

Four-week of local electromyostimulation training on fingerboard increases the isokinetic wrist strength and endurance

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Abstract

Purpose: Electromyostimulation (EMS) has been used for both physical therapy and strength improvements for a few decades. This study aimed to investigate the effects of a four-week local-EMS training performed on a fingerboard (FT) in wrist strength and endurance.

Material: Sixteen physically active, non-climber students were divided into EMS+FT and FT groups. Each group performed the same training program about 25 min a day, 3 days a week for four weeks. The EMS+FT implementation was performed with a signal width of 260 ms and a frequency of 60 Hz. Before and after training, isokinetic measurements were collected. The parameters used in the research during flexion and extension at 60 and 180°/sec were; Peak Torque (PT), Peak Torque/Body Weight (PT/BW), and Average Power (AP).

Results: The EMS+FT group showed statistically significant alterations in all of the parameters ($p < 0.01$ and $p < 0.05$) except in the left wrist AP during flexion and extension at 180°/sec. However, the FT group showed significant changes in only right wrist AP during extension at 60°/sec, and right and left wrist AP during flexion at 180°/sec, and left wrist PT during extension at 180°/sec.

Conclusions: Accordingly, it could be inferred that FT done by using EMS for four weeks improve the isokinetic wrist strength and endurance significantly. Muscular fitness has an essential role in climbing performance, and this study points that EMS trainings on fingerboard could be used to enhance the climbing performance.

Keywords: electrical contraction, isokinetic forearm endurance, isokinetic forearm strength, sport climbing, fingerboard.

Introduction

Electromyostimulation (EMS) has been used for both physical therapy [1] and strength improvements for a few decades [2-4]. The principle of EMS is to gain muscle strength through pulsed, repetitive electrical contractions [5, 6] by recruiting more motor units and muscle fibers which activated with high threshold [7]. Main objectives of using this kind of equipment in sport is reported to shorten the training session, and to specialize in targeted aims for better performance [8]. In recent years, many reviews have examined the effects of voluntary contraction with or without using EMS, and EMS training alone on muscular strength, muscular endurance, power, jumping, balance, speed, and performance not only in sedentary adults also in athletes [4, 5, 8-11]. Some general information from these studies could be summarized that; EMS training enhances both muscle mass and function without any change in body fat [12, 13], using EMS is effective to prevent muscle loss during the rehabilitation phase [5], and more research is needed to determine how effective is only EMS training or EMS training + voluntary contraction for muscle strength development. While in some studies it was found that EMS training

provides equally or even more enhancements in gaining strength [3, 14], others reported voluntary contraction's effectiveness [4, 15]. These articles also show that using EMS could be varied as locally and whole body. While whole body EMS allows stimulating several muscle groups concurrently on a wide electrode area, local EMS interventions activate a single or small number of specific muscles. Another suggestion is that while currents with high frequency are used to gain maximal muscle strength, low frequency currents are used in order to induce muscle endurance [8].

It is suggested that to control the wrist efficiently and optimal use of wrist muscles are critical for both daily activities and sports [16]. Being the most preferred discipline of rock climbing, sport climbing has become very popular both as a competitive and recreational activity [17]. As in all sport branches, special training is needed also in sport climbing. Due to the complex structure of sport climbing [18], athletes and sedentary people who climb recreationally need to improve their grip performance [19]. Both finger flexors' isometric strength and endurance are evaluated as the key factor of bouldering [20] and lead climbing performances [21] in sport climbing [22]. According to [23] climbers spend 36.3 % of the total time statically during climbing. A fingerboard, also known as a hangboard, is one of the sport

specific strength training equipment to advance isometric finger strength in climbing. Some studies observed about 21.5 % increase in finger strength after four weeks of fingerboard training [24]. Finger flexors' isometric contraction is believed as the most used type of muscle activation during climbing [25], and fingerboard trainings (FT) provide climbers isometric training opportunities on several different artificial grips [26].

