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Bilateral effect of unilateral isokinetic concentric training and Russian current stimulation on quadriceps strength

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Abstract: Isokinetic training and Russian current stimulation have been advertised to increase muscle strength. So, the purpose of this study was to compare between unilateral isokinetic concentric training and Russian current stimulation on the quadriceps strength of ipsilateral and contralateral limbs. Sixty healthy male subjects were randomly assigned into 3 equal groups; Isokinetic group; received isokinetic concentric training. Russian group; received Russian current stimulation, and control group: did not receive any training program. Isokinetic and Russian groups trained for 4 weeks, 3 session/week on the dominant quadriceps femoris muscle. Biodex Multi-joint System 3, Biodex, Shirley, NY, used to measure the isokinetic concentric peak torque/body weight before and after 4 weeks training for all groups at angular velocity 30°/s. For contralateral and ipsilateral quadriceps strength there was significant increase in the quadriceps strength of isokinetic and Russain group (p= 0.000). However, there was no significant increase in the quadriceps strength of control group (p= 0.214, 0.061) respectively. There was no significant difference between isokinetic and Russian group for the value of increasing of the quadriceps strength (p= 0.391, 0.579) respectively. The percent of improvement of ipsilateral side was significantly higher than the improvement of contralateral side for isokinetic and Russian group (p= 0.004, 0.006) respectively. So, Isokinetic training and Russian current stimulation have equal level of effectiveness in improving the concentric strength of the contralateral and ipsilateral quadriceps muscle. In spite of, the improvement of ipsilateral side was higher than that of the contralateral side.

Keywords: Quadriceps Strength, Isokinetic Training, Russian Current

1. Introduction

It is widely believed that unilateral strength training increases strength in the homologous muscle group of the contralateral limb[1, 2, 3]. Munn et al.[2] concluded that unilateral training produces a small but statistically significant effect on the strength of the homologous muscles on the contralateral side (an increase of 8% of initial strength of the untrained limb). The adaptation to a strength or resistance training program is due to two principal, but conceptually different mechanisms; muscle hypertrophy and neural adaptation[4, 5]. The results of effective programs are usually observed as increased one repetition maximum (1RM) or improved ability to develop force and power. While muscle hypertrophy is associated with increased cross-section of the myocyte and whole-muscle [6, 7], neural adaptation is not[8].

Neural adaptation refers to changes in the nervous control of the muscle. This may include improved neural drive, activation, and control of the muscle fibers[9-15]. Moreover, motor units are recruited by impulses from the central nervous system to the motor neurons. It has been suggested that strength training may increase firing frequency and thereby increase the potential for force development[16].

Since the nervous system is involved in the training adaptation, unilateral strength training may also affect the contralateral muscles, either because the neural drive is "spilled-over," or because adaptation in the neuromuscular system may be accessible to the untrained side[17]. However, the exact mechanisms for contralateral effects remain unknown. Nonetheless, contralateral effects in the homologous muscle have been observed after unilateral strength training [3, 10, 18].

The isokinetic used to assess and improve muscle function for both rehabilitation and training purposes [19-21]. The widespread application of isokinetic dynamometers relates to their ability to accurately quantify muscle function through the total range of movement at constant velocity. Thus, this system allows maximal muscle contractions and enables measurements with high reproducibility [20, 21].

Electrical stimulation is extensively used in physical therapy. The ability of neuromuscular electrical stimulation (NMES) especially Russian current protocols to improve the skeletal muscle performance of healthy muscles [20-23] has been accepted and demonstrated both in research studies and in rehabilitation practice[21, 24].

Several studies have found that NMES and voluntary exercises are equally effective in increasing the strength of the quadriceps femoris muscle in healthy individuals[25, 26]; while others have found NMES[27-29] to be more effective. So, the aim of this study was to compare between unilateral concentric isokinetic training and Russian current stimulation on the strength of ipsilateral and contralateral limbs.

2. Materials and Methods

2.1. Subjects

Table 1. *Demographic data for isokinetic, Russian and control groups*

Groups	Isokinetic group, *n* = 20 Mean ± SD	Russian group, *n* = 20 Mean ± SD	Control group, *n* = 20 Mean ± SD
Age, years	23.05 ± 3.27	22.50 ± 3.77	21.73 ± 3.72
Weight, kg	74.90 ± 6.54	76.58 ± 7.50	76.38 ± 8.32
Height, cm	171.60 ± 4.95	169.85 ± 5.55	172.95 ± 6.24

Sixty healthy male subjects, they were randomly assigned into 3 equal groups; isokinetic group, Russian group and control group participate in this study. The subjects were selected from the student of Faculty of Physical Therapy, Cairo University, Egypt. Isokinetic group; received isokinetic concentric training technique on the dominant quadriceps femoris muscle at angular velocity 30°/s. Russian group; received Russian current stimulation on the dominant quadriceps femoris muscle. Both groups trained for 4 weeks, 3 session/week, and control group: did not receive any form of training.

