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Acute Effects of Neuromuscular Electrical Stimulation on Vertical Jump Performance

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Abstract Understanding the acute effects neuromuscular electrical stimulation (NMES) applied to the quadriceps group can have on vertical jump was the primary objective of this study. Multiple studies have indicated improvements in muscular strength, power, and performance can be made over time through NMES. This study is unique because no previous studies have conducted research into the effects of NMES on vertical jump immediately after isometric stimulation to the quadriceps group. A group of 24 subjects were randomly divided into equal 12-member experimental and control groups. All subjects were pretested in the countermovement jump (CMJ) to determine maximum jumping height. Treatment consisted of placing electrodes on the quadriceps of members of the experimental group and turning the Marc Pro Device on 1.7 Hz for 15-minutes. Sham treatment consisted of placing electrodes on the quadriceps of members of the control group and turning the Marc Pro Device on 0.0 Hz for 15-minutes. All subjects then engaged in a post treatment CMJ test. The difference between pretest and posttest jump scores was computed to determine the effects of treatment. A statistically significant increase in experimental group CMJ scores occurred from pre-test to posttest ($p < .05$). It was hypothesized that an increase in blood flow and activation of the fast-twitch muscle fiber to the applied muscle group facilitated increased muscular power. NMES is an easily applied performance enhancement strategy that could be an important addition to athletes and active individuals.

Keywords Quadriceps, Countermovement, Fast-twitch

1. Introduction

Multiple studies have demonstrated that improvements in strength, power, and vertical jump performance can be made over time using neuromuscular electrical stimulation (NMES) [3,12,13,19]. Previous research has also established that NMES can effectively supplement a well-designed strength and conditioning program. Maffiuletti et al. [12] reported a significant increase in squat jump height in basketball players after a four-week training program in conjunction with NMES. Squat jump performance increased by 14% after NMES training indicating this method can be used to enhance the contractile qualities of muscle. Martinez-Lopez et al. [14] showed that a NMES training program can lead to significant improvements in squat jump, countermovement jump and depth jump. This NMES training program occurred twice per week and combined with plyometric training was useful for the improvement of every kind of vertical jump ability required for sprint and hurdle disciplines in teenage athletes [14]. Similar findings from Gulick and Castel [10] indicated that patterned electrical neuromuscular stimulation (PENS) paired with jump training increased vertical jumping more than jump training alone. Importantly, the applicability of NMES in conjunction with sports training appears to have relevance regardless of training status, as Filipovic [6] demonstrated that NMES training enhanced the athletic performance of highly trained athletes. Two dynamic whole-body NMES sessions in combination with 30 squat jumps and 6-7 soccer training sessions per week were sufficient in effectively improving maximal strength, sprint times, jump performance, and kicking capacity in professional soccer players [6].

While evidence strongly supports the use of NMES to improve athletic performance, there appear to be best practices that should be followed to maximize the effects of NMES on power development. Analysis from Martínez-López et al. [14] showed that the highest vertical jump performances were obtained in participants who applied NMES before plyometric training. These improvements were significant from the first 15 days of training and continued to increase during the next two training periods. Such an improvement did not occur

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amongst the group that performed plyometric training before applying NMES. Despite a significant increase in the first 15 days, there was a regression that lessened the benefits previously acquired. Amongst the group in which NMES was superimposed on the quadriceps during plyometric training there were no significant differences between any of the measurements [14]. Additionally, Herrero et al. [9] suggest that when anaerobic power development is a primary training outcome, NMES should be applied isometrically instead of being superimposed while performing plyometrics because this application has more benefits to vertical jump and sprinting abilities.

Despite the mounting evidence that supports the application of NMES for athletic development, no previous studies have examined the effects of NMES on vertical jump immediately after isometric stimulation to the quadriceps group. Thus, the objective of this study was to gain a better understanding of the acute effects of NMES applied to the quadriceps group and the subsequent influence on vertical jump. Studying this data and applying it to future training methods can help advance the field of strength and conditioning, specifically relating to acute and long-term power development.

