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Original scientific paper

Effects of Neuromuscular Electrical Stimulation and Resistance Training on Knee Extensor/Flexor Muscles

Milan Pantović, Boris Popović, Dejan Madić and Jelena Obradović

University of Novi Sad, Faculty of Sport and Physical Education, Novi Sad, Serbia

A B S T R A C T

Neuromuscular electrical stimulation (NMES) has recently drawn a lot of attention as means for strengthening of voluntary muscle contraction both in sport and rehabilitation. NMES training increases maximal voluntary contraction (MVC) force output through neural adaptations. On the other hand, positive effects of resistance training (RT) on muscle strength are well known. The aim of this study was to investigate effects of a 5-week program of NMES compared to RT program of same duration. Sample of 15 students' of faculty of sport and physical education (age 22±2) were randomized in two groups: NMES (N=7) and RT (N=8). NMES group performed NMES superimposed over voluntary muscle contraction, RT group performed resistance training with submaximal loads. Subjects were evaluated for knee isokinetic dynamometry on both sides (60° and 180° s). After intervention no significant difference between groups were observed in isokinetic dynamometry (p=0.177). However, applying pair sample t test within each group revealed that peak torque increased in NMES group (p=0.002 for right knee extensors muscles, p=0.003 for left, respectively, at 60° and p=0.004 for left knee extensors muscles, at angular velocity 180°). In RT group (p=0.033 for right knee extensors muscles, p=0.029 for right knee flexor muscles, at angular velocity 60°). Our results indicate that NMES has equal potential if not in some way better than classical RT, having in mind that overload on locomotor apparatus during NMES is minimal and force of muscle contraction is equal on both sides, for enhancement of knee muscles concentric peak torque.

Key words: *neuromuscular electrical stimulation, whole body vibration, muscle power*

Introduction

Recently neuromuscular electrical stimulation (NMES) draw a lot of attention as means for strengthening of voluntary muscle contraction, so NMES found its place in strength training, rehabilitation, in testing purposes and as post – exercise recovery tool[1]. Some authors suggest that NMES could be effectively used for muscle twitch potentiation (post activation potentiation) with minimal fatigue while enhancing joint muscle performance[2–3]. Studies report increase of a maximal voluntary contraction (MVC) but without extensive muscle hypertrophy in just few NMES sessions[4]. Application of isometric NMES showed considerable gains in maximal isometric strength in well trained athletes[5]. For example, several studies showed that short-term NMES training improves athlete's vertical jump performance and voluntary muscle strength[6–9]. Some author's state usefulness of NMES combined with plyometric training for improvement of vertical jump ability[10]. On the other hand, NMES combined with plyometric training increased both jumping height and sprint run, however; NMES training alone did not result in any improvement in jumping explosive strength development or even interfered in sprint run[11]. Only few studies were conducted with NMES superimposed over voluntary muscle contraction. For instance, one group of authors compared the effects of the fatigue induced by voluntary muscle contraction and voluntary muscle contraction superimposed with NMES, on postural control[12]. Furthermore, some authors noticed that NMES superimposed over voluntary contraction was equally effective as voluntary muscle contraction training in MVC improvements, but authors noticed greater cross-education effects in NMES group[13]. Effectiveness of RT program is well known and explained in number of studies[14–17].

The aim of this study was to investigate effects of a 5-week program of NMES compared to RT program of

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same duration. First hypothesis of this study was that NMES superimposed over low plyometric voluntary contractions will result in strength gains of knee extensor and flexor muscles; furthermore, it was hypothesized that RT program will increase knee extensor and flexor muscle strength production. Second hypothesis was that superimposed NMES training will result in similar strength gains compared with RT.

Material and Methods

Subjects

Fifteen male subjects volunteered the study. Subjects were students of Faculty of Sport and Physical Education, University of Novi Sad, Serbia, age 20 years±6 months. None of them had previous muscular/osteoarticular injury. The subjects from both groups were present at 100% of the sessions. They were randomized into 2 groups: NMES group (N=7) and resistance training (RT) group (N=8). NMES group received superimposed NMES training, which had stimulated quadriceps femoris muscle with an 110 Hz current for 13 min for improving muscle power. RT group performed resistance training with submaximal loads. The subjects from NMES group had not any previous experience of electrically evoked contractions, subjects from RT group had previous experience in RT program. Isokinetic dynamometry for both groups was measured before experimental procedure, and one week after the end of the experimental programs.