The aim of the present study is to investigate the influences of four week local EMS training on wrist muscular strength and endurance. To our knowledge, this is the first study comparing the isokinetic strength and endurance responses between EMS+FT and FT alone in sport climbing. In order to achieve this goal, local EMS electrodes were placed on forearm flexors because of the fact that a fingerboard is used only with arms.

Material and Methods

Participants. A total number of 16 physically active, non-climber sport sciences students, who had attended a regular physical activity program for at least six months prior to this research, participated in the study voluntarily. Subjects were randomly divided into fingerboard training group (FT: 4 males and 4 females, the mean age 22.75 ± 1.83 years, body height 173.63 ± 9.84 cm, body weight 59.50 ± 7.75 kg) and EMS+fingerboard training group (EMS+FT: 5 males and 3 females, mean age 22.38 ± 2.45 years, body height 171.00 ± 8.96 cm, body weight 64.75 ± 14.69 kg). Both groups did not take a part in any other exercise program for the four weeks during the study. The exclusion criteria were having any previous or current musculoskeletal injuries in upper body extremities. All subjects were informed about the study risks and benefits, and after familiarization, each participant was given a written informed consent form. This study was performed in accordance with the ethics of World Medical Association (Declaration of Helsinki, code DoH-Oct2013), and was approved by Ankara University Ethical Committee on Human Research (01/13).

Study design. This randomized controlled trial aims to investigate the effects of four-week local EMS training performed on a fingerboard on wrist muscular strength and endurance. To achieve this goal, a total of four EMS electrodes were placed on the flexor digitorum superficialis (FDS) muscle, two on the right and two on the left arm. Both FT and EMS+FT groups completed the same training program about 25 minutes a day, three days per week for four weeks. All fingerboard trainings were performed between 4 and 6 pm on non-consecutive days, and subjects were asked to come to the training as fully rested. Two days earlier and two days after the four-week period of the study, participants attended an isokinetic wrist muscle strength and endurance test.

Procedures. Training process. Participants visited the performance laboratory for the first time for familiarization, and they were informed about the study design. The fingerboard and its biggest jug hold used in the current study were shown. They were taught how to grip the hold and how to endure hanging on at different

angles of elbow. The jug hold allowed participants to wrap it with their index, middle, ring and pinky fingers. While thumb was holding the jug with the distal interphalangeal joint, the other fingers were wrapping it with 90° of proximal interphalangeal joint. Owing to the fact that rock climbing requires feet to release from wall during climbing, all fingerboard trainings were performed with the feet were in the air.

All subjects were also taught about the EMS implementation. The EMS practice was performed with a Bosch TENS+EMS Dual Therapy device (Stuttgart, GERMANY) with a signal width of 260 ms and a frequency of 60 Hz. The EMS device was fixed subject's waist, and its four electrodes were placed on forearms of both right and left upper extremities. Two of the electrodes located on flexor digitorum superficialis muscle of the right arm and other two on the left. Subjects performed another trial with using EMS.

Table 1. The angle of the elbow and hanging and resting times of the training protocol.

| Angle of the elbow | Hanging time (sec) | Resting time (sec) |
|----------------------------|--------------------|--------------------|
| 180° | 15 | 15 |
| 90° | 15 | 15 |
| 45° | 15 | 60 |
| 180° | 20 | 15 |
| 90° | 15 | 15 |
| 45° | 10 | 60 |
| 180° | 25 | 15 |
| 90° | 15 | 15 |
| 45° | 5 | 180 |
| Total time for one circle: | | 8.40 min |

Table 1 shows one circle of the training session. All participants performed one circle of training without EMS and another one by using EMS on their first visit. After finishing familiarization session, participants were randomly divided into fingerboard training group, in which they performed isometric fingerboard training, and EMS+FT group (EMS+FT) in which they practiced the same training with using EMS. The number of the training circle was two for the first two weeks of the study, and it was increased to four for the last two weeks of the study. Each participants had a 10-minute warm-up, and a 5-minute time resting time procedure before every training session. Warm-up procedure contained of 5 min of jogging and 5 min of upper arm stretching exercises.

