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Ergogenic Effect of Neuromuscular Electrical Stimulation During Rest and Submaximal Exercise [Version 1, 1 Approved with Reservations]

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Abstract

Purpose: To determine the ergogenic effect of neuromuscular electrical stimulation (NMES) amongst an apparently healthy population during submaximal exercise.

Methods: In Session 1, twenty apparently healthy males (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 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 (VO2), 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 level at 0.008.

Results: 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).

Conclusions: 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.

Keywords

Neuromuscular Electrical Stimulation; Submaximal Exercise; Apparently Healthy; Ergogenic

Introduction

Neuromuscular electrical stimulation (NMES) has gained wide traction within the clinical realm. Previous clinically-related studies have shown its effectiveness and utility amongst individuals with spinal cord injuries [1], cardiac transplant [2], chronic obstructive pulmonary disease [3-6], chronic heart failure [7-13], stroke [14,15], and critical care patients [16]. Within these aforementioned studies, NMES was shown to be effective in enhancing isokinetic and isometric quadriceps muscular strength [3,4,7,8,10], 6-minute walking test [3,4,8,10-12], and peak workload and aerobic capacities [2,3,11-13].

There are, however, relatively fewer studies conducted to determine the effects of NMES utilization on apparently healthy individuals [17-24]. Collectively, these researchers displayed improvements in a myriad of physiological and performance metrics such as submaximal and maximal aerobic capacities [17,18,22-24], respiratory exchange ratio [17], caloric expenditure [20], 6-minute walking test [22], and blood pressure parameters [22]. The general consensus amidst the research studies investigating the efficacy of NMES amongst a cohort of apparently healthy individuals was 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 utilization 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 during submaximal exercise. It was hypothesized thatNMES would enhance the physiological metrics associated with submaximal exercise via deploying the cascading effect of Frank-Starling mechanism, more precisely, increasing venous blood return, increasing end-diastolic ventricular volume, increasing stroke volume, thereby increasing cardiac output to peripheral skeletal muscles. From a practical perspective, given the ease, feasibility, and cost-effectiveness of NMES devices, findings from this study will provide consumers and practitioners that much more information with respect to the effectiveness of NMES from an ergogenic/training perspective.

Methods

Subjects

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)adorning any electronic cardiac monitoring equipment, 2) wearing any implanted metallic/electronic devices, 3) had a tendency to bleed internally, 4) suspected or diagnosed with coronary heart disease, 5) prior experience(s) with NMES, and/or 6) suspected or diagnosed with seizures or epilepsy. If an individual met any of the aforesaid 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 or further question(s) regarding the study, the volunteers then signed the informed consent form approved by the University's Institutional Review Board for human subject use. To that end, twenty apparently-healthy males between the ages of 21 to 70 years were recruited to participate in this study.

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 4 Sessions within a span of two weeks after completing the Session 1. The purpose of said requirement was to prevent any acute changes, specifically, physiological evolvement or devolvement, knowing that these participants were apparently-healthy individuals and continued a normal exercise routine independent of the research study. Prior to each session, volunteers were asked to refrain from any type of caffeinated food/beverages that may influence the physiological parameters of interest during exercise performance. Additionally, researchers asked participants to abstain from vigorous physical activity/exercise the night before each Session. Below highlights the details of each Session required for each participant.

Session 1: Equipment Familiarization and Practice

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

Once the 3-minute practice session was completed, 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 nose and placementof the clip (Series 9105, USA). Once introduced to and shown, participants placed the two-way valve mouthpiece into the mouth and nose clip on the nose as per instructed by the research technician. Both two-way valve and mouthpiece were supported by the Rudolph headgear (Series 2726) specifically designed to

support Rudolph valves. Once the two-way valve mouthpiece, headgear,and nose clip were comfortably on, participants performed another 3-minute practice session on the PhysioStep MDX Recumbent Elliptical Cross Trainer. Once the 3-minute practice period was completed, a research technician carefully removed the two-way valve mouthpiece, headgear, and nose clip from the participants.

After the previously-mentioned 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). Following the detailed description of the NMES, the research technician verbally and visually specified the particular locations and placement of the two 5. 1 cm x 5. 1cm (25. 81 cm^2) adhesive electrodes on each quadriceps. To be more precise, 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 conducted in previous studies [17,24]. Once the accommodation period was completed, a research technician removed the HR monitor from participant's torso and participants exited the PhysioStep MDX Recumbent Elliptical Cross Trainer. Upon exit, the primary investigator allowed the participants to randomly-select three folded pieces of paper. Unfolding the folded pieces of paper in the order chosen by participant's displayed the subsequent interventions for Sessions 2-4. Once the order of intervention for each Session was solidified, participants then set another day and time for Session 2 and once secured, participants exited the University's Human Performance Laboratory.