2. Methods

Experimental Approach to the Problem

An experimental design was utilized in conjunction with a paired independent samples *t*-test. Twenty four subjects (12 males and 12 females) were randomly divided into equal member experimental and control groups made up of 6 males and 6 females each. All subjects were pretested in the CMJ to determine maximum jumping height. In a single-blind fashion, subjects in the treatment group were treated with NMES to the quadriceps, while subjects in the control group received sham treatment in identical testing conditions. Sham treatment consisted of placing the electrodes on the quadriceps of the control group and turning the Marc Pro Device on 0.0 Hz for the duration of the 15- minutes. All subjects then engaged in a post treatment CMJ test. Pre- and post-test mean CMJ height was compared to determine the effects of treatment.

Subjects

Twelve males and 12 females with a mean age of 33 years, height of 172 centimeters, weight of 75 kilograms, and BMI of 23.5 kg/m^2 were recruited from a fitness center in Southern California. A minimum number of 14 subjects were required for the experiment as determined by *a priori* power analysis (Gpower: Faul, Erdfelder, Lang, & Buchner, 2009). Criteria for selection included being an active, healthy volunteer capable of performing a 17-inch box jump. Performing the box jump was required to allow for some consistency amongst the participants in terms of overall jumping ability. All subjects wore light workout clothing, athletic shoes, and shorts during testing to ensure exposure of the quadriceps group. All subjects were required to refrain from strenuous exercise 24 hours prior to the study.

The sampling frame or accessible population reflected the principles of convenience sampling [2]. Although convenience sampling has its limitations in terms of being able to generalize the results, the sample population was reflective of the general population especially considering the gender balance included in the study. This study was approved by Institutional Review Board (IRB), and the subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Procedures

Subjects were randomly divided into an experimental (X1) and a control group (X2). The experimental group received ultra low frequency NMES treatment and the control group received sham treatment. The control group served to control the eight threats to internal validity [2]. Testing conditions were identical for both groups with the exception of the frequency at which the NMES was applied (X1 = 1.7 Hz, X2 = 0.0 Hz), in accordance with previous research [3]. Each subject was tested separately during a designated 30-minute period.

CMJ technique required each subject begin in a standing position with their feet parallel to each other and approximately hips width apart. The subject completed two warm-up CMJs. These jumps served the purpose of a CMJ specific warm-up involving maximal-effort explosive muscle contractions and allowed the test administrator the opportunity to correct any flaws in CMJ technique [14]. During the concentric phase of the jump the subject was required to reach upward with one arm in order to replicate established vertical jump testing protocol. Nuzzo, Anning, and Scharfenberg [15] indicate many subjects do not attain a maximum CMJ height until the third trial. These findings demonstrate the importance of administering a minimum of 3 trials when assessing maximum CMJ in recreationally active males and females. Rest periods of 20 seconds were given between each CMJ effort, approximating to a 1:20 work to rest ratio. This was determined to be sufficient to regenerate the immediate ATP phosphocreatine energy system between each CMJ and to avoid peripheral muscle fatigue effects [3]. During each CMJ the height was recorded via the My Jump application.

The app My Jump was developed as a mobile tool that can accurately measure CMJ height. Balsalobre-Fernández, Tejero-González, del Campo-Vecino, and Bavaresco [1] tested the My Jump app's ability to measure CMJ performance against a 1000 Hz force plate. The results showed near perfect agreement for CMJ height when comparing methods ($r = 0.995$; $p < 0.001$) and near perfect reliability between observers (ICC = 0.997; 95% CI: 0.996-0.998; $p < 0.001$). Stanton, Wintour, and Kean [17] concluded that My Jump is a valid and reliable measure of

