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Effects of 12 Weeks Concentric and Eccentric Resistance Training on Neuromuscular Adaptation of Quadriceps Muscle

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ABSTRACT

Background: Manipulating resistance training program variables is a commonly used tool for optimizing maximum muscle strength in rehabilitation and/or exercise training programs. The current study purposed to compare the effects of 12 weeks of concentric and eccentric resistance training on neuromuscular adaptation of quadriceps muscle.

Methods: Twenty-six male subjects (age, mean±SD, 22.1±2.4 yr; body mass, 72.3±9.9 kg; height, 1.75±0.08 m) were recruited for this controlled laboratory study. Subjects were randomly divided into two groups: the eccentric training group (No=13) and the concentric training group (No=13). The maximal isometric voluntary contraction (MVIC) of quadriceps muscles, vertical jumping, and surface electromyography (EMG) signals were recorded before and after 12 weeks of resistance concentric and eccentric training. Repeated-measures Analysis of Variance (ANOVA) was used to test differences between means before and after resistance training.

Results: The maximal isometric voluntary contraction of the quadriceps muscle and vertical jumping were significantly increased after eccentric and concentric training ($P<0.05$). Eccentric exercise resulted in a greater increase in maximal isometric voluntary contraction of the quadriceps muscle and vertical jumping compared to concentric training ($P<0.05$). The amplitude of surface EMG signals was also significantly increased after eccentric and concentric training ($P<0.05$), with a greater increase observed in the eccentric than the concentric training group ($P<0.05$).

Conclusion: The results of this study showed higher increases in muscle force output and EMG activity after eccentric training. This may indicate that stretch combined with overloading is the most effective stimulus for enhancing neuromuscular activity during dynamic resistance exercise. The knowledge gained from this study may be relevant for designing exercise and/or rehabilitation training to improve muscle output.

Introduction

Neuromuscular adaptations to exercise training are associated with a significant increase in muscle force [1]. Neuromuscular adaptations may occur at the level of the motor cortex, spinal cord, and/or neuromuscular junction following training [2]. For instance, increased muscle activity recorded by electromyography (EMG) has been observed during the early phase of strength training in association with significant gains in muscle strength [3, 4] but in the absence of changes of muscle mass or changes in membrane characteristics within the skeletal muscle [5]. The neuromuscular adaptions to resistance training are dependent on the type of muscle contractions

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performed and both neuromuscular adaptations and improvement in muscle force vary depending on whether eccentric, concentric, or isometric contractions are executed [6, 7]. Of the three types of muscle contractions that can be utilized during exercise (concentric, isometric, and eccentric), eccentric exercises are those actions in which the muscle lengthens under tension, resulting in muscle fiber damage and an immediate reduction in muscle power and activity [8-10]. Although all forms of exercise may induce impressive muscle adaptation, it is not always clear which method is best for maximizing adaptation. It has been proposed that training using eccentric action can decrease the activation threshold of fast-twitch motor units and increase their initial firing rates [1, 11]. These adaptations in motor-unit behavior are likely to improve power production and the rate of torque development [12], variables that positively affect muscle performance. The current study compared the effects of 12 weeks of concentric and eccentric resistance training on neuromuscular function of the quadriceps muscle.

Methods

Procedure

In this controlled laboratory study, Maximal isometric voluntary contractions of the quadriceps muscle, surface EMG signals, and vertical jumping were recorded before and after eccentric and concentric resistance training. Subjects warmed up on a bicycle ergometer (LC4, Monark Exercise AB, Sweden) for 10 min before recordings were taken (Figure 1).

Subjects

Twenty-six male subjects (age, mean±SD, 22.1±2.4 yr; body mass, 72.3±9.9 kg; height, 1.75±0.08 m) were recruited for this controlled laboratory study. Subjects were randomly divided into two groups: the eccentric training group (No=13) and the concentric training group (No=13). All subjects were right leg dominant and not involved in regular exercise of their knee extensor muscles for at least one year before the experiment. The study was conducted in accordance with the Declaration of Helsinki, approved by the Local Ethics Committee (BOJ 1395070), and written informed consent was obtained from all subjects prior to inclusion.

Training Protocols

The eccentric training group performed an eccentric exercises of their right quadriceps muscles using a weight-training machine (Universal Gym, USA) while in the supine position. The leg press was brought to the starting position (170º - 180º knee extension, 180º=full knee extension) using two assistants, and the subject lowered the load in an eccentric mode to the end position (90º knee flexion) in a controlled maneuver. This allowed the subjects to perform multiple repetitions using eccentric contractions against relatively high loads and delayed the onset of fatigue by eliminating the concentric contraction. The concentric group also performed concentric exercises (starting position of 90º knee flexion to the finish position of 180º knee extension) on a weight-training machine (Universal Gym, USA) in the same position as the eccentric training group. Subjects performed 3 sets of 12 repetitions 3 days per week for 12 weeks (Figure 2).

