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Research paper

The Effects of Eccentric Versus Concentric Resistance Training on Neuromuscular Fatigue and Strength of Quadriceps Muscle

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Abstract

Background: Eccentric exercise has been commonly used as an intervention to improve muscle strength. However, change in neuromuscular activity over a fatiguing sustained contraction after eccentric training have received less attention The purpose of the present study was to investigate the effects of eccentric versus concentric resistance training on neuromuscular fatigue and strength of quadriceps femoris muscle **Methods:** Twenty-four male subjects recruited for this controlled laboratory study. Subjects were randomly divided into two groups, eccentric training group (No= 12), and concentric training group (No=12). Maximal knee extension force and surface electromyography (EMG) signals were recorded before and after 12-week resistance eccentric and concentric trainings. Muscle fiber conduction velocity (MFCV) and root mean square (RMS) were computed from raw EMG signals. **Results:** Eccentric training contributes to a higher increase in MFCV and RMS of EMG as compared to concentric exercise ($P < 0.05$). Moreover, MFCV rate of reduction over sustained contraction for eccentric group was significantly higher than concentric group ($P < 0.05$). **Conclusion**: A higher reduction in MFCV observed after eccentric training can underestimate the value of this type of training to improve neuromuscular fatigue.

Keywords: Multichannel surface EMG, MFCV, Fatigue

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Introduction

Muscle fiber conduction velocity (MFCV) and root mean square (RMS) of electromyography (EMG) has been commonly used as neuromuscular variables to explain motor control changes within the skeletal muscle. Muscle fiber conduction velocity is the speed at which an action potential propagates along the membrane of a skeletal muscle fiber (Farina et al., 2001). Previous studies have shown that muscle fiber conduction velocity decreased during a sustained contraction (Farina et al., 2001; Hedayatpour et al., 2007, 2009; Nasrabadi et al., 2018), most likely due to the accumulation of metabolites within muscle fibers. An increase in extracellular K+ during a sustained contraction contributes to depolarization of the sarcolemmal membrane (Leppik et al., 2004) which in turn reduce membrane excitability and conduction velocity (Fortune & Lowery, 2009). Moreover, RMS of EMG provides some information about motor unit recruitment, motor unit firing rate and neural drive from central nervous system to muscle fibers (Hedayatpour et al., 2014; Mazani et al., 2018; Pope et al., 2016). However, muscle adaptation to exercise is dependent on the type of muscle contraction (Hedayatpour et al., 2015) and therefore, it is expected that both MFCV and EMG RMS show different behavior to eccentric and concentric training. It has been reported that muscle adaptations observed after eccentric exercise were different from those observed after isometric and concentric exercise (Hedayatpour et al., 2012). During eccentric exercise, a greater tension developed within the skeletal muscle results in muscle fiber damage (McNeil & Khakee, 1992) and muscle soreness (Hedayatpour et al., 2010, 2008), and may contribute to a greater adaptation within the skeletal muscle. Additionally, eccentric contraction is characterized by different neural control of movement as compared with isometric and concentric exercise (Nakazawa et al., 1993), a factor which may further contribute to change in neuromuscular activity within the skeletal muscle. The purpose of this study was to investigate the effects of eccentric versus concentric resistance training on neuromuscular fatigue and strength of quadriceps femoris muscle. It is hypothesized that change in neurounuscualr activity and muscle function after eccentric exercise to be different from the concentric training. The result of this study may help to understand mechanisms underlying motor control changes after eccentric exercise.

Materials and Methods

Participants: Twenty-four male subjects (age, mean ± SD, 21.2 ± 2.5 yr, body mass 73.5 ± 11.9 kg, height 1.77 ± 0.06 m) participated in this study. Participants were randomly assigned to two groups, eccentric training group (No= 12) and concentric training group (No=12). All subjects were inactive and had not been involved in any regular exercise training for at least one year before the experiment.

Resistance Training Protocols

Subjects performed eccentric exercise in supine position on weight-training machine (Universal Gym, USA). The subject lowered the load in an eccentric mode from the initial position (full knee extension = 180 º) to the end position (knee flexion = 90 º) in a controlled manoeuvre. Two assistants helped subject to bring the leg to the initial position (full knee extension = 180 º) to avoid muscle fatigue and /or injury during concentric phase. In the concentric group, the load was lifted from the initial position (knee flexion =90 º) to the end position (full knee extension = 180 º) in a controlled maneuver using the same training machine (Universal Gym, USA) and in the same position as eccentric training group. Each participant performed one repetition maximum (1-RM) using concentric contraction, and workload for exercise training was defined as 80% of the value of 1-RM. The subject in each training group performed 3 sets of 12 repetitions with 80% of the 1-RM with 3 minutes of rest in between. For each participant, 1-RM was measured every week and the weights were adjusted accordingly.