Isokinetic tests. Participants' isokinetic muscular strength and endurance measurements were tested on isokinetic machine (System 4 PRO model, Biodex Medical Systems, Shirley, NY, USA) on wrist joint during flexion and extension at 60 °/s and 180 °/s angular velocities. For 5 repetitions at 60 °/s angular velocity Peak torque (PT, N.m), peak torque/body weight (PT/BW, %) and average power (AP, W) were collected for muscle strength, and same parameters were also collected for 10 repetitions at

180 °/s for muscle endurance. The resting period between tests was 30 seconds. Before testing, participants were told to warm up at an arm ergometer for four minutes at between 60-80 rpm. In four minutes of resting time after the warming up, the test protocol was started. Pre-tests were taken two days before the study period, and post-tests were recorded in two days right after the study was finished.

Statistical analyses. In the current study, IBM SPSS Statistics (Version 23 for Windows; IBM, Armonk, NY, USA) was used for statistical data analyses. Firstly, the distribution of data was tested by Shapiro Wilk to determine the parametric or nonparametric data analyses. In accordance with the distribution of the data Paired Sample t-Test or Wilcoxon Test was chosen for pre and post-test analyses, and Independent Paired t-Test or Mann-Whitney U Test was used for inter group analyses. Alpha value was set at 0.05 for all of the statistical analyses.

Results

Pre and post-tests of wrist isokinetic strength and endurance measurements both at 60 °/s and 180 °/s are presented in Table 2 and 3 respectively.

Table 2 shows that using EMS while fingerboard training increases the wrist muscle strength significantly. In EMS+FT group, all the PT parameters recorded at 60°/s, developed from 18.77 to 31.57 %. The percentage of the alterations observed in PT/BW was between 18.61 - 33.02 %, and the highest change was seen in right wrist AP parameter for EMS+FT group (81.62 %).

When examining the Table 3, it could be seen that only significant increases observed in the FT group were in the right and left wrist AP parameters during flexion

($p < 0.01$ and $p < 0.05$), and in left wrist extension PT parameter at 180 °/s ($p < 0.01$). However, the EMS+FT group showed statistically significant changes in all of the parameters except in the left wrist AP parameters during flexion and extension at 180 °/s. The alteration rate was from 17.64 to 42.20 % in PT, 20.98 to 41.60 % in PT/BW. Besides, similarly to the result at 60 °/s the highest change observed in right wrist AP parameter (81.46 %).

Another substantial finding of the research was that both groups showed enhancements in all of the strength and endurance parameters, even though these alterations were mainly not significant in the FT group generally.

Discussion

The purpose of the current study was to examine the effects of four-week local EMS training on isokinetic muscle strength and endurance in wrist, and compare it with fingerboard training. It is considered that isometric training might induce more muscle force comparing with dynamic training [27], and isometric strength and endurance are more substantial for climbing [28]. It was reported that climbers' isometric contraction time ratio was 4:1 compared with resting time [29]. However, to transfer the obtained isometric strength and endurance to all types of movements in climbing requires to perform the isokinetic training at different angles of the targeted joint. According to Thompson et al. [30] an isometric training provides strength improvements only in $\pm 15^\circ$ of the selected joint. Some studies about climbing also reported that different elbow or shoulder angles cause unequal strength production in finger flexors [31, 32]. Thus, in the present study, different angles of elbow were chosen to adapt the wrist to be able to generate strength in

Table 2. Isokinetic strength values and their mean differences obtained from pre and post-tests at 60 °/s for both right and left wrists during flexion and extension.