Training

The subjects were randomized into 2 groups. The NMES group followed NMES training program, composed of 3 NMES sessions a week over 5 weeks period. NMES programs were performed with a portable stimulator (COMPEX SPORT, Switzerland) delivering a maximal current intensity tolerable by subjects. Electrical current was delivered over quadriceps femoris muscle through two self-adhesive conducting electrodes 5x5 cm^2 and one 5x10 cm^2 self-adhesive conducting skin electrodes, for each leg. The positive electrodes (5x5 cm^2) were placed over the distal motor points next to knee and the negative (5x10 cm^2) electrode were placed over the proximal motor points of vastus medialis and vastus lateralis muscle. The NMES group underwent a power NMES training program plyometry program of the stimulator). This program included 2 periods: warm-up (10 mA, 5 Hz, 5 min), work-out plyometry: 13 min). After each session subjects have performed lower limbs stretching. Biphasic symmetrical rectangular-wave (450 microseconds) pulsed currents were used (ramp-up: 1.8 s; ramp down: 1.2 s). With the plyometry program, steady tetanic stimulations of 6 s (110 Hz current) were followed by pauses of 18 s during the work-out period. The current was raised up according to the changes in subject's pain threshold until maximally tolerated intensity was delivered at each session (adjusted throughout the session). The quadriceps muscles of both legs were stimulated while subjects performed voluntary exercise, which consisted of 3–5 consecutive jumps from semi-squat position during 6 s of steady tetanic stimulation period.

The RT group followed submaximal resistance training program (Table 1) that was consisted of: 5 sets of one main exercise and 3 sets two additional exercises (85–90 % 1RM) executed until failure. The each subject's one repetition maximum (1RM) for each exercise was measured; optimal load for each exercise was estimated using charts for multiple repetitions based on the 1RM[18]. Tree day resistance training program was rotated 4 times a week (same training day routine was done every 6 days) over 5 weeks period.

TABLE 1
RT GROUP TRAINING PROGRAM – MAIN EXERCISES

	Exercise	Tempo	Reps	Sets	Rest
DAY 1					
Main exercise	Squat	31X1	85–90 % 1RM	5	90s
DAY 2					
Main exercise	Bench press	31X1	85–90 % 1RM	5	90s
DAY 3					
Main exercise	Chin up	31X1	85–90 % 1RM	5	90s

Tempo of exercise – first number represents duration of eccentric fase of movement in seconds, second number represents isometric pause in streched position in seconds, third number represents duration of concentric phase in seconds, fourth number represents isometric pause in shortened position. If instead of number stand X than the movement is performed explosively with full acceleration.

All the subjects of the two groups continued their usual physical activity (also their usual diet) throughout the whole duration of the experiment.

Testing

Isokinetic measurement of concentric/ hamstring and quadriceps torque was measured using an isokinetic dynamometer (Cybex – NORM – CSMI, Stoughton, Massachusetts). Testing had four sets. For first two tests angular velocity was set at 60°/s with five repetitions trial test, before four repetition tests. For third and fourth set angular velocity was set at 180°/s with four repetitions and fifteen repetitions respectively. Test was performed for each leg. These sets were performed with a 2 min rest between sets. Subjects were seated on the Cybex with their hip joint at approximately 90° flexion, their upper bodies secured with dual crossover straps and their waist secured by a waist strap. The range of motion of the knee was set at 90° of full extension, with the upper leg secured using the thigh strap to limit excess movement of the knee and limb. The main tested variable was peak torque. Before the commencement of each testing speed, participant was allowed to familiarize himself with 3 trials. Verbal encouragement at a conversational level was given during testing. The testing apparatus was regularly calibrated according to the manufacturer instructions.

Statistical analysis

The training effects were compared within and between groups. For analyzing the difference between pre and post-test scores within the groups it was used paired sample t tests. In order to determine the multivariate statistical significance of the differences between the experimental groups at the final measurement to analyze the effects of treatments, multivariate and univariate covariance analyses (MANCOVA and ANCOVA) were used. Significance level was set at p=0.05. All statistical methods were performed using IBM SPSS, Statistic software, Version 20.

Results

Observed paired sample t test results for NMES group (Table 2) showed statistically significant changes in right and left knee extensors muscles at 60°/s velocity (p=0.002, p= 0.003 respectively). Also at higher speeds was noticed statistically significant change in left knee extensors muscles at 180°/s velocity (p=0.046).

In RT group (Table 3) statistically significant changes were noticed only for right leg at lower angular velocities (60°/s) for right leg knee extensor and flexor muscles (p=0.033, p=0.029). Higher velocities did not record any statistically significant changes after implemented RT experimental treatment.