Workload

The workload was determined for each subject based on his initial one repetition maximum (1-RM) using concentric contraction, and load was defined as 80% of the initial value of 1-RM. One repetition maximum was defined as the heaviest load that can be moved over a specific range of motion, one time, and with correct performance. The dynamic 1-RM was determined by having the subjects perform one repetition at each successive load using a weight-training machine (Universal Gym). The load was increased in 1- to 5-kg increments with a 30-s break between each attempt. Each subject was required to be able to lift his maximum load in a smooth, controlled motion [13].

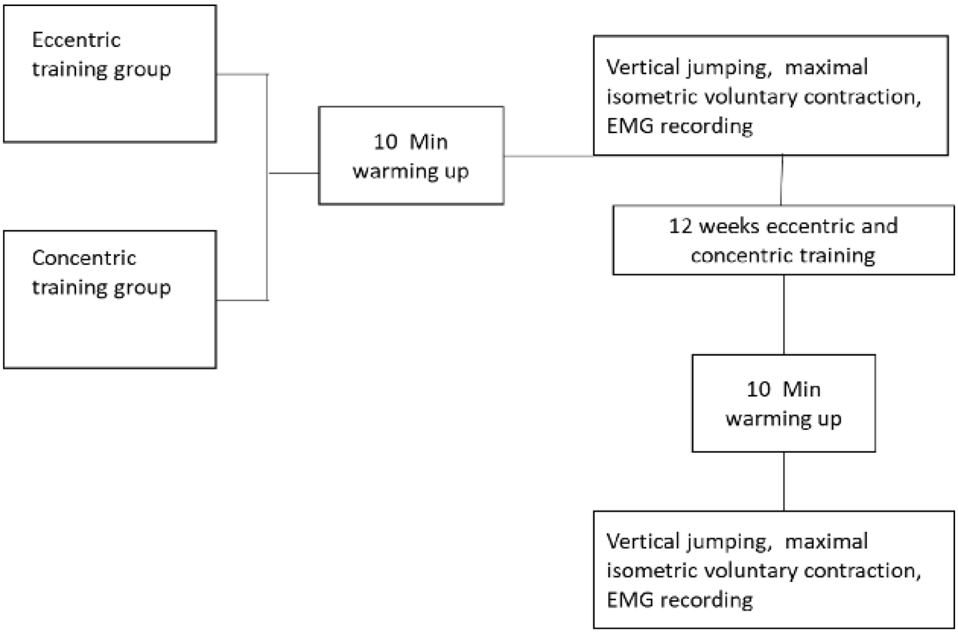

Figure 1: Schematic representation of recording muscle performance and electromyography (EMG) signals before and after eccentric and concentric resistance training

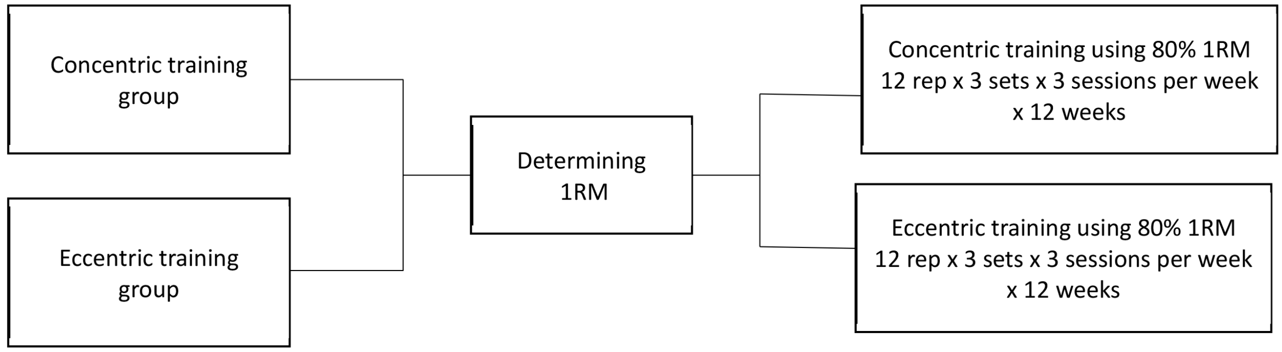

Figure 2: Schematic representation of training protocol

The subjects performed 3 sets of 12 repetitions with 80% of the 1-RM with three minutes of rest between sets. 1-RM was evaluated for each subject every week, and the weights were adjusted accordingly. Because the weights were adjusted every week, the number of repetitions was also adjusted so that the total weight lifted by each subject could be equated. All sessions were supervised individually by a single experimenter.