All participants were selected using the following inclusion criteria: 1) the participants had to be young (age range between 18 and 25 years); 2) have normal body mass index (between 20 and 24.9kg/m²); 3) avoid any other physical activity during the training period. The participants' exclusion criteria were history of musculoskeletal disorders, neurological deficits affecting lower limb as strokes, sciatica and polyneuropathy, metabolic or vascular disease with a neurological component such as diabetes, systemic inflammatory arthritis as rheumatoid arthritis or reports of pain in the knee joints. Table (1) presents the demographic characteristics of the participants.

All of the evaluation and training procedures were explained before they began and all participants signed a consent statement. The study was approved by the Ethics Committee of Faculty of Physical Therapy, Cairo University.

2.2. Procedure

Before evaluation, the participants familiarized themselves with the testing and training procedures. The evaluation was applied to both the right and the left limbs before and after the training program, while training applied only on the dominant side quadriceps. After a five-minute warm-up on a stationary bicycle at a speed of 20km/h and load of 20W, the participants stretched the quadriceps femoris and hamstring muscles of both limbs. Each muscle group was stretched three times for 30 sec alternatively.

Following the warm-up, the participants were positioned in an isokinetic dynamometer (Biodex Multi-joint System 3, Biodex, Shirley, NY), with hip angle of 100º. The trunk, pelvis and thigh were stabilized using straps, in accordance with the equipment instructions. The rotation axis of the dynamometer was aligned with the axis of the knee, at the level of the lateral epicondyle of the femur, while it was attached to the distal part of the leg, about 5cm above the medial malleolus. A gravity effect correction was calculated with the leg nearly parallel to the ground. The isokinetic device was calibrated before each evaluation and training session, as recommended by the manufacturer.

Following this, the participants had their knees positioned at 90° flexion and were familiarized with the procedures. They were then asked to perform three maximal voluntary isokinetic knee extension contractions for five seconds at angular velocity 30°/s, with one-minute rest intervals between contractions. Three minutes after the last isokinetic contraction, the participants were familiarized with the isokinetic contraction and then performed five maximal isokinetic concentric knee extension contractions at angular velocity 30°/s, from 90° to 15° (0° being full extension), totaling 75° of range of motion (ROM). Verbal encouragement, as well as visual feedback from the equipment, was given in an attempt to achieve maximal voluntary effort level during all the contractions that each participant was asked to perform. The same procedures were repeated with the contralateral limb[30]. The peak torque/body weight (PK/BW) of the quadriceps femoris muscle was measured before training and after 4 weeks of training of three groups. A mean was calculated of the best 3 of the 5 contractions.

2.3. Training Procedures

Isokinetic group performed training sessions three times a week for four weeks. Each session included a five-minute warm-up period on a stationary bicycle, followed by three sets of quadriceps stretching as previously described. After being placed in the same position as in the evaluation sessions on the isokinetic dynamometer, the participants performed three sets of ten maximal isokinetic concentric repetitions at angular velocity 30º/s for the dominant side, observing a resting period of three minutes between the sets.

Russian current group performed training three times a week for four weeks. NMES (phyaction 787, Neitherlands) was used. The carrier wave frequency was 2,500Hz, modulated at 50bursts/s, with a pulse duration of 200µs and an interburst interval of ten minutes. This configuration is known as Russian current[23]. Two self-adhesive electrodes (5 x 13cm) were placed on the participant's thigh: one approximately 10cm below the iliac anterosuperior spine in the proximal region of the quadriceps; and the other over the distal portion of the quadriceps femoris, about 5cm above the suprapatellar line, over the belly of the vastus medialis obliquus muscle. At each training session, the amplitude of current used was the maximum each participant could tolerate. The stimuli were applied only during knee extensor contraction, therefore there was no NMES application during passive knee flexion.

2.4. Data Analysis

Data was analysed using the Statistical Package for Social Sciences (SPSS version 16). Analysis of variance (ANOVA) was used to investigate the effect of isokinetic and Russian current training on strength of ipsilateral and contralateral quadriceps at an angular velocity 30^{o}/s. The level of significant was set at 0.05 for all statistical tests.