Multivariate analysis of covariance between groups did not yielded statistically significant differences, since F=18.322 and P=0.175, which indicates that there was no significant difference between groups after implemented experimental protocols.

Although there was no statistically significant differences between NMES and RT after implemented experimental protocols, observing percentage change of isokinetic parameters (Figure 1) it could be noticed higher amount of strength increase in extensors muscle group for NMES group both in dominant and nondominant leg relative to RT group. Particularly those differences are noticeable for non dominant leg at lower angular velocities and for dominant leg at higher velocities of knee extensors muscle group.

Discussion

Implemented experimental program of NMES superimposed over voluntary contraction and RT training has caused statistically significant strength increase in some

TABLE 2

DIFFERENCIES BETWEEN INITIAL AND FINAL MEASUREMENT IN NMES GROUP

	$\overline{X}_1$	SD_1	$\overline{X}_2$	SD_2	t	p
Extensors right leg 60°/s	198.14	30.89	217.85	30.00	–5.201	0.002
Extensors left leg 60°/s	208.28	33.99	230.28	31.51	–4.801	0.003
Flexors right leg 60°/s	138.14	21.66	145.85	23.61	–1.401	0.211
Flexors left leg 60°/s	135.00	20.68	127.85	49.77	0.541	0.608
Extensors right leg 180°/s	139.28	20.70	155.42	25.59	–1.536	0.175
Extensors left leg 180°/s	144.14	21.70	153.14	19.36	–2.515	0.046
Flexors right leg 180°/s	115.14	26.67	122.71	20.01	–1.407	0.209
Flexors left leg 180°/s	114.42	22.58	118.85	24.90	–0.937	0.385

TABLE 3

DIFFERENCIES BETWEEN INITIAL AND FINAL MEASUREMENT IN RT GROUP

	$\overline{X}_1$	SD_1	$\overline{X}_2$	SD_2	t	p
Extensors right leg 60°/s	225.75	33.90	246.25	27.25	–2.657	0.033
Extensors left leg 60°/s	234.87	29.19	237.12	25.42	–0.380	0.716
Flexors right leg 60°/s	142.37	23.21	158.12	25.64	–2.736	0.029
Flexors left leg 60°/s	143.37	23.32	144.25	25.86	–0.107	0.918
Extensors right leg 180°/s	162.62	14.40	165.37	14.60	–1.010	0.346
Extensors left leg 180°/s	159.00	20.57	166.25	18.91	–1.253	0.251
Flexors right leg 180°/s	115.00	22.84	123.37	19.14	–1.522	0.172
Flexors left leg 180°/s	113.62	17.83	111.37	21.65	0.607	0.563

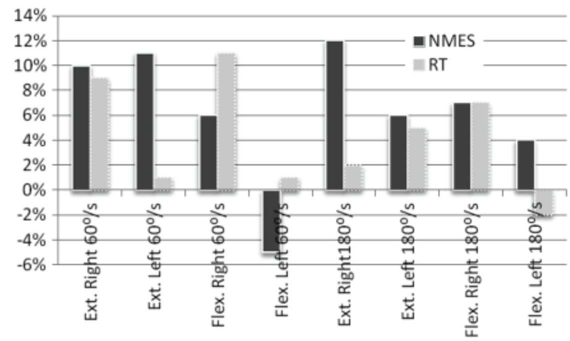

Fig. 1. Average change in percent for observed groups.

observed isokinetic parameters. We hypothesized that NMES group will achieve similar strength gains as RT group. Final outcomes of our study support our hypothesis. Furthermore, NMES regarding strength gains in knee extensor muscles achieved better, but not statistically significant, results than RT in all observed parameters. It was noticed reduction in strength gains for apparently nondominant limb in RT group. Subsequently to that knowledge, all participants filled in manual laterality questionnaire – Modified Edinburgh Handedness Inventory[19], also subjects were asked to use their preferred leg in instep kicking of football ball. According to manual laterality questionnaire results, and instep kick test all subjects were right-handed (legged). That information gave partly an explanation for such results and indicates that some neural mechanisms[20] are responsible for such bilateral force productions differences in RT. Bilateral deficit was broadly investigated by many authors[21,22]. Some authors propose that bilateral multi joint exercise (e.g. squat) increase activation of dominant quadriceps[23]. Other group of authors suggested several mechanisms for explanation of bilateral muscle deficit such as: selective inhibition of motor units, training level, habitual usage of body segments, interhemispheric interference, lateral inhibition, division of attention, and limitation of central neural drive[24]. On the other side, explanation for strength improvements in NMES group could be found in very nature of motor units activation by electrical impulse. For instance, recently was proposed several mechanisms of muscle activation via NMES, just to name a few: non-selective motor units activation, high contractions intensity, targeted muscle activation, external origin of muscle contractions[5]. If we add that all those mechanisms were activated during low pliometry, which means that for instance targeted muscle contraction of type IIx muscle fibers via superimposed NMES was done in concentric, but also in eccentric manner, which probably could in greater extent caused muscle damage and later reconstruction of type IIx fibers in greater extent than traditional isometric approach to NMES. Also could be noted existence of impact during somatosensory electric stimulation, on direct and crossed brain activation, corticospinal excitability, and motor performance[25]. However, this study was reported with some methodological limitations. Firstly, subject sample should be larger, and results from this study should not be generalized to other population having in mind that students of faculty of sports and physical education involved in this study already have weight training and exercise experience. Secondly, this study was conducted without control group, but since the subjects were young adults, it wasn't expected significant contribution of biological growth and maturation on final outcome of results.