Session 2: Rest and Rest+NMES

The aim of Session 2 was to determine the effects of NMES during a rested state. Similar to Session 1, participants met researchers at University's Human Performance Laboratory during the appointed day and time. A research technician adjusted the previously-recorded individualized settings of the PhysioStep MDX Recumbent Elliptical Cross Trainer prior to the participants being seated. Once seated, a research technician placed a HR monitor, two-way valve mouthpiece, and nose clip onto the participant. Once the mouthpiece and nose clip were comfortably placed, participant performed Trial 1, which was a 5-minute Rest period on PhysioStep MDX Recumbent Elliptical Cross Trainer while researchers collected data. All physiological metrics were collected on a ParvoMedic TrueOne 2400 Metabolic Measurement System (USA), which was calibrated prior to each trial. Participant's systolic and diastolic blood pressure (SBP and DBP, respectively) was quantified at the beginning of and at the end of each rest and exercise trials via Omron®Digital Blood Pressure Monitor (HEM-907XL, Japan). Once the 5-minute Rest period was completed, participants were afforded a 3-minute rest period. During the 3-minute rest period, primary investigator cleansed the area of interest with alcohol-soaked preparation pads, then placed the NMES electrodes on participant's left and right quadriceps as previously described. With respect to the individualized NMES settings, the magnitude of intensity was predicated upon participant's subjective comfort level. The desired goal was for the stimulation to invoke a visibly mild, comfortably-tolerated muscular contraction in the lower limbs which would mimic the magnitude of a voluntary contraction produced during exercise. 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. Amplitude and frequency of the NMES were selected primarily due to participant's individualized comfort level. More specifically, while at rest, the primary investigator slowly increased NMES amplitude one notch at a time and frequently checked with participants to ensure that participants were subjectively comfortable. Once 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 at any point if or when 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. Researchers sought to match the magnitude of contraction as much as possible amongst participants. 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 during the 3-minute period. The research technician used the individual's age and the newly-recorded resting heart rate to derive an age-predicted maximum heart rate (HR_{max}). Once the age-predicted HR_{max} was calculated, the research technician multiplied the age-predicted HR_{max} by 0. 30 and 0. 40, which corresponded to submaximal exercise intensities between 30%-40% of the participant's age-predicted HR_{max}. Once 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 PhysioStep MDX Recumbent Elliptical Cross Trainer. Similar to Trial 1, all physiological metrics were collected into the ParvoMedic TrueOne 2400 Metabolic Measurement System. Once Trials 1 and 2 were completed, a research technician removed the HR monitor and NMES electrodes from participants and participants exited the PhysioStep MDX Recumbent Elliptical Cross Trainer. Participants established another day and time for the next Session and then exited the University's Human Performance Laboratory.

Session 3: Arms and Arms+NMES

The aim of Session 3 was to determine the effects of NMES

during an exercise routine employing only the arms. Similar to Session 2, participants met researchers at University's Human Performance Laboratory during the appointed day and time. Upon arrival, a research technician placed a HR monitor on the participants, then were properly positioned in the PhysioStep MDX Recumbent Elliptical Cross Trainer. Once positioned comfortably with the two-way valve mouthpiece in participant's mouth and nose clip on participant's nose, participants sat comfortably on PhysioStep MDX Recumbent Elliptical Cross Trainer for 5 minutes while researchers collected resting data. After the 5-minute resting data was collected, with respect to Trial 1, participants grasped onto both handles of the PhysioStep MDX Recumbent Elliptical Cross Trainer, placed both feet together on a stationary landing in front of the machine, and performed a 5-minute Arms only exercise session 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 regards to Trial 2, similar to Trial 1, participants grasped onto both handles of the PhysioStep MDX Recumbent Elliptical Cross Trainer, placed both feet together on a stationary landing in front of the machine, and performed a 5-minute Arms only plus NMES (Arms+NMES) exercise session while researchers collected physiological data. Once Trials 1 and 2 were completed, a research technician removed the HR monitor and NMES electrodes from participants and then participant exited the PhysioStep MDX Recumbent Elliptical Cross Trainer. The primary investigator and participants established another day and time for the final Session, then participants exited University's Human Performance Laboratory.