CMJ. Gallardo-Fuentes et al. [7] reported that My Jump can be used by clinicians in the field as an alternative to laboratory testing. The My Jump app has demonstrated very small differences in jump height measurement values amongst observers with no previous experience in video analysis. This is despite the fact that the take-off frame, the frame in which the participant left the ground and the landing frame, the frame in which the participant landed on the ground had to be selected manually. This highlights the usability of My Jump for sports practitioners and their athletes [7], a finding corroborated by the authors of the present study, who can attest to the usefulness of the My Jump app as a cost-effective and easy-to-use alternative for measuring vertical jump performance. Driller, Tavares, McMaster and O'Donnell [5] conducted an independent study to assess My Jump and concluded that there was almost perfect agreement between the My Jump app and force plate for both jump height ($r = 0.96$) and flight time ($r = 0.96$).

After the three pre-jump CMJ measurements each subject sat down at a designated testing area on a standard exercise mat with his or her back against a wall. Each subject's quadriceps were exposed allowing the test administrator to apply the NMES electrodes. Two electrodes were placed over identical locations on each leg. Two-inch round electrodes with conductive hydrogel were placed on dry, oil-and lotion-free skin. One electrode was placed over the vastus medialis muscle approximately two inches superior to the patella along the median line of the femur. The other electrode was placed over the rectus femoris muscle along the median line of the femur.

Following either sham or experimental treatment, all subjects were then retested in the CMJ. Two warm-up CMJs were permitted. Each participant then performed three CMJs with rest periods of 20 seconds between each effort. Each CMJ was again recorded via the My Jump application.

Statistical Analyses

The data was analyzed using SPSS version 25. A paired independent samples *t*-test was utilized to determine statistical significance, which was set at $p \leq 0.05$. Descriptive statistics (mean ± SD; 95% confidence intervals) and effect sizes (d) were also calculated as appropriate.

3. Results

A paired independent samples *t*-test showed a statistically significant increase in experimental group CMJ scores (cm) from pre-test ($M = 28.69$, $SD = 6.87$) to posttest ($M = 30.14$, $SD = 7.42$), $t(11) = 1.796$, $p < .05$ ($d = .24$). A statistically significant decrease in control group CMJ scores (cm) was noted from pre-test ($M = 30.72$, $SD = 6.51$) to posttest ($M = 29.18$, $SD = 6.24$), $t(11) = 1.796$, $p < .05$. The mean increase in experimental CMJ scores was 1.45 with a 95% confidence interval ranging from 26.61 to 33.67 (cm). The mean decrease in control CMJ scores was 1.54 with a 95% confidence interval ranging from 26.21 to 32.15 (cm).

4. Discussion

Results indicate that acute application of ultra-low frequency NMES to the quadriceps group can lead to statistically significant improvement in vertical jump performance. Such findings are unique in that they mark the first instance known to the authors to demonstrate increases in vertical jump height immediately following a lone session of NMES solely to the quadriceps. Similar findings have previously been demonstrated by Kaçoglu and Kale [10] in which control (0Hz), low (30Hz) or high (100Hz) frequency NMES was applied to both the quadriceps and calf muscles. Subjects maintained a 90º static squat-position during the application of NMES and rested for 90 seconds in a sitting position after the treatment. Following the rest period, squat jump (SJ) and CMJ were tested using a wireless jumping assessment device placed on the waist. Significant improvement in SJ and CMJ height ($p<.0.05$) was obtained after the lower body NMES application in comparison to control frequency [10]. Findings from the present study add to the body of knowledge in this area, as the use of NMES electrodes placed only on the quadriceps, and without an active contractile condition demonstrate the potency of the treatment, as well as simplify its potential application.