Conclusion

These results from this study are very encouraging and demonstrate that NMES superimposed over voluntary contraction improve muscle strength of involved muscles in same amount as RT. Furthermore, our results indicate that NMES has not only equal potential, but in a way better than classical RT, regarding knee joint extensor muscles, having in mind that overload on locomotor apparatus during NMES is minimal and produced force of muscle contraction is equal on both sides. Also should be noted that bilateral deficit during NMES for enhancement of knee muscles concentric peak torque is present smaller amount that with RT. All this findings open new possibilities in application of superimposed NMES in strength training both in sport and rehabilitation purposes.

Future recommendations

The results from this study arise question how NMES actually increase magnitude of voluntary muscle force production. Furthermore, it would be crucial to investigate effects of NMES on motor cortical and spinal mechanisms and in what extent NMES influence motor control system. These findings could improve practical application of NMES in sport performance, but also in management of sarcopenia, or muscle atrophy due to some progressive disease or injury.

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M. Pantović

University of Novi Sad, Faculty of Sport and Physical Education, Lovćenska 16, 21000 Novi Sad, Serbia
e-mail: milan.pantovic@yahoo.com

EFEKTI NEUROMIŠIĆNE ELEKTRIČNE STIMULACIJE I KLASIČNOG TRENINGA SNAGE NA SNAGU MIŠIĆA OPRUŽAČA I PREGIBAČA U ZGLOBU KOLJENA

S A Ž E T A K

Neuromišićna električna stimulacija (NMES) je u posljednje vrijeme privukla dosta pažnje na sebe, kao prikladna metoda za povećanje voljne mišićne kontrakcije, kako u sportu tako i u rehabilitaciji. NMES povećava maksimalnu voljnu mišićnu kontrakciju (MVC) putem neuralne adaptacije. Sa druge strane, utjecaj treninga snage (RT) na razvoj MVC je dobro poznat. Cilj ovog istraživanja je ispitati efekte petotjednog programa NMES u usporedbi sa RT programom istog trajanja. Uzorak od 15 studenata fakulteta sporta i fizičkog vaspitanja (uzrasta 22±2) je nasumično podijeljen u 2 grupe: NMES (N=7) i RT (N=8). NMES grupa je izvodila NMES za vrijeme voljne mišićne kontrakcije (niska pliometrija), dok je RT grupa izvodila trening snage sa submaksimalnim opterećenjem. Snaga mišića ekstenzora u zglobu koljena je evaluirana putem izokinetičke dinamometrije pri brzinama (60º i 180º s). Nakon intervencije nije uočena statistički značajna razlika u parametrima izokinetičke dinamometrije (p=0,175). Primjenom t testa za zavisne grupe, uočeno je statistički značajno povećanje obrtnog momenta u NMES grupi za mišiće opružače u zglobu koljena desne noge (p=0,002), za lijevu nogu pri kutnoj brzini od 60º/s (p=0,003), a uočeno je i statistički značajno poboljšanje rezultata za mišiće opružače u zglobu koljena lijeve noge pri ugaonoj brzini od 180º/s) (p=0,004). U RT grupi uočeno je značajno povećanje za mišiće opružače u zglobu koljena desne noge (p=0,033) i za mišiće pregibače u zglobu koljena desne noge, pri ugaonoj brzini od 60º/s) (p=0,029). Ovi rezultati ukazuju na podjednak, ukoliko ne i veći, potencijal NMES u odnosu na RT, imajući u vidu da je opterećenje lokomotornog aparata prilikom NMES minimalno, kao i da je razvoj maksimalne mišićne kontrakcije ravnomjeran za oba ekstremiteta.