Session 4: Arms + Legs and Arms+ Legs + NMES

The aim of Session 4 was to determine the effects of NMES during an exercise routine employing both arms and legs. Similar to Session 3, participants met researchers at University's Human Performance Laboratory during the final appointed day and time. Upon arrival, a research technician placed a HR monitor on the participants, then were properly positioned in the PhysioStep MDX Recumbent Elliptical Cross Trainer. Once positioned comfortably with the two-way valve mouthpiece in participant's mouth and nose clip on participant's nose, participants sat comfortably on PhysioStep MDX Recumbent Elliptical Cross Trainer for 5 minutes while researchers collected resting data. After the 5-minute resting data was collected, with respect to Trial 1, participants grasped onto both handles of the PhysioStep MDX Recumbent Elliptical Cross Trainer, a research technician strapped participant's feet/shoes into the pedals on PhysioStep MDX Recumbent Cross Trainer. Once feet/shoes were comfortably strapped and secured, researchers instructed participants to refrain from voluntarily contracting the legs during this Session and to allow the PhysioStep MDX Recumbent Elliptical Cross Trainer to passively move the legs for the participants. The rationale for said requirement was to inhibit the influence of the Frank-Starling mechanism via voluntary muscular contractions from the lower limbs. Once participants understood the task, participants grasped onto both handles of the PhysioStep MDX Recumbent Elliptical Cross Trainer and performed a 5-minute arms with passive legs (Arms+Legs) exercise session 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. After the 3-minute rest period, with respect to Trial 2, participants grasped onto both handles of the PhysioStep MDX Recumbent Elliptical Cross Trainer and performed a 5-minute Arms+Legs with NMES (Arms+Legs+NMES) exercise session while researchers collected physiological data. Once Trials 1 and 2 were completed, a research technician removed the HR monitor and NMES electrodes from participants, exited the PhysioStep MDX Recumbent Elliptical Cross Trainer, and then exited University's Human Performance Laboratory.

Statistical Analyses

Mean and standard deviations for descriptive characteristics of participants were calculated. 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). Eighteen paired sample t-tests were used to determine if there were significant mean differences between the NMES and non-NMES trials. All of the analyses were conducted using IBM SPSS Statistics 23. Lastly, the Bonferroni correction was employed due to the multiple tests, therefore, alpha level was established at 0. 008.

Results

As stated previously, the purpose of the investigation was to determine the ergogenic effect of NMES during submaximal exercise for apparently healthy individuals. At the conclusion of the study, twenty volunteers were recruited, zero dropped out, therefore all twenty participants results were included in the statistical analyses. Table 1 displays the descriptive measures of the study participants.

Eighteen paired sample t-test were performed using the collected physiological variables to determine if there was a difference between the NMES and non- NMES trials. Physiological variables collected during rest and submaximal exercise were VO_2, HR, SBP, DBP, RER, and RPP. Bonferroni correction established the alpha level at 0. 008. 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 1: Descriptive characteristics of all participants (N = 20).

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

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)	71.3 ± 13.9	71.4 ± 13.3
Systolic Blood Pressure (mmHg)	127.6 ± 13.2	130.1 ± 14.4
Diastolic Blood Pressure (mmHg)	73.3 ± 12.6	73.3 ± 11.8
Rate Pressure Product (RPP)	89.4 ± 21.2	92.5 ± 25.1

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)	104.4 ± 12.1	105.06 ± 11.3
Systolic Blood Pressure (mmHg)	151.6 ± 14.6	146.1 ± 16.8
Diastolic Blood Pressure (mmHg)	64.3 ± 13.4	62.0 ± 9.6
Rate Pressure Product (RPP)	158.1 ± 15.3	155.1 ± 19.5

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)	105.4 ± 10.0	105.5 ± 9.3
Systolic Blood Pressure (mmHg)	149.6 ± 21.1	147.6 ± 19.7
Diastolic Blood Pressure (mmHg)	62.3 ± 11.8	65.4 ± 8.2
Rate Pressure Product (RPP)	156.6 ± 26.8	155.4 ± 23.8

Discussion

The objective of this study was to determine the acute ergogenic effects of NMES during alternating intervals of rest and submaximal exercise amongst an apparently healthy male population. The physiological variables of interest included HR, VO_2, SBP, DBP, RER, and RPP. Paired t-tests were utilized to determine the differences between non-NMES trials versus NMES trials during rest and submaximal exercise. 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). To this end, NMES did not elicit an ergogenic effect, therefore, the initial hypothesis was not accepted.

