0

*$p < 0.008$

Table 4. Paired *t*-test between Arms+Legs Non-NMES versus NMES trials.

	Non- NMES	**NMES**
Submaximal VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	16.5 ± 3.8	15.9 ± 3.3
Respiratory Exchange Ratio (RER)	0.96 ± 0.064	0.95 ± 0.07
Heart Rate (bpm)	105.0 ± 10.0	106.0 ± 9.0
Systolic Blood Pressure (mmHg)	150.0 ± 21.0	148.0 ± 20.0
Diastolic Blood Pressure (mmHg)	62.0 ± 12.0	65.4 ± 8.0
Rate Pressure Product (RPP)	157.0 ± 27.0	155.0 ± 24.0

DISCUSSION

The objective of this study was to determine the ergogenic effect of NMES amongst an apparently healthy population of males during submaximal exercise. The physiological variables of interest included HR, VO_2, SBP, DBP, RER, and RPP. It was hypothesized that NMES would enhance the physiological metrics associated with submaximal exercise. Paired t tests were utilized to determine the differences between non-NMES trials versus NMES trials during rest and submaximal exercise. The only observed significant mean difference was the RER values between the Arms only trial and the Arms+NMES trial (0.94 and 1.00, respectively). To this end, NMES did not elicit an ergogenic effect, therefore, the hypothesis was not accepted.

As previously noted, there is a wealth of literature on the beneficial effects of NMES amongst a variety of clinical populations (4-6, 8, 10, 12, 13, 16-19, 20-23). However, the literature is sparse when comparing the effects of NMES in apparently healthy individuals (1-3, 7, 9, 11, 14, 15). Similar to the current study's research protocol, in 1997, Eijsbouts and colleagues investigated the independent effects of NMES during submaximal and maximal exercise amongst 11 apparently healthy males. The 11 participants were required to perform arm-cranking exercise with and without NMES. The NMES electrode pads were placed upon the quadriceps, hamstrings, tibialis anterior, and gastrocnemius. The NMES settings were established at 35Hz, with a duty cycle of 2.5 seconds on and 5 seconds off (7). Upon completing the protocol, unlike the current study, there was an increase in VO_2 without a concurrent increase in HR, stroke volume, ventilation, and cardiac output. Similar to Eijsbouts et al.'s (7) study, however, there was a significant decrease in RER upon NMES utilization during submaximal and maximal exercise. More specifically, in Eijsbouts et al.'s (7) study, during submaximal exercise mean RER values decreased from 1.07 ± 0.03 to 1.04 ± 0.04 from arm-cranking exercise to arm-cranking exercise plus NMES, respectively. Additionally, during maximal exercise, mean RER values decreased from 1.25 ± 0.07 to 1.19 ± 0.06 from arm-cranking exercise to arm-cranking exercise plus NMES, respectively. Within the current study, results revealed a similar significant mean decrement in RER from Arms only (1.0 ± 0.04) to Arms+NMES (0.94 ± 0.04). However, given the relatively large standard deviations associated with mean RER values within both studies, these differences appear to be of minor physiological significance.

In 2005, Banerjee et al. conducted a study with a similar testing protocol. Banerjee et al. (2) chose to implement an electrical muscle stimulation (EMS) program which resulted in a shivering-type contraction. To accomplish this, the NMES was applied to both quadriceps, hamstrings, and gluteus maximus. The NMES settings were set at a frequency of 4 Hz. Ten participants (8 males; 2 females) underwent four data collection sessions. Each session was 12 minutes in duration. Every 3 minutes, stimulation intensity was incrementally increased by 10% up to a maximum of 40%. Banerjee et al. (2) reported improvements in a variety of physiological metrics such as VO_2, VCO_2, minute ventilation (V_e), and HR values post intervention. While the NMES frequency setting in Banerjee et al.'s (2) was similar (4 Hz) to the current study (2-5 Hz), unfortunately the duty cycles within said study were not clearly stated. In Banerjee et al.'s (2) study the on- and off-duty cycle produced shivering-like contractions, whereas, the current study's NMES setting with respect to the duty cycle delivered a rhythmic, pulsatile impulse that evoked a mild to

moderate contraction throughout the exercise session. Another difference between the two studies was the duration of each session. The duration for each session in Banerjee et al.'s (2) study was approximately 2.5 times more (12 minutes) compared to the duration within the current study (5 minutes). Lastly, another difference that may attribute to the lack of congruency between Banerjee et al.'s (2) study and the current study may be the volume of lower leg muscles being stimulated. More specifically, in Banerjee et al.'s (2) study, a greater amount of surface area was stimulated, such as the quadriceps, hamstrings, and gluteus maximus, whereas in the current study, only the quadriceps were stimulated.

In 2011, Hsu and colleagues investigated the various NMES stimulatory settings and its effects on energy expenditure (i.e., caloric expenditure) in apparently healthy adults. Forty adult volunteers (18 males and 22 females) agreed to take part in the study. NMES was used for 10 minutes at each of three different intensity levels, varying from sensory level (i.e., participants can barely feel a slight tingling sensation), motor threshold (i.e., participants can feel a mild/moderate physical muscular contraction), and maximum intensity (i.e., participants can feel a strong physical muscular contraction while still being relatively comfortable). To measure energy expenditure, cardiopulmonary gas exchange was monitored during rest, NMES, and recovery stages. Stimulation was applied at a 20 Hz frequency level, with a 1-second on and 2-seconds off cycle. Hsu and associates (11) found the motor threshold and maximum intensity levels to produce a significant increase in energy expenditure. They also revealed a linear dose response relationship between stimulation intensity and energy expenditure. More specifically, the higher the stimulation intensity (20 Hz, max amplitude of 30 mA, average amp of 10-15 mA) the more energy expended (Low: 68.34 Kcal/hr; Medium: 71.89 Kcal/hr; High: 76.14 Kcal/hr) (11). Similar to the current study, the NMES settings for the duty cycle were virtually identical with Hsu et al.'s (11) study, 1-second on, 1-second off versus 1-second on, 2-seconds off, respectively. However, the frequency utilized in Hsu et al.'s (11) study was about 15 Hz higher and the total stimulation time 5 minutes longer.