| Parameters | FT group | | | | EMS+FT group | | | |
|---|---------------|---------------|-------|-------|---------------|---------------|--------|-------|
| | Pre-test | Post-test | % | Sig. | Pre-test | Post-test | Sig. | % |
| Right wrist during flexion at 60 °/sec | | | | | | | | |
| PT (N.m) | 36.86 ± 11.23 | 45.11 ± 20.18 | 22.38 | .094 | 39.74 ± 8.31 | 50.30 ± 13.53 | .038* | 26.57 |
| PT/BW (%) | 63.44 ± 18.06 | 75.63 ± 27.40 | 19.22 | .089 | 62.20 ± 10.42 | 76.79 ± 14.27 | .048* | 23.46 |
| AP (W) | 13.75 ± 6.21 | 22.86 ± 12.18 | 66.25 | .123 | 15.78 ± 4.68 | 28.66 ± 14.82 | .012* | 81.62 |
| Left wrist during flexion at 60 °/sec | | | | | | | | |
| PT (N.m) | 40.26 ± 16.27 | 41.83 ± 14.43 | 3.90 | .779 | 38.68 ± 14.99 | 50.89 ± 16.29 | .001** | 31.57 |
| PT/BW (%) | 67.64 ± 18.88 | 69.77 ± 20.59 | 3.15 | .624 | 58.48 ± 15.83 | 77.79 ± 17.14 | .001** | 33.02 |
| AP (W) | 16.93 ± 8.89 | 18.53 ± 9.10 | 9.45 | .236 | 18.08 ± 8.74 | 25.13 ± 8.52 | .018* | 38.99 |
| Right wrist during extension at 60 °/sec | | | | | | | | |
| PT (N.m) | 25.80 ± 13.41 | 28.58 ± 10.08 | 10.76 | .208 | 23.71 ± 7.75 | 29.13 ± 8.90 | .031* | 22.86 |
| PT/BW (%) | 43.35 ± 17.86 | 47.81 ± 12.16 | 10.29 | .197 | 36.13 ± 7.10 | 45.00 ± 9.25 | .024* | 24.55 |
| AP (W) | 12.28 ± 4.90 | 16.21 ± 6.88 | 32.00 | .040* | 12.15 ± 4.23 | 15.89 ± 5.72 | .031* | 30.78 |
| Left wrist during extension at 60 °/sec | | | | | | | | |
| PT (N.m) | 25.74 ± 11.23 | 28.75 ± 9.13 | 11.69 | .194 | 26.48 ± 8.93 | 31.45 ± 11.77 | .005** | 18.77 |
| PT/BW (%) | 43.18 ± 14.23 | 48.39 ± 11.03 | 12.07 | .244 | 40.56 ± 8.90 | 48.11 ± 13.47 | .006** | 18.61 |
| AP (W) | 12.75 ± 6.55 | 14.78 ± 4.26 | 15.92 | .214 | 15.15 ± 6.15 | 18.13 ± 7.53 | .004** | 19.67 |

Note: PT: Peak torque, PT/BW: Peak torque/body weight, AP: Average power. * $p < 0.05$; ** $p < 0.01$

Table 3. Isokinetic endurance values and their mean differences obtained from pre and post-tests at 180 °/s for both right and left wrists during flexion and extension.