As previously noted, on the one hand, there is a wealth of literature displaying the beneficial effects of NMES amongst a variety of clinically-related populations [1-16]. On the other hand, however, the literature is relatively sparse when comparing the effects of NMES amongst a population of apparently healthy individuals [17-24]. 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 male individuals. The 11 participants were required to perform arm-cranking exercise with and without NMES. The NMES electrode pads were fixated upon the quadriceps, hamstrings, tibialis anterior, and calves. The NMES settings were established at 35Hz, with a duty cycle of 2. 5 seconds on and 5 seconds off [17]. Upon completing the protocol, unlike the current study, results revealed an increase in VO_2 without a concurrent increase in heart rate, stroke volume, ventilation, and cardiac output. Similar to Eijsbouts et al. 's [17] study, however, there was a significant decrease in RER upon NMES utilization during submaximal and maximal exercise. More specifically, in Eijsbouts et al. 's [17] 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). In agreement with Eijsbouts et al. 's [17] findings, given the relatively large standard deviations associated with mean RER values within both studies, these differences appeared to be of minor physiological significance.

In 2005, Banerjee et al. conducted a study with a similar training protocol to the current investigation. Banerjee et al. [18] chose to implement an electrical muscle stimulation (EMS) program which resulted in a shivering-type of contraction. In order 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%. Incongruent with the current study, Banerjee et al. [18] reported improvements in a variety of physiological metrics post intervention. These improvements in physiological metrics were seen in VO_2, VCO_2, minute ventilation (V_e), and HR values. While the NMES frequency setting in Banerjee et al. 's [18] study was relatively similar (4 Hz) to the current study (2-5 Hz), unfortunately the duty cycles within said study was not clearly stated. Banerjee et al. 's [18] study 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 [18] 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 [18] study and the current study may the amount of lower leg muscles being stimulated. More specifically, Banerjee et al. 's [18] study stimulated a greater amount of surface

area, such as the quadriceps, hamstrings, and gluteus maximus, whereas the current study only stimulated the quadriceps.

In 2007, Angelo et al. recruited 12 participants and examined the simultaneous effects of NMES use and endurance cycling on VO_{2max}. All 12 participants completed a 4-week aerobic cycling exercise program that required subjects to exercise 4 days per week for 50 minutes per session. Additionally, within three of the 16 exercise sessions, six participants experienced simultaneous NMES stimulation during the three 50-min exercise session. Results of said study revealed that the group receiving the NMES treatments displayed a significant increase (13. 1%) in VO_{2max}. As noted within the results of the current study, unlike Angelo et al. 's [19] study, there were no changes in any physiological metrics (i. e. , VO_2). This noted difference between results may be explained by the length of each exercise session (5 minutes versus 50 minutes) and the methodological protocol in and of itself. More precisely, Angelo and associates [19] required the subjects to exercise during the 50-minute cycling session with concurrent NMES stimulation. The NMES combined with voluntary muscular contraction is speculated to augment the force in which the muscles contract during the cycling session. It is this augmented force production that may have enhanced the VO_2 by about 13%. Within the current study, subjects were required to passively exercise (i. e. , refrain from voluntarily contracting the quadriceps) while receiving concurrent NMES stimulation, therefore, teasing out the influence of voluntary muscle contraction and focusing upon the solo effects of NMES during aerobic exercise.

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 given to the volunteers 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 as relatively comfortable as possible). 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 [19] found the motor threshold and maximum intensity levels to produce a significant increase in energy expenditure. Said researchers 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) [19]. While the previously mentioned study focused primarily on energy expenditure, the findings could be related to the basis of the current study as well. Theoretically, an increase in energy expenditure would transcend into weight management (e. g. , weight loss), which then would correlate with improved cardiovascular health. Similar to the current study, the NMES settings for the duty cycle were virtually identical with Hsu et al. 's [19] study, 1-second on, 1-second off versus 1-second on, 2-seconds off, respectively. However, while the duty cycles were virtually identical, the frequency utilized in Hsu et al. 's [19] study was about 15 Hz higher and the total stimulation time 5 minutes longer. Given said information, this difference in findings may suggest the importance of inducing higher frequencies and stimulatory times to potentially invoke differences in cardiovascular metrics, however, this might be at the expense of generating some degree of discomfort for the individual [23].