In another similarly designed study, Berry, Tate, and Conway [3] demonstrated that applying transcutaneous spinal direct current stimulation (tsDCS) to the T11, and T12 thoracic vertebrae produced a lasting resistance to central fatigue and enhanced explosive vertical jump performance. These effects lasted for at least 3 hours and were in the absence of a physical training intervention. The key finding of this study was that after sham treatment there was a gradual decrease in vertical jump performance noted over the duration of each exercise set and the testing period altogether. However, the active tsDCS treatment resulted in improved CMJ performance that did not vary over the entire 180-minute test period. The authors suggested that tsDCS exerts effects on central fatigue mechanisms as well as increasing motor output. While the function of tsDCS varies slightly from NMES, the similarity in results seen across sham and active treatment groups between the present study and that of Berry, Tate, and Conway [3] is of interest. Additionally, the sustainability of increased vertical jump performance for hours after use has relevance to the application of such modalities by athletes, trainers, and coaches, and warrants further research.

Given the design of the present study, neuromuscular fatigue would not have come into play prior to CMJ testing. However, one of the mechanisms that could explain our results is certainly in agreement with the proposed increased motor unit output described by Berry, Tate, and Conway [3]. In the case of an electrically imposed contraction, the mechanisms of muscle activation differ from those encountered with voluntary contraction [16]. NMES reverses the order of motor unit recruitment observed with voluntary contraction by preferentially stimulating fast twitch muscles with a larger fiber area [4,11]. NMES can thus enhance muscular power by improving synchronization in fast twitch fibers during voluntary muscle action [12]. Additionally, it has been suggested that NMES may enhance calcium release from the sarcoplasmic reticulum of the muscle cell, which could lead to an increase in strength of muscular contraction for up to two hours [8]. Additional mechanisms that may explain results in the present study include fiber type transformation, nitric oxide (NO) production, mitochondrial biogenesis, and angiogenesis [10,20].

Of note in the present study, a decrease in control group CMJ performance was observed that could be attributed to the testing procedure required to observe the acute effects of NMES. After recording three CMJs each control subject sat down for 15-minutes and received sham treatment. Unprompted, several subjects in the control group reported feeling “numbness” or the “fallen asleep” feeling after getting up from the 15-minute sham treatment. Such reports may indicate lack of circulation in the leg musculature resulting from the 15 minutes of inactivity. Importantly, no participants in the experimental group indicated any sensations of “numbness” or “falling asleep.” These findings are in line with proposed mechanisms from previous research, which suggest that ultra-low frequency NMES may cause an increase in microcirculation and angiogenesis in the applied muscle group [19]. Such a physiologic mechanism has implications for muscle recovery as well as facilitation of improved athletic performance.

The current study made use of a warm-up protocol similar to that performed by Nuzzo, Anning, and Scharfenberg [15]. An extended warm up could have potentially increased the control group jump scores closer to the original jump attained. A possible limitation to the present study was the fact that the subjects, although physically active, were considered moderately trained individuals. It is not certain whether the testing protocol used in this study would show similar improvements in jumping performance in highly trained or elite athletes. Additionally, all participants were at least 24 years of age, so the typical high school and college aged populations could respond differently to NMES treatment. Such questions should be addressed in future research.

While several lines of important future research on the application of NMES have been identified in the preceding paragraphs, findings from the present study, together with the current body of research, indicate cautious support for the application of NMES towards acute vertical jump improvement. Such findings, together with the simplistic application of NMES, make it a potentially attractive modality for use in athletic populations. Athletes regularly find themselves in prolonged, restricted conditions such as during team travel, which can result in reductions of blood flow and delay of the recovery process. The NMES device is portable due to its size, and after receiving instruction from team trainers and/or coaches, athletes are able to apply the device themselves, reducing the need for input from support staff during periods of difficult and reduced player access [18].

5. Conclusions

Results from the present study show that the acute application of NMES to the quadriceps group can lead to significant improvements in vertical jump performance in a healthy, adult population. NMES may improve the probability of retaining jumping ability after a period of inactivity, and athletes in sports involving multiple vertical jumps such as basketball and volleyball may therefore benefit from the use of NMES. NMES and the concurrent use of the MyJump mobile application indicate that the future use of technology in sport performance is promising.

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