Maximal Isometric Torque of Knee Extension

A load cell (SIWAREX R, 500 kg, Siemens, Germany) was used to measure maximal isometric quadriceps strength. Each subject sat comfortably on a chair fixed with a belt at the hip and with the right knee in 90º of flexion. A strap, connected by a chain to a load cell, was attached to the ankle to measure knee extension isometric force. A goniometer was used to measure knee angle. The central axis of the goniometer was aligned with the axis of the knee flexed in 90°.

Force was provided to the subjects as visual feedback on an oscilloscope. Each subject performed a total of three 5-second maximal isometric voluntary contractions (MIVC) of knee extension, each separated by a 2-min rest period. During each MIVC, verbal encouragement to exceed the previous force level was provided. The highest MIVC value was considered as the reference value.

Vertical Jumping

Vertical jumping was begun the subject in a flat-footed stance and one arm raised and touching a wall. The subject then jumped as high as possible and touched the wall again; jump height was considered as the vertical distance between touch locations. Each subject performed 3 trials, and the highest value was considered as the reference value.

EMG Recording

Surface EMG signals were recorded from nine locations distributed over the quadriceps muscles by circular Ag–AgCl surface electrodes (Ambu Neuroline, conductive area 28 mm2) during maximal voluntary contractions of the quadriceps muscle [13]. The distances from the anterior superior iliac spine (ASIS) to the medial, superior, and lateral border of the patella, corresponding to the vastus medilais (medial location), rectus femoris (middle location), and vastus lateralis (lateral location), were measured, respectively. Nine pairs of electrodes were placed in a bipolar configuration (2-cm interelectrode distance) at 20%, 30%, and 40% of the measured distance in the longitudinal direction. Before electrode placement, the skin was shaved and lightly abraded in the selected locations. Surface EMG signals were amplified (EMG amplifier, EMG-16, LISiN-OT Bioelettronica, Torino, Italy, bandwidth 10–500 Hz), sampled at 2048 Hz, and stored after 12-bit A/D conversion. A ground electrode was placed around the right ankle.

Signals Analysis

Matlab software (Matlab 2018a, the Mathworks Inc., Natick, MA, USA) was used to analyze EMG signals. The root mean square (RMS) of EMG was estimated for epochs of 250 ms. The values obtained from 250 ms were averaged within the 5-second maximal voluntary isometric contractions. To compare changes across testing sessions, the percentage change between pre-training and post-training values (Percentage change=Post-training value - Pre-training value/Post-training value ×100) was calculated.

Statistical Analysis

One-way repeated-measures ANOVA was applied to analyze changes in maximal voluntary isometric contraction and vertical jumping from pre-training to post-training condition with training group (concentric and eccentric) as a factor. Three-way repeated-measures ANOVA was used to assess the dependency of EMG RMS on muscle (vastus lateralis (VM), rectus femoris (RF) and vastus lateralis (VL): average for three locations in the longitudinal direction), training group (concentric and eccentric), and testing session (pre-training and post-training). Moreover, two-way ANOVA was applied to the percentage change of EMG RMS across MVIC (percentage change from pre-training to post-training), with muscle and training group as factors. Normal distribution and the homogeneity of variance of the data were assessed using Levene's and Shapiro-Wilk tests, respectively. The significance level was set at $P<0.05$ for all statistical procedures.

Results

Maximal isometric quadriceps strength increased significantly for the concentric and eccentric training groups from pre- to post-training conditions ($F=69.6$, $P<0.001$). Similarly, a significant increase in vertical jumping was observed after both concentric and eccentric training ($F=29.6$, $P<0.001$). A significant interaction was also observed between training group and testing session. The percentage increase in maximal isometric quadriceps strength was significantly larger after eccentric training than after concentric training (F=15.7, P<0.002; Figure 3). Similarly, eccentric training resulted in a greater increase in vertical jumping compared to concentric training (F=14.9, P<0.006; Figure 4). EMG RMS measured during maximal isometric quadriceps contraction was significantly increased for both eccentric and concentric groups (F=71.5, P<0.001); however, the EMG RMS rate of increase depended on the interaction between training group and testing session (F=16.4, P<0.002). The percentage increase of EMG RMS was significantly higher in the eccentric group than the concentric group (P<0.05, Figure 5). Moreover, the percentage change in EMG RMS depended on the interaction between muscle and training, and eccentric training resulted in a greater increase in EMG RMS for RF and VM muscle in post-training conditions (F=9.5, P<0.001; Figure 6).