| Parameters | FT group | | | | EMS+FT group | | | |
|--|---------------|---------------|-------|--------|--------------|---------------|--------|-------|
| | Pre-test | Post-test | % | Sig. | Pre-test | Post-test | Sig. | % |
| Right wrist during flexion at 180 °/sec | | | | | | | | |
| PT (N.m) | 29.16 ± 10.81 | 36.69 ± 16.88 | 25.82 | .123 | 25.69 ± 5.61 | 36.53 ± 6.43 | .001** | 42.20 |
| PT/BW (%) | 49.90 ± 16.16 | 61.24 ± 21.52 | 22.73 | .223 | 40.38 ± 8.55 | 57.18 ± 5.62 | .001** | 41.60 |
| AP (W) | 12.70 ± 6.56 | 19.89 ± 10.19 | 56.61 | .010** | 12.89 ± 5.13 | 23.39 ± 8.27 | .012* | 81.46 |
| Left wrist during flexion at 180 °/sec | | | | | | | | |
| PT (N.m) | 30.45 ± 16.10 | 34.11 ± 15.08 | 12.02 | .208 | 29.53 ± 9.88 | 34.74 ± 8.60 | .017* | 17.64 |
| PT/BW (%) | 50.74 ± 19.83 | 56.80 ± 18.97 | 11.94 | .230 | 44.88 ± 7.19 | 52.84 ± 8.43 | .039* | 17.74 |
| AP (W) | 13.94 ± 8.30 | 18.94 ± 10.75 | 35.87 | .025* | 18.33 ± 8.42 | 22.23 ± 9.05 | .141 | 21.28 |
| Right wrist during extension at 180 °/sec | | | | | | | | |
| PT (N.m) | 19.75 ± 7.70 | 25.65 ± 17.98 | 29.87 | .123 | 17.43 ± 3.96 | 22.93 ± 4.86 | .003** | 31.55 |
| PT/BW (%) | 33.50 ± 9.18 | 42.06 ± 23.91 | 25.55 | .123 | 26.99 ± 2.38 | 35.69 ± 5.44 | .004** | 32.23 |
| AP (W) | 12.81 ± 4.21 | 16.65 ± 9.28 | 29.98 | .118 | 11.36 ± 3.15 | 16.83 ± 7.01 | .037* | 48.15 |
| Left wrist during extension at 180 °/sec | | | | | | | | |
| PT (N.m) | 18.91 ± 8.06 | 22.31 ± 7.75 | 17.98 | .050* | 19.64 ± 5.09 | 23.79 ± 7.54 | .016* | 21.13 |
| PT/BW (%) | 31.78 ± 9.79 | 37.75 ± 10.28 | 18.79 | .099 | 30.51 ± 5.46 | 36.91 ± 10.12 | .021* | 20.98 |
| AP (W) | 12.03 ± 5.13 | 13.09 ± 2.89 | 8.81 | .263 | 15.36 ± 6.45 | 18.08 ± 8.69 | .173 | 17.71 |

Note: PT: Peak torque, PT/BW: Peak torque/body weight, AP: Average power. * p< 0.05; ** p< 0.01

different angles.

It is well known that when the angle of the climbed surface increases, most of the body weight is moving by small muscle groups in the upper extremities [28]. This change is about 44 % as the climbing surface alters 10° from vertical to overhanging [33]. Since forearm muscles are the main reason of fatigue and lactate concentration [29, 34], and forearm muscle strength has a substantial role during climbing [35], EMS electrodes were placed on forearm finger flexors in the present study. Flexor digitorum superficialis and profundus are considered as the most effective muscles in climbing [28]. The reason of choosing the hold with the biggest grip on the fingerboard was to prevent subjects from injury. The wrist strength is specifically investigated in some studies. Chu E et al. [16] sought the effects of 6 weeks of resistance training on motor control and wrist strength, and found that both motor control abilities and wrist strength improve after six weeks of training. Schweizer et al. [25] investigated the relationship between some strength parameters and climbing performance and reported that the only predictor of the performance in sport climbing was wrist flexion. In the present study EMS+FT group showed from 18.77 to 31.57 % changes on PT, 18.61 - 33.02 % on PT/BW, and 19.67 to 81.62 % on AP parameters during wrist flexion and extension at 60 °/sec. The observed changes in muscular endurance during flexion and extension at 180 °/sec in wrist were from 17.64 to 42.20 on PT, 20.98 to 41.60 on PT/BW, and 17.71 to 81.46 % on average power. Increase in muscular endurance of elite climbers is considered due to improved local vasodilation capacity, reoxygenation during resting and deoxygenation during

isometric contractions in the literature [36]. Besides, a rise in arterial blood pressure is also thought to be a factor to enhance the isometric contraction of hand [37]. The positive changes observed both in strength and endurance values in the current study might be occurred by the same mechanisms.

Neural adaptations that occur with both muscle activation and increased electromyographic activity could be seen mainly after short EMS training periods [9, 38]. In the present study, positive changes to EMS+FT training on isokinetic muscle strength and endurance were seen in four weeks. Besides, along with significant changes observed in EMS+FT group, the FT group also showed statistically significant or insignificant positive alterations. They increased PT between 3.90 - 25.82 %, PT/BW 3.15 - 19.22 %, and AP 9.45 - 66.25 % at 60 °/sec. Enhancements derived from 180 °/sec were between 12.02 - 29.87 % for PT, 11.94 - 25.55 % for PT/BW, and 8.81 - 56.61 % for AP. Similarly to EMS+FT group the highest alterations were observed in average power values. These outcomes are in line with the literature. A research, in which isometric, isotonic, and isokinetic training procedures were compared, showed that most increase in strength was observed after isometric training implementation [39], similar study was performed by Medernach et al. (2015) [26]. Researchers investigated the effects of 4-week fingerboard training with 3 sessions per week in boulderers. Even though their subjects consisted of highly advanced climbers, they found significant changes on grip strength and endurance level in competitive boulderers.