A study conducted by Lee et al. [22] followed a similar model to the current study, whereby the goal was to evaluate the effect of NMES on cardiopulmonary function in healthy adults. In 2012, Lee and associates recruited 36 participants (16 males; 20 females) and designed an experimental protocol in which NMES is applied to the quadriceps muscles, while sitting, for 30 minutes each day throughout a 2-week period. Before and after the experimental period, researchers measured VO_{2max}, metabolic equivalent, maximum and resting heart rate, maximum and resting blood pressure, maximum rate pressure product, as well as conducting exercise tolerance and 6-minute walk tests. Lee et al. [22] used a 35 Hz frequency, 10-seconds on time, and 12-seconds off-time. After 2 weeks of NMES intervention, Lee et al. [22] revealed a significant increase in VO_{2max}, 6-minute walk test, maximum heart rate, maximum systolic blood pressure, exercise tolerance test duration, and a decrease in resting systolic blood pressure. These results allowed the aforementioned researchers to conclude NMES to be a beneficial tool in improving cardiopulmonary health in healthy adults [22], which is in contrast to lack of findings within the current study.

While the current study investigated virtually identical cardiovascular parameters, there were several key differences. For example, the current study included simultaneous exercise and NMES treatments, whereas the participants within Lee et al. 's [22] study only performed sitting, rested position. Another relative difference was the length of the study. More specifically, the current study required the participants to attend three 5-minute NMES sessions (15 minutes) within 2 weeks, whereas Lee and colleagues [22] 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 [22] 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 aforementioned differences in session duration, study protocol, and NMES settings that may explain the differences in findings between the Lee et al. 's [22] 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 [23] 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 would use this initial level of individual's comfort and tolerance level as baseline to develop an individualized NMES protocol. Researchers measured $VO_{2submax}$, heart rate, blood lactate, ratings of perceived exertion, and subjective discomfort before and after the NMES treatments. Crognale et al. [23] suggested that NMES may elicit an aerobic-like exercise response without undue discomfort and that NMES to 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 frequency of training sessions. Crognale and associates [23] 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 [23] 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. Therefore, the lack of agreement in findings may be explained by said methodological differences in research design between Crognale et al. 's [23] study and the current study.

Similar to study conducted by Angelo and associates [19], Masayuki et al. [24] investigated the effects of combining NMES and aerobic cycling on 11 male subjects. The difference between the two aforementioned studies, however, was that Masayuki et al. [24] 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 [19] and the current study, Masayuki et al. [24] stimulated the agonist and antagonist muscles to provide a resistance/strength component to the aerobic exercise program. Masayuki and associates [24] assessed VO_2, CO_2 output, V_e, and heart rate during a cycling protocol with voluntary contraction alone and a cycling protocol with voluntary contraction plus HTS protocol. Masayuki et al. [24] 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 cycling protocol with voluntary contraction alone. Masayuki and colleagues [24] suggested that HTS protocol is a novel, alternative method to combine both aerobic and resistance training concurrently.

The lack of congruent findings between Masayuki et al. 's [24] study and the current study is that the current study did not stimulate the antagonistic muscles during aerobic exercise, but rather utilized the NMES to stimulate the agonistic muscle groups only. Moreover, Masayuki et al. 's [24] 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 [24] study, to reiterate, the current study stimulated only the agonistic muscles, but more importantly, required that the subject's muscles of interest to remain as passive as possible during the 5-minute aerobic exercise. As stated with previously discussed apparently healthy studies, 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 [24] study compared to the current study. Additional differences between the two studies was that the current study, similar to that of Angelo et al. 's [19] study, stimulated the agonist muscles only. It is these methodological incongruences that may explain the differential results in physiological metrics.

Conclusions

Earlier studies investigating the use of NMES with apparently healthy participants have displayed a positive effect on a variety of performance-related and cardiovascular-related metrics. More precisely, previous researchers examining the effects of NMES on apparently healthy individuals have revealed improvements in VO_{2max}, $VO_{2submax}$, walking tests, heart rate, and blood pressure values. Despite the myriad of improvements per NMES utilization within the aforementioned studies, in the current study, however, the only statistically significant difference was displayed between the NMES and non-NMES RER values during Armsonly exercise. While said values were found to be significant, from a practical perspective, however, these differences were deemed non-physiologically significant. The lack of agreement in findings may be attributed to numerous methodological differences, specifically, 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 acute ergogenic effect amongst an apparently healthy male population.

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