3. Results

Table 2. *Descriptive statistics of PT/BW of the three groups*

Groups		Isokinetic group, *n* = 20 Mean ± SD	Russian group, *n* = 20 Mean ± SD	Control group, *n* = 20 Mean ± SD
Ipsilateral side	pretest	207.78 ± 23.06	200.32 ± 22.37	193.37 ± 26.50
	posttest	256.25 ± 33.08	250.61 ± 36.44	194.62 ± 25.44
Contralateral side	pretest	202.99 ± 22.22	194.79 ± 21.81	189.11 ± 25.85
	posttest	232.98 ± 31.43	223.89 ± 30.75	192.25 ± 26.55

Table 3. *Percent (%) of change of the three groups*

Groups	Isokinetic group, *n* = 20 Mean ± SD	Russian group, *n* = 20 Mean ± SD	Control group, *n* = 20 Mean ± SD
Ipsilateral side	23.75 ± 12.56	25.08 ± 11.81	0.75 ± 1.42
Contralateral side	14.51 ± 5.06	14.96 ± 9.83	1.69 ± 2.94

There was no significant difference between three groups for age, weight and height (p= 0.508, 0.744 and 0.244) respectively. Analysis of variance of contralateral quadriceps strength of the three groups revealed that there was no significant difference between pre values of the three groups (p= 0.177). There was significant increase in the quadriceps strength of isokinetic and Russain group (p = 0.000). However, there was no significant increase in the quadriceps strength of control group (p= 0.214). There was no significant difference between isokinetic and Russian group for the value of increasing of the quadriceps strength (p = 0.391), the increase in quadriceps strength of isokinetic group was significantly higher than control group (p = 0.001). Moreover, the increase in quadriceps strength of Russian group was significantly higher than control group (p = 0.010), as shown in Table 2.

Analysis of variance of ipsilateral quadriceps strength of the three groups revealed that there was no significant difference between pre values of the three groups (p= 0.175). There was significant increase in the quadriceps strength of isokinetic and Russain group (p = 0.000). However, there was no significant increase in the quadriceps strength of control group (p= 0.061). There was no significant difference between isokinetic and Russian group for the value of increasing the quadriceps strength (p = 0.579), the increase in quadriceps strength of isokinetic and Russian group was significantly higher than the increase in the control group (p = 0.000), as shown in Table 2.

For isokinetic group, the percent of improvement of ipsilateral side was significantly higher than the improvement of contralateral side (p= 0.004). For Russian group, the percent of improvement of ipsilateral side was significantly higher than the improvement of contralateral side (p= 0.006). For control group, there was no significant difference in percent of change between ipsilateral and contralateral sides (p = 0.203), as shown in Table 3.

4. Discussion

The current study was conducted to compare between unilateral concentric isokinetic training and Russian current stimulation on the strength of ipsilateral and contralateral limbs. The results proved that there was no significant difference between concentric isokinetic training and Russian current stimulation in increasing the quadriceps strength of ipsilateral and contralateral limbs. Moreover, the ipsilateral improvement of quadriceps strength was higher than that of the contralateral improvement.

Our results were coincident with the findings of Maffiuletti et al.[31] who found that short-term electrical stimulation increased maximal voluntary strength by 12%, which was accompanied by neural adaptations (cross-educational effect and increased muscle activation) and muscle adaptations in healthy individuals. Similarly, Yaz et al.[32] have found that both Russian current and low frequency current were capable to increase the maximum extensor peak torque of quadriceps muscles, even that the low frequency current was more effective than Russian current. Moreover, the recruitment order of electrical stimulation is reversed relative to volitional exercise. During volitional activity, the slow oxidative (SO) muscle fiber types are recruited first, whereas fast glycolitic (FG) are the most difficult to recruit. During electrical stimulation of the muscle the order of muscle fiber recruitment is reversed, with the largest-diameter muscle fibers FG being recruited first and the smaller-diameter SO muscle fibers being recruited later[33].

The findings of the present study were supported by the findings of Evetovich et al.[34] who examined the effects of unilateral concentric isokinetic leg extension training on peak torque in the trained and untrained limbs. They found a significant increase in peak torque in both the trained and untrained limb for the trained group but no significant change in peak torque in either limb for the control group. Moreover, the results of the present study was supported by the findings of Muellbacher et al.[35] who found that voluntary muscle activation of the ipsilateral abductor pollicis brevis significantly facilitated the motor evoked potentials and F-waves recorded from the contralateral abductor pollicis brevis.