Maximal Voluntary Isometric Contraction (MVIC). Maximal voluntary isometric contraction was measured using a load cell. The subject performed maximal isometric voluntary contraction (MIVC) of quadriceps in 90º of knee flexion by pulling a strap, connected by a chain to a load cell and foot ankle. Visual feedback of force was provided on an oscilloscope (1.5 GHz Bandwidth). Subjects performed three 5-second MVIC of Quadriceps femoris muscle with 2 min rest in between. Subjects were encouraged to generate the greatest force. The highest MIVC among three MVICs was selected as the reference value.

Submaximal sustained contraction: Participants also performed submaximal isometric knee extension contraction at 50% MVC sustained until task failure, with the participant in the same position as in the MVCs. Task failure was defined as a drop in force >5% MVC for more than 5 s after strong verbal encouragement to the subject to maintain the target force value.

Multi-Channel Surface Electromyography (EMG) Recording: Multi-channel surface EMG signals were recorded using an EMG amplifier (EMG-USB2+, OT Bioelettronica, CMMR > 95 dB) (Figure 1). One adhesive arrays (interelectrode distance 5 mm, electrodes 5 mm ×1 mm) was placed on the distal region of the vastus medialis muscle with respect to the muscle fiber orientation and innervation zone. Before placing the electrode array, the shape of the action potentials was visually inspected using a metal liner array. The metal liner array was moved on the muscle to find a good propagation of action potential with respect to the innervation zone. Prior to electrode placement, the skin was shaved and cleaned with alcohol. In order to record a high-quality signal, conductive gel was also inserted into the cavities of the adhesive electrode array. EMG signals were amplified bipolar (bandwidth 10–500 Hz), sampled at 2048 Hz, and stored after 12-bit A/D conversion.

Signal analysis: Muscle fiber conduction velocity was estimated within the epoch of 250 ms from high quality signals showing a good propagation of the action potentials with respect to innervation zone [14]. Accordingly, root mean square (RMS) of EMG were estimated from all channels of the EMG array for epochs of 250 ms and were averaged to obtain one representative value for RMS.

Statistical analysis: One-way analysis of variance (ANOVA) with repeated measure was used to evaluate change in MVIC from pre-exercise to post-exercise condition with training group (eccentric and concentric) as independent factors. Moreover, two-way ANOVA with repeated measure was used to assess change in MFCV and RMS across maximal isometric contraction and submaximal sustained contraction (% change from the pre-training to the post-training), with training group (eccentric and concentric) as independent factors. Student-Newman-Keuls post hoc test with ANOVA was used to make pairwise comparisons among sample means.

Results

Muscle function: A significant increase in maximal isometric quadriceps strength ($F=35$, $P > 0.001$) and time to task failure ($F=15$, $P > 0.003$) was observed after 12- week resistance eccentric and concentric training. The increased MVIC for the eccentric group was significantly greater than the concentric group ($P > 0.05$). Moreover, concentric training resulted in a greater increase in time to task failure with respect to eccentric training ($P > 0.05$, Table 1).

EMG & MVIC: MFCV significantly increased after 12 weeks of resistance eccentric and concentric training ($F=39.8$, $P > 0.0001$). The increased MFCV depended on the interaction between training group (concentric and eccentric) and testing session (pre-exercise and post-exercise). Eccentric training resulted in higher increase in MFCV as compared to concentric group ($F=9.8$, $P > 0.009$). EMG RMS significantly increased after 12-week resistance eccentric and concentric training ($F=28.5$, $P > 0.0001$). An increase in EMG RMS was also depended on the interaction between training group (concentric and eccentric) and testing session (pre-exercise and post-exercise). Eccentric group reflected a greater increase in EMG RMS at post-exercise testing session as compared to concentric training group. (F=7.5, P > 0.019, Table 1).

Figure 1- about her

Variables	**Eccentric training**	**Concentric training**
MVIC (kg)	45 ±4.1% *	32 ±3.5%
Time to task failure (s)	19 ±1.3%	30 ± 2.8%*
EMG ARV (μV)	26 ± 1.8*	16± 1.5
MFCV (m/s)	15.3±1.2 *	8.8± 0.75

Table 1: Percent increase in MVIC, Time to task failure, EMG ARV and MFCV after eccentric and concentric training.* show difference in percent increase between eccentric and concentric training.