While the current study investigated similar cardiovascular parameters to Lee et al (14), there were several key differences. For example, the current study included simultaneous exercise and NMES treatments, whereas the participants within Lee et al.'s (14) study only performed sitting, rested position. Another relative difference was the length of the study. The current study required the participants to attend three 5-minute NMES sessions (15 minutes) within 2 weeks, whereas Lee and colleagues (14) required the subjects to attend fourteen 30-minute sessions (420 minutes). Lastly, there was a relatively marked difference in NMES stimulation parameters. Lee and associates (14) utilized a 35 Hz frequency, 10-seconds on time, and 12-seconds off time, whereas the current study deployed a 2-5 Hz frequency, 1-second on time, and 1-second off time. It is these differences in session duration, study protocol, and NMES settings that may explain the differences in findings between the Lee et al.'s (14) study and the current study.

In 2013, Crognale and colleagues conducted a study investigating the physiological and subjective effects of NMES, as well as stimulation habituation, and differences between male and female responses. Sixteen participants (8 males and 8 females) performed 9 habituation sessions followed by 2 days of an NMES protocol with increasing incremental intensities.

Subjects were required to attend 3 sessions per week for 4 weeks. Each session was 60 minutes in duration. Similar to the current study, within Crognale et al.'s (3) study, there was no set template for NMES intensities as it was self-directed and modulated at a level of the individual's comfort and tolerance. The researchers then used this initial level as baseline to develop an individualized NMES protocol. Researchers measured VO_2, HR, blood lactate, ratings of perceived exertion, and subjective discomfort before and after the NMES treatments. Crognale et al. (3) suggested that NMES may elicit an aerobic-like exercise response without undue discomfort and that NMES may be a beneficial ergogenic aid for apparently healthy individuals. Because the current study also based a portion of the stimulation settings on patient comfort, perhaps the differing results could be attributed to the frequency of training sessions. Crognale and associates (3) deployed 11 sessions for each participant, in addition to increasing intensity whenever the participant could tolerate a stronger stimulus. The current investigation, on the other hand, consisted of only 3 sessions with a fixed stimulation intensity. Moreover, in Crognale et al.'s (3) study, subjects were required to perform 60 minutes of NMES stimulation for 3 days per week for 4 weeks. Within the current study, subjects were required to perform 5 minutes of NMES stimulation for 3 days spread across a 1-week span.

Similar to study conducted by Angelo and associates (1), Masayuki et al. (15) investigated the effects of combining NMES and aerobic cycling on 11 male subjects. The difference between the two studies, however, was that Masayuki et al. (15) deployed a hybrid training system (HTS) protocol. Fundamentally, the HTS protocol is a series of voluntary muscle contractions during a co-contracted state. More precisely, it involves electrical stimulation of the antagonistic muscles during a voluntary agonistic muscular contraction. This type of hybrid training protocol is, in essence, allowing individuals to simultaneously perform strength training while performing aerobic exercise. That being said, unlike Angelo et al.'s (1) and the current study, Masayuki et al. (15) stimulated the agonist and antagonist muscles to provide a resistance/strength component to the aerobic exercise program. Masayuki and associates (15) assessed VO_2, CO_2 output, V_e, and HR during a cycling protocol with voluntary contraction alone and a cycling protocol with voluntary contraction plus HTS protocol. Masayuki et al. (15) revealed that the combined cycling protocol with voluntary contraction plus HTS protocol increased VO_2 by about 20% (~ 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$) compared to a cycling protocol with voluntary contraction alone. Masayuki and colleagues (15) suggested that HTS is a novel, alternative method to combine both aerobic and resistance training concurrently.

The lack of congruent findings between Masayuki et al.'s (15) study and linked to the fact that in the current study, the antagonistic muscles were not stimulated during aerobic exercise, but rather utilized the NMES to stimulate the agonistic muscle groups only. Moreover, Masayuki et al.'s (15) study required the participants to actively/voluntarily contract the muscles during the cycling protocol while receiving NMES stimulation. The confluence of active muscular contractions with NMES stimulation would adequately explain the approximate 20% increase in oxygen consumption. Unlike Masayuki et al.'s (15) study, the subjects were required to remain as passive as possible during the 5-minute aerobic exercise. Also, the NMES frequency and exercise duration was higher (40 Hz versus 2-5 Hz) and longer (8-15 minutes versus 5 minute) in Masayuki et al.'s (15) study compared to the current study. Additional differences between

the two studies were that the current study, similar to that of Angelo et al.'s (1) study, stimulated the agonist muscles only. It is these methodological incongruences that may explain the differential results in physiological metrics.

In conclusion, previous researchers examining the effects of NMES on apparently healthy individuals have revealed improvements in VO_{2max}, VO_2, walking tests, HR, and blood pressure values. In the current study, however, the only statistically significant difference was displayed between the NMES and non-NMES RER values during Arms only exercise. From a practical perspective, these differences were deemed non-physiologically significant. The lack of agreement in findings may be attributed to numerous methodological differences, including, NMES settings, exercise modalities, duration of trials/sessions, relative length of studies, and surface area coverage via NMES between the current study and previously-mentioned studies. Viewed in concert, findings from this study suggests that NMES utilization does not evoke an increase in HR, VO_2, SBP, DBP, and RPP during a single bout of exercise amongst an apparently healthy male population.

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