Discussion

The main findings of this study revealed that 12 weeks of eccentric resistance training resulted in a significantly greater increase in quadriceps strength and vertical jumping compared with the concentric training program. Moreover, EMG activity of the quadriceps muscle measured after 12 weeks of eccentric training was significantly greater than that observed after 12 weeks of concentric training. The results indicate that resistance eccentric training is more effective than concentric resistance training in improving muscle force and neuromuscular adaptation.

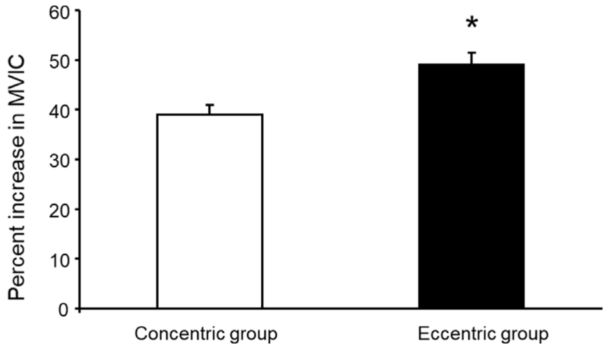

Figure 3: Percentage increase in maximal isometric voluntary contraction (MVIC) of quadriceps muscle (mean±SE, %,) after 12 weeks of concentric (white) and eccentric (black) resistance training. Asterisk (*) indicates that the percentage increase in MVIC was significantly higher for the eccentric group than for the concentric group (P<0.05).

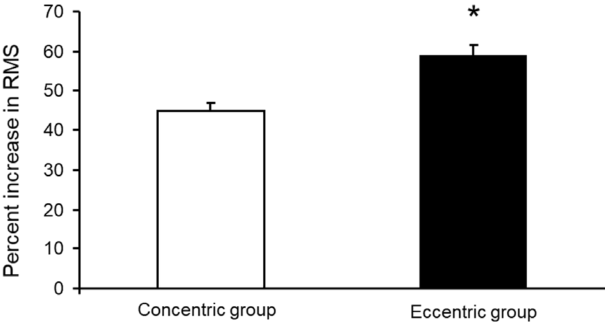

Figure 5: Percentage increase in root mean square of EMG (RMS) (mean±SE, %,) after 12 weeks of concentric (white) and eccentric (black) resistance training. Asterisk (*) indicates that the percentage increase in EMG RMS was significantly higher for the eccentric group than for the concentric group (P<0.05).

Muscle Function

All subjects in both eccentric and concentric training groups were able to perform maximal voluntary isometric contractions and achieve higher force levels compared with pre-training. Moreover, both eccentric and concentric training groups improved their vertical jumping with respect to pre-training conditions. However, the increased maximal isometric force and vertical jumping after 12 weeks of the eccentric training program were significantly higher than those observed after 12 weeks of concentric training. In agreement with these results, previous studies have also shown that both concentric and eccentric resistance training programs contribute to a significant increase in muscle strength and vertical jumping, and eccentric training was more effective than the concentric training in increasing muscle output [14, 15].

Electromyography

The EMG activity of the quadriceps muscle during maximal voluntary isometric contraction performed after 12 weeks of eccentric and concentric resistance training was significantly greater than pre-training conditions. However, the increased EMG activity observed after eccentric training was significantly higher than that seen after concentric training.

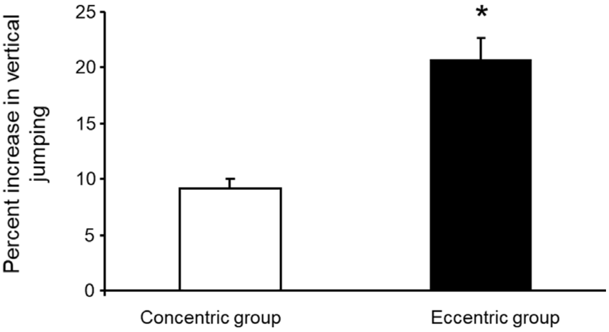

Figure 4: Percentage increase in vertical jumping (mean±SE, %,) after 12 weeks of concentric (white) and eccentric (black) resistance training. Asterisk (*) indicates that the percentage increase in vertical jumping was significantly higher for the eccentric group than the concentric group (P<0.05).