However, the results of the current study was against the finding of Housh et al.[36] who examined the effect of unilateral concentric isokinetic training on strength and hypertrophy of the extensor and flexor muscles of the forearm and leg of ipsilateral and contralateral limbs. They found significant increases in peak torque for trained forearm extension and flexion as well as trained leg flexion. There were no significant increases in peak torque, however, for any movement in the contralateral limbs.

Munn et al.[2] stated that the effect of unilateral resistance training on the maximal voluntary strength of the contralateral limb was 7.8% that was less than the findings of the current study that were 14.51% and 14.96 for isokinetic group and Russian group, respectively. This was 35.1% of the effect on the trained limb that was higher than the findings of the present study that were 23.75 % and 25.08 for isokinetic group and Russian group, respectively.

There was no significant difference between isokinetic and Russian groups for the value of increasing of the quadriceps strength that was against the findings of Hortobagyi et al.[37] found that voluntary training was less effective (37% strength gain) compared with EMS training (104%) contralateral side, that may be due to the difference in mode of voluntary training, they used eccentric contraction training. However, These findings were in agreement with the results of Zhou et al.[38] who placed 30 subjects on 4 weeks training program for the dominant quadriceps femoris muscle three times per week, divided the subjects into three groups voluntary isometric training and EMS and control group. It was reported that both voluntary exercise and electrical stimulation induce similar contralateral strength (cross education), and concluded that both voluntary exercise and electrical stimulation techniques improve contralateral strength with equivalent efficacy.

There are many explanations for the occurrence of the cross education. Hortobagyi et al.[37] suggested that the spinal and supra-spinal adaptations were uncoupled with EMS training and testing, and proposed three reasons for the speculation that the site of cross education likely resides at the spinal level. First, the magnitude of electromyography activity recorded from the contralateral quadriceps muscle during training was not proportional to the magnitude of the strength gain. Secondly, voluntary training was less effective (37% strength gains) compared with EMS training (104%). This suggests that EMS training is able to access mechanisms that are not accessible by central drive during voluntary training. Thirdly, the greater strength gain achieved by EMS training cannot be fully explained by the accommodation to the discomfort associated with transcutaneous stimulation. It is possible that the noxious sensations associated with EMS may activate supra-spinal mechanisms, which subsequently affect the contralateral muscle activity. The results of the present study demonstrated that with the same intensity and repetitions EMS training can induce similar levels of cross education as voluntary training, which provides further evidence for the possible spinal mechanisms.

The improvement in quadriceps strength of isokinetic and Russian groups is supported by the findings of Zhou[3] who stated that the cross education refers to the contralateral effect of chronic motor activity in one limb. The effect can enhance or diminish motor activity and is specific to the homologous muscles and the training task. The mechanisms underlying the phenomenon involve adaptations in the nervous system, probably at the level of the spinal cord.

Recently, Pearce et al.[39] used transcranial magnetic stimulation (TMS) to measure corticospinal responses following 3 weeks of unilateral arm training on the contralateral, immobilize arm. The results provide the first evidence of corticospinal mechanisms, assessed by TMS, underpinning the use of unilateral strength training to retain strength and muscle thickness following immobilization of the contralateral limb. Moreover, Hendy et al.[40] concluded that cross education provides a unique opportunity for enhancing rehabilitation following injury. By gaining an understanding of the neural adaptations occurring during immobilisation and cross education, future research can utilize the application of unilateral training in clinical musculoskeletal injury rehabilitation.

There are some limitations of this study. First, the total study time was limited to 4 weeks, which could be extended to achieve a greater benefit of Russian current stimulation and isokinetic training on quadriceps muscle strength. Secondly, the gender in this study was limited to males only. Thus, the appropriateness of generalizing the results is confined to this specific population. Finally, the only isokinetic parameter examined in this study was concentric peak torque, other isokinetic parameters, such as eccentric peak torque, power, work, and fatigue, were not considered.

5. Conclusion

It can be concluded that the isokinetic training and Russian current stimulation have equal level of effectiveness in improving the concentric strength of the contralateral and ipsilateral quadriceps femoris muscle. Moreover, the improvement of ipsilateral side was higher than that of the contralateral side. So, it is recommended to use the cross education mechanism by isokinetic training or Russian current stimulation especially for rehabilitation of subjects who have condition that prevent them from exercising one limb.

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