EMG & submaximal sustained contraction: Quadriceps femoris muscle showed a greater reduction in conduction velocity over sustained contraction after eccentric training as compared with concentric training over sustained contraction raining (F=3.5, P > 0.05; Figure 3). Moreover, EMG RMS significantly increased during sustained contraction, with a larger increase observed for eccentric training group compared to concentric training group (F=6.5, P > 0.039; Figure4)

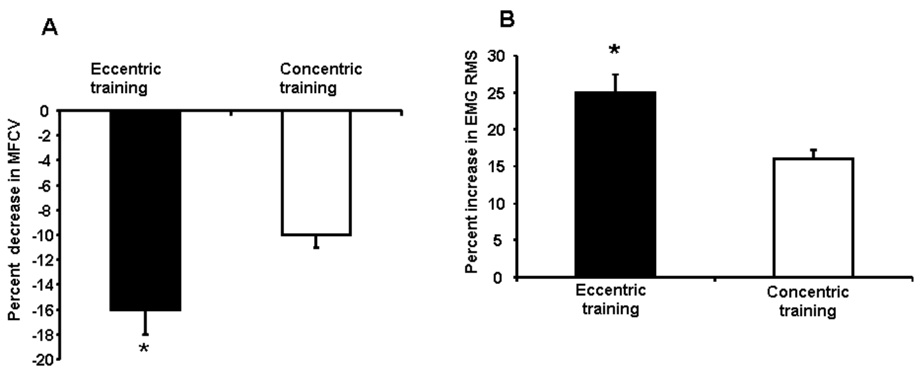

Figure 1: A) percent reduction in MFCV over submaximal sustained contraction (percent reduction from initial epoch to the last epoch in 10-time interval). B) percent increase in EMG RMS over submaximal sustained contraction (percent increase from initial epoch to the last epoch in 10-time interval). * Indicate differences in percent change between eccentric and concentric training.

Discussion

Muscle function & EMG: The results of this study showed that both eccentric and concentric resistance training contribute to a significant change in MFCV and

RMS of EMG. However, percent change in EMG variables observed after eccentric training was significantly higher than concentric training. Moreover, the increased maximal voluntary contraction of quadriceps after 12 weeks of eccentric training was significantly larger than those observed after 12 weeks of concentric training. The findings indicate that resistance eccentric training induces greater neuromuscular adaptation within the quadriceps than concentric training. Accordingly, the results of previous studies also showed a higher increase in muscle strength after eccentric training. Carvalho et al. (2014) demonstrated that strength-training combined with stretching eccentric exercises can improve muscle force. Similarly, previous studies showed that both concentric and eccentric resistance training program contribute to a significant increase in muscle strength of the lower and upper limbs, and eccentric training was more effective than the concentric training to increase muscle strength (Mazani et al., 2018; Rhea et al., 2003; Prestes et al., 2015). Higher MFCV observed after eccentric strength training may be explained by preferential recruitment of fast twitch motor unit. It has been reported that eccentric contraction be associated with the preferential recruitment of fast twitch motor units as compared to isometric and concentric contraction (Moritani et al., 1987). Fast twitch motor unit is characterized by higher recruitment threshold, higher firing rate and is considered to produce higher muscle fiber conduction velocity (Hedayatpour et al., 2007; Senn et al., 1997). Additionally, a larger increase in EMG RMS observed after eccentric training indicated that eccentric exercise contributed to an increase in motor unit recruitment and/or motor unit firing rate within the quadriceps femoris muscle. It has been shown that strength training using eccentric action results in a greater cortical activation (Fang et al., 2001) and as a result, it can enhance neural transmission in the corticospinal pathways and increased excitability of motor neurons (Aagaard et al., 2002).

Neuromuscular fatigue: MFCV is the speed at which an action potential propagates along the membrane of a skeletal muscle fiber and commonly used to explain neuromuscular fatigue (Lindstrom et al., 1970). In this study, we observed a higher reduction in MFCV over sustained contraction for eccentric training group as compared to concentric training. A higher reduction in MFCV could be explained by preferential recruitment of fast twitch muscle fiber. It has been proposed that eccentric training reduce recruitment threshold of fast twitch muscle fiber (Dartnall et al., 2009). Fast twitch fibers are known to produce higher tension (Edström and Kugelberg, 1968) and higher lactate (Essen and Haggmark, 1975) contributing to lower pH (Troup et al., 1986) during both dynamic and static contractions to exhaustion. During sustained fatiguing contractions, local accumulation of metabolites reduces the pH of the extra-cellular environment and increases K+ permeability in the muscle fiber membrane as a consequence of stimulation of the ATP-dependent and/or Ca2+- dependent K+ channels (Castle & Haylett, 1987), which in turn increases the excitation threshold and decreases muscle fiber conduction velocity (Jones, 1981)

Conclusion

A greater improvement in neuromuscular activities and maximal force observed after resistance eccentric training may indicate that eccentric exercise is more effective to improve neuromuscular activity associated with explosive movement. However, a higher neuromuscular fatigue observed after eccentric training can underestimate the value of this type of training to improve neuromuscular fatigue.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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