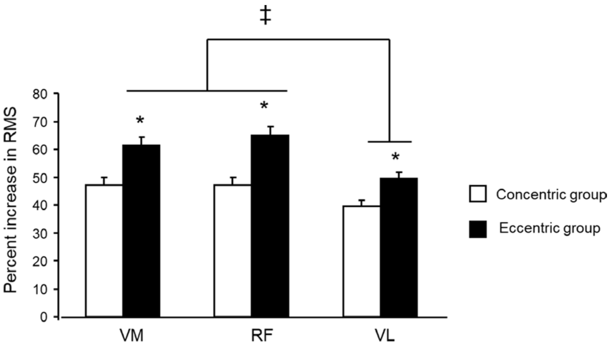

Figure 6: Percentage increase in root mean square of electromyography (EMG) (RMS) (mean±SE, %,) for the vastus medialis (VM), rectus femoris (RF), and vastus lateralis (VL) muscles after 12 weeks of concentric (white) and eccentric (black) resistance training. Asterisk (*) indicates that the percentage increase in EMG RMS of the three muscles was significantly higher for the eccentric group than for the concentric group (P<0.05). Symbol (‡) indicates that the percentage increase in EMG RMS of the VM and RF muscles was significantly higher than that of the VL muscle (P<0.05).

A higher increase in EMG RMS after eccentric training can be attributed to the increased neural drive from higher motor centers to the muscle fibers, which in turn results in a greater motor unit recruitment and/or motor unit discharge rate; variables can effectively increase EMG amplitude [16]. During a muscle contraction, the central nervous system controls the production of increased muscle force by increasing motor unit firing rates and/or the recruitment of additional motor units [16, 17]. The central nervous system employs a different neural strategy to control skeletal muscle during eccentric contractions versus isometric or concentric muscle contraction [1]. This is evidenced, for example, by the preferential recruitment of fast twitch motor units [11]. Fast twitch motor units are characterized by higher firing rates and conduction velocity and is considered to produce higher EMG amplitude [18].

Numerous studies have investigated changes in motor unit firing rates after resistance training and have shown that change in the motor unit firing rate is dependent on the type of muscle contraction. Kamen and Knight [18] found a 15% increase in motor unit firing rates following 6 weeks of dynamic training of the quadriceps muscles. Similarly, Vila-Chã et al. [19] reported a significant increase in firing rates of vasti motor units after six weeks of resistance training. It has been proposed that stretch combined with overloading is the most effective stimulus for enhancing motor unit firing rates during dynamic resistance exercise. For instance, Dartnall et al. [20] showed an ~40% decline in biceps brachii motor unit recruitment thresholds and an 11% increase in minimum motor unit discharge rates immediately after and 24 h after eccentric exercise. Thus, more biceps brachii motor units were active at the same relative force after eccentric exercise. Additionally, it has been shown that cortical activities for movement preparation and execution were greater during eccentric than concentric tasks, most likely due to the concurrent modulation (gating by presynaptic input) of the Ia afferent input from the lengthening muscle to reduce the unwanted stretch reflex and subcellular muscle damage [21]. Thus, the brain probably plans and programs eccentric movements differently than it does concentric muscle tasks [22]. Moreover, neuroimaging studies have shown that cortical activities associated with the processing of feedback signals are larger during eccentric than concentric actions, likely due to the higher degree of movement complexity and/or stretch-related transcortical reflexes to control the stretched muscle [23]. Additionally, eccentric training resulted in a greater EMG activity for the VM and RF muscle as compared to the concentric training group, indicating differing activation levels among synergistic muscles during eccentric compared to concentric contractions [24, 25].

Conclusion

The results of this study showed a higher increase in muscle force output and EMG activity after eccentric training. A higher increase in EMG activity observed after eccentric exercise may indicate that stretching combined with overloading is the most effective stimulus for enhancing neuromuscular activity during dynamic resistance exercise. However, more research is needed to examine the effectiveness of eccentric exercise on neuromuscular adaptation and muscle performance with larger sample sizes and increased statistical power. The knowledge gained from this study may be relevant to the design of exercise and/or rehabilitation training to improve muscle output.

Due to individual differences, it was not possible to control all exercise training parameters (e.g., workload, movement velocity, etc.) over the 12 weeks of the resistance training program. This problem is common to many exercise interventions and may impede precise interpretation of the data. However, the weights and number of repetitions were adjusted every week, so that the total weight lifted by each subject could be equated. Moreover, all training programs and physiological measurements were inspected by a qualified experimenter to avoid variation in measurements and training performance.

Conflict of Interests: None declared.

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