POSTACTIVATION POTENTIATION COUNTERACTS LOW-FREQUENCY FATIGUE OF QUADRICEPS MUSCLE DURING EXPLOSIVE STRENGTH TRAINING SESSION

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ABSTRACT

Repeated activation of muscle induces processes resulting in decreased performance (fatigue) as well as enhanced performance (postactivation potentiation, (PAP)). This implies that at any time during contraction, fatiguing effects are being countered by potentiation effects, and vise versa. Therefore, which of the processes will be prevalent during and after explosive strength training is not clear.

The purpose of this investigation was to study the acute neuromuscular responses to one explosive strength training session. Eleven healthy untrained men (aged 22—35 years) performed explosive strength training session of six sets (five repetitions each) of the unilateral isometric contractions at an angle of 90 degrees in the knee. The contractility of the muscle was monitored via the electrically evoked contractions at 1, 20, and 50 Hz (P 1, P 20, and P 50, respectively) before (Ini), after the first and sixth sets as well as during the 5 and 30 min recovery period (A 5 and A 30, respectively). Contraction time (CT) and relaxation time (RT) of a single twitch (P1) of quadriceps was registered. Maximal voluntary contraction (MVC) force as well force developed during 100 ms ($MVC_{0-100ms}$) was also determined. The ratio of P 20 / P 50 kinetics after exercise was used for the evaluation of low-frequency fatigue (LFF). There was statistically significant repetition effect observed on MVC ($p = 0.045$) and $MVC_{0-100ms}$ ($p = 0.012$). After the first set there was a significant increase in muscle force induced by very low (1 Hz) and low (20 Hz) stimulation frequencies and did not change during all explosive strength training session ($p < 0.05$). The ratio of P 20 / P 50 recorded after the first set increased significantly ($p < 0.05$), however 30-min after the explosive strength training session it was significantly decrease in P 20 / P50 ratio compared to its Ini level ($p < 0.05$). The present study showed that potentiation increases P 20 / P 50 ratio during the explosive strength training session, however the subsequent (after 30 min of recovery) decline in P 20 / P 50 ratio is an outcome of diminishing influence of potentiation on the background of persistent LFF. Therefore, when muscles are potentiated, it may seem as if no LFF is present.

Keywords: *explosive strength training, low-frequency fatigue, maximum voluntary contraction, post-activation potentiation.*

INTRODUCTION

Fatigue that manifests itself by a reduced force ratio at low and high stimulation frequencies is referred to as low-frequency fatigue (LFF). A selective reduction of force at low stimulation frequencies might be due to a reduction in Ca^{2+} release and a rightward shift of force-frequency relationship (Westerblad et al., 1993; De Ruiter et al., 2005). LFF occurs following many different types of exercise (De Ruiter et al., 2005) and recovery of this phenomenon can take up to 24 hours (Edwards et al., 1977). Although the underlying mechanism for production LFF is unknown, an impaired link between T-tubule and sarcoplasmic reticulum was proposed to be the cause for reduced calcium release (Westerblad et al., 1993; Hill et al., 2001).

In contrast to LFF, postactivation potentiation (PAP) may increase the force and rate of force development of low-frequency tetanic isometric contractions (Vandenboom et al., 1993). The most common explanation for PAP is phosphorylation of myosin regulatory light chains (Houston, Grange, 1990; Sweeney et al., 1993). This mechanism increases the sensitivity of the contractile proteins to activation by the ionized calcium (Ca^{2+}) that is released by the sarcoplasmic reticulum, thereby enhances the force of the twitch and rate of force development and decreases its time to peak force (Sweeney et al., 1993; O'Leary et al., 1997).

PAP also may facilitate the volitional production of force (Sale, 2004; Hodgson et al., 2005). It has been shown that neural facilitation was achieved with the short and strong contractions (Trimble & Harp, 1998). At the spinal level, A. Guillich and D. Schmidtbleicher (1996) attribute the short-term increase in explosive force following a few maximum voluntary contractions (MVCs) to an improved neuromuscular activation. Evidence of this postcontraction neural potentiation is provided by increased H-reflex amplitudes (Guillich, Schmidtbleicher, 1996; Hodgson et al., 2005).

It is clear from the above discussion that repeated activation of muscle induces processes resulting in decreased performance (fatigue) as well as enhanced performance (PAP) (MacIntosh, Rassier, 2002; Hodgson et al., 2005). This implies that at any time during contraction, fatiguing effects are being countered by potentiation effects, and vice versa. It has been shown that maximal repetitive contractions themselves can activate the mechanisms responsible for PAP (Sale, 2004), however, high volume stimuli typically elicit low frequency fatigue (LFF) (Chiu et al., 2004). This type of fatigue occurs within the range where potentiation is believed to enhance force output (Sweeney, Kushmerick, 1985). Therefore, which of the processes PAP or LFF will be prevalent during and after explosive strength training is not clear. The aim of the present study was to examine the manifestation of postactivation potentiation and fatigue of quadriceps muscle during and after explosive strength training session.

METHODS

Subjects. Eleven healthy untrained men (aged 22—35, mass 82.9 ± 6.0 kg) gave their informed consent to participate in this study. The subjects were physically active but did not take part in any formal physical exercise or sport program. Each subject read and signed written informed consent form consistent with the principles outlined in the Declaration of Helsinki.

Explosive strength training session. "Explosive" muscle strength is a term to describe the ability to rapidly develop muscular force (Aagaard et al., 2002). The subjects were seated in a steel framed straight-backed adjustable chair and the right leg was clamped in a force-measuring device with the knee kept at an angle of 90°. The explosive strength training session included six sets of five repetitions of unilateral isometric contractions performed as explosively as possible. The sets were repeated every 5 min, whereas 30 min after the sixth set only three MVC were performed. Each set consisted of five consecutive explosive repetitions of approximately 0.1—0.5-second interval between them. For each repetition the subjects were thoroughly instructed to act "as forcefully and as fast as possible".

Force Measurements. The equipment and technique used for measuring force were the same as used in the previous studies (Ratkevicius et al., 1995; Skurvydas, Zachovajevas, 1998). Briefly, before the explosive strength training session the subjects were seated in a steel framed straight-backed adjustable chair and appropriate adjustments were made to ensure an optimal riding position. A seatbelt attached to the side of the chair passed around the subject's waist and chest to firmly secure the pelvis and upper body for minimizing uncontrolled movements. The right leg was clamped in a force-measuring device with the knee kept at an angle of 90° (full extension 180°) during all experiment. A 6-cm-wide plastic cuff, placed around the right leg just proximal to the malleoli, was tightly attached to a linear variable differential transducer. The output of the transducer, proportional to isometric knee extension force, was amplified and digitized at a sampling rate of 1 kHz by a 12-bit analogue-to-digital converter incorporated in a personal computer. The digitized signal was stored on a hard disk for subsequent analysis. The output from the force transducer was also displayed on a voltmeter in front of the subject.

Maximal voluntary contraction (MVC) force as well MVC developed during 100 ms ($MVC_{0\text{-}100ms}$) was determined.

Electrical Stimulation. A high-voltage stimulator (MG 440, Medicor, Budapest, Hungary) was used to deliver electrical stimuli to the quadriceps muscle through surface electrodes (9 × 18 cm) padded with cotton cloth and soaked in saline solution. One stimulation electrode was placed just above the patella, while another one covered a large portion of the muscle belly in the proximal third of the thigh. The electrical stimulation was always delivered in trains of square wave pulses of 1 ms duration (voltage 150 V, which induces approximately 60—80 percent of MVC). To maximize recruitment of fibres, the highest possible stimulation voltage was employed. The subjects were familiarized with electrical stimulation during the introductory visit before the onset of experiments. We measured the contractile force of the quadriceps muscle, evoked by electrical stimulation at 1 Hz (P 1), 20 Hz (P 20), and 50 Hz (P 50) (the duration of each electrical stimulation series was 1 s). The rest interval between muscle electrical stimulation was 3 s. Contraction time (CT) and relaxation time (RT) of a single twitch (P 1) of quadriceps muscle as well as half relaxation time of the force evoked by 50 Hz (RTP 50) was also registered. The ratio of P 20 / P 50 kinetics after exercise was used for the evaluation of LFF (Edwards et al., 1977).

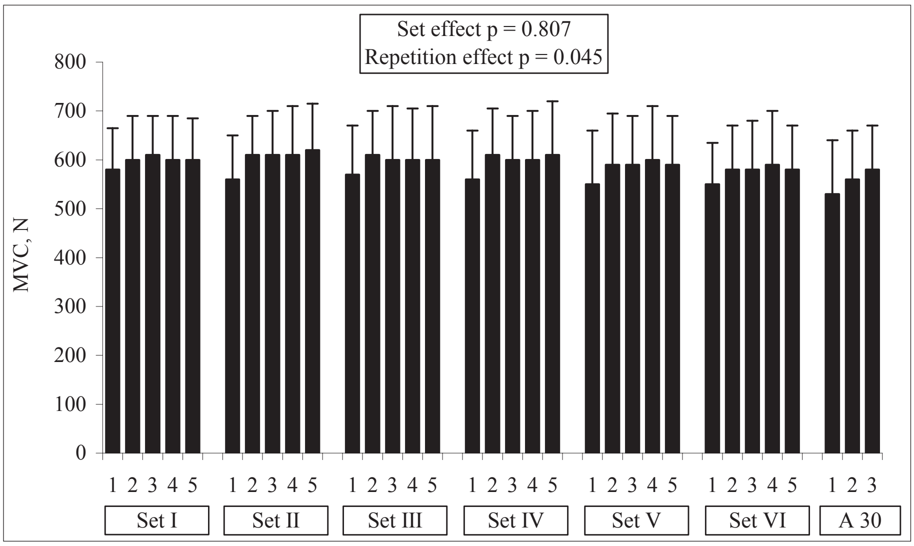
Experimental Protocol. The experiment was designed to study acute neuromuscular responses to one explosive strength training session. The participants performed a warm up of at least 5 minutes that would prepare them for maximal effort. Five minutes afterwards, the subject was seated in the experimental chair and contractility of the muscle was monitored via the electrically evoked contractions at 1, 20, 50 Hz and MVC (MVC was reached twice with 1 min rest in between) at a 90 degrees knee angle. Then the explosive strength training session was performed under the supervision of the authors of this study. Contractility of the quadriceps muscle was studied immediately after the first and the sixth sets, and following 5 and 30 minutes after the explosive strength training session. Following 30 min the period of recovery only three MVC repetitions were performed. Care was taken that the muscle characteristics were recorded within the given time following the explosive strength training session and in the same order prior to the training session.

Statistics. The two-way ANOVA for repeated measurements was used to test the statistical differences within the sets and repetitions. The dependency of changes in muscle contraction force upon the repetitions and sets was evaluated applying the “SPSS” statistical package 2-factor ANOVA method. When the ANOVA was significant, a paired Student’s *t* test was used to determine differences between separate measurements. Statistical significance was set at $p < 0.05$. The values were expressed as the mean ± standard deviation (SD).

RESULTS

There was a statistically significant repetition effect observed on MVC ($p = 0.045$) (Fig. 1) and $MVC_{0\text{-}100ms}$ ($p = 0.012$) (Fig. 2) indicating muscle force and force development velocity enhancements during explosive strength training session. After the first set there was a significant increase in muscle force evoked by very low (1 Hz) and low (20 Hz) stimulation frequencies and it remained during all the training session ($p < 0.05$) (Fig. 3, 5). Five minutes after the end of the training session peak torque at 1 Hz (Fig. 3) and 20 Hz (Fig. 5) returned to its Ini mean level. After the first set of explosive strength training session there was a significant decrease in contraction time (CT) of a single twitch (P 1) of quadriceps muscle and it did not change during all the training session and following 5 and 30 minutes of recovery ($p < 0.05$) (Fig. 4). No changes in relaxation time (RT) of a single twitch (P 1)

Figure 1. **Changes in maximal voluntary contraction force (MVC) during the explosive strength training session**



Note. 6 sets (5 explosive repetitions each) of consecutive MVCs of the quadriceps muscle which were repeated every 5 min. After 30 min of recovery (A 30) only 3 repetitions were performed. The values are means ± SD for 11 subjects.

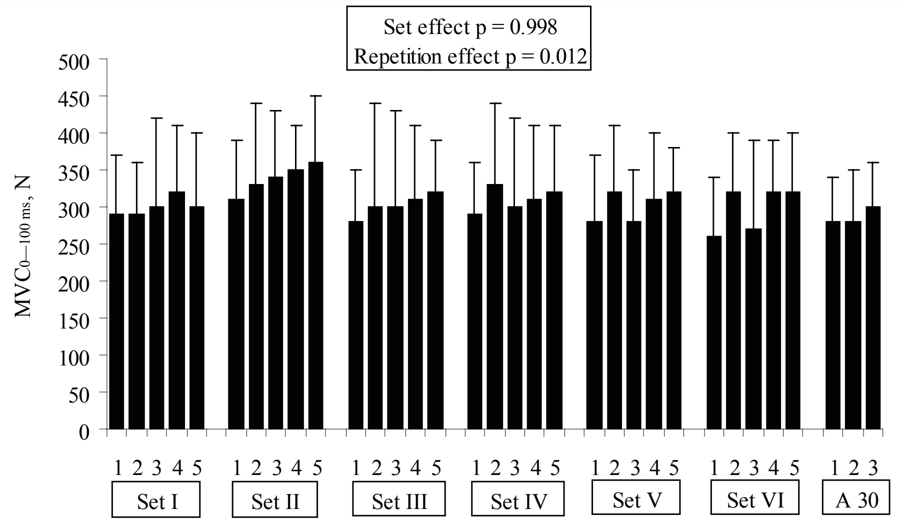


Figure 2. **Changes in maximal voluntary contraction force developed during 100 ms ($MVC_{0\text{-}100ms}$) during the explosive strength training session**

Note. 6 sets (5 explosive repetitions each) of consecutive MVCs of the quadriceps muscle which were repeated every 5 min. After 30 min of recovery (A 30) only 3 repetitions were performed. Values are means ± SD for 11 subjects.

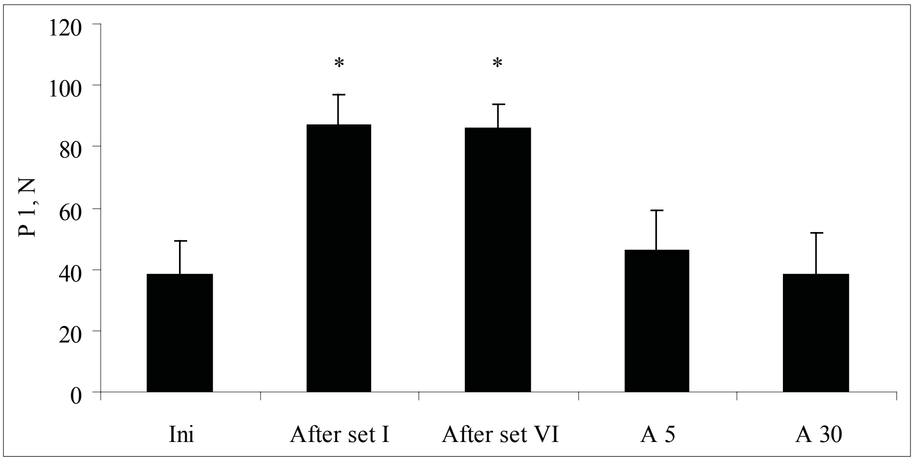


Figure 3. **Contraction force of a single twitch (P1) of quadriceps muscle before the experiment (Ini), and after first (set 1) and sixth (set VI) sets, and following 5 and 30 minutes of recovery (A 5 and A 30, respectively)**

Note. Values are means ± SD; * — significance ($p < 0.05$) compared to the initial mean level (n = 11).

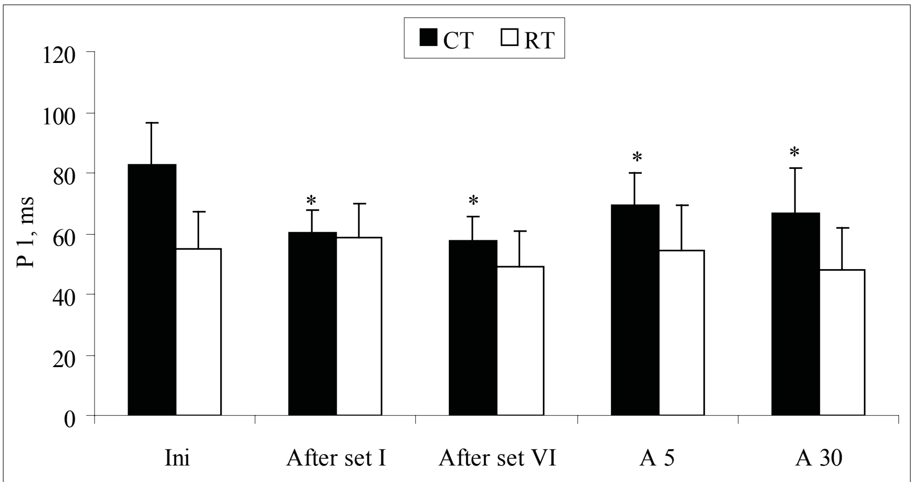


Figure 4. **Contraction time (CT) and relaxation time (RT) of a single twitch (P1) of quadriceps muscle before the experiment (Ini), and after first (set 1) and sixth (set VI) sets and following 5 and 30 minutes of recovery (A 5 and A 30, respectively)**

Note. Values are means ± SD; * — significance ($p < 0.05$) compared to the initial mean level (n = 11).

of quadriceps muscle during all explosive strength training session and following 5 and 30 minutes of recovery were noticed ($p > 0.05$) (Fig. 4).

The values of P 20 / P50 ratio are shown in Fig. 6. The ratio of P 20 / P 50 recorded after the first set increased significantly ($p < 0.05$). After the first and the sixth sets as well as 5 min following training session P 20 / P 50 ratio returned to its Ini mean level, however 30-min after the training session it decreased significantly ($p < 0.05$) (Fig. 6.).

DISCUSSION

We studied the acute neuromuscular responses during and after one explosive strength training session through voluntary and electrically evoked contractions. The presented increase in MVC and

Figure 5. **Contraction force evoked by 20 Hz stimulation frequencies (P 20) of quadriceps muscle before the experiment (Ini), and after first (set 1) and sixth (set VI) sets, and following 5 and 30 minutes of recovery (A 5 and A 30, respectively)**

Note. The values are means ± SD; * — significance ($p < 0.05$) compared to the initial mean level ($n = 11$).

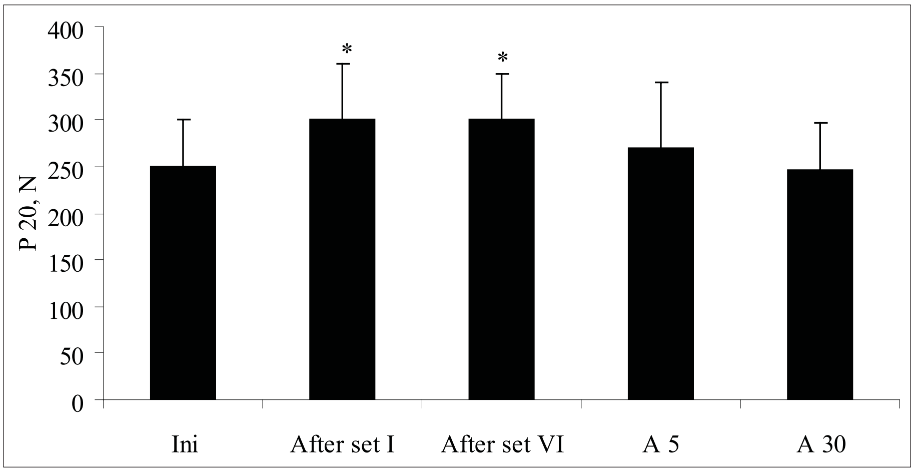