Several studies examined the effects of EMS training on some extremities and body parts other than wrist. For

instance, Herrero et al. [14] compared the effects of four weeks weight+EMS training with weight training alone on knee strength, and found more increase in weight+EMS group than weight training group alone (40.2 % and 31.4 %, respectively). In another study, effects of EMS, plyometric training, EMS+plyometric training were compared on sprint time, jumping ability, and maximal isometric strength values, and researchers found that EMS+plyometric training significantly increases jumping height and sprint performance. Similarly, Maffioletti et al. [9] demonstrated enhancements on knee extensor strength and squat jump performance in basketball players after four weeks of EMS training. Furthermore, EMS (9.1 %), or EMS+plyometric training (16.3 %) provides enhancement on maximal strength [40]. Brocheriet et al. [41] investigated the effects of short-term using of EMS (30 muscle contractions with 4 second duration), and found improvements on isokinetic strength and short skating performance in ice hockey players after three weeks of training. Using EMS on knee extensor, plantar flexor, and gluteus muscles showed significant developments on power and muscle strength in Rugby players after 12 weeks [38]. Silinskas et al. [42] applied EMS on calf muscles and found about 6 % increase in right muscle MVC in healthy men, and about 5 % improvement in 10-m sprint time in trained athletes, only after 10 sessions of training in three weeks. All these studies and many others demonstrated positive influences of using EMS, and the gains observed in strength and some performance parameters are similar to the changes reached in the present study.

The results derived from the current study are significant not only for the performance but also for injury prevention for climbers, due to the fact that the injuries on wrist usually depend on the lack of strength and joint control in wrist [43]. Josephsen et al. [44] found significant relationship with resistance training and decrease in injury in boulderers. Some authors [2] reported that most injuries are observed in hand and fingers in rock climbing [26, 44, 45]. Therefore, improving the muscle strength and endurance on these parts of the body is crucial.

A same or similar study could be performed with any level of rock climbers including advanced or elite athletes. According to Filipovic et al. [8] even the elite level athletes should not change the number of training

sessions to improve their strength by using EMS. Congruently, reported 30 to 40 percent of strength improvement in trained athletes after using EMS. Besides, as climbing involves grips in different directions, future studies could investigate the effects of wrist training at different directions such as flexion-extension, pronation-supination, and ulnar-radial deviation. It is reported that strength improves with direction-based strength and joint training [16]. In the present study, strength training was performed in vertical axis and on a jug hold for the subjects consisted of non-climber individuals. Different grips for advanced or elite climbers could provide them better strength development at different joint angles, or using jug holds with different directions could be helpful with transferring the strength to climbing performance in beginners.

Conclusion

Although the participants were physically active individuals, training on a sport specific plate, such as fingerboard, improved their wrist strength and endurance in the both EMS+FT and FT groups. Apart from this, the EMS+FT group showed significant increases in almost all of the parameters. Accordingly, it could be inferred that fingerboard trainings done with EMS during three days a week for four weeks improve the wrist strength and endurance significantly. Being one of the basic components of rock climbing, muscular fitness has an essential role in climbing performance. This study points that EMS trainings on fingerboard could be used to enhance the climbing performance. Future studies could include measuring the isokinetic strength and endurance of muscle groups not placed with EMS in order to understand whether EMS is effective only in the muscle groups in which it is placed. In order to compare the difference between only climbing training to fingerboard training with EMS, a similar study could be employed with another experimental group who climbs only. Additionally, the more functional information about the effects of EMS could be given using EMS during climbing training.

Conflict of interest

The authors of the article declare that there is no conflict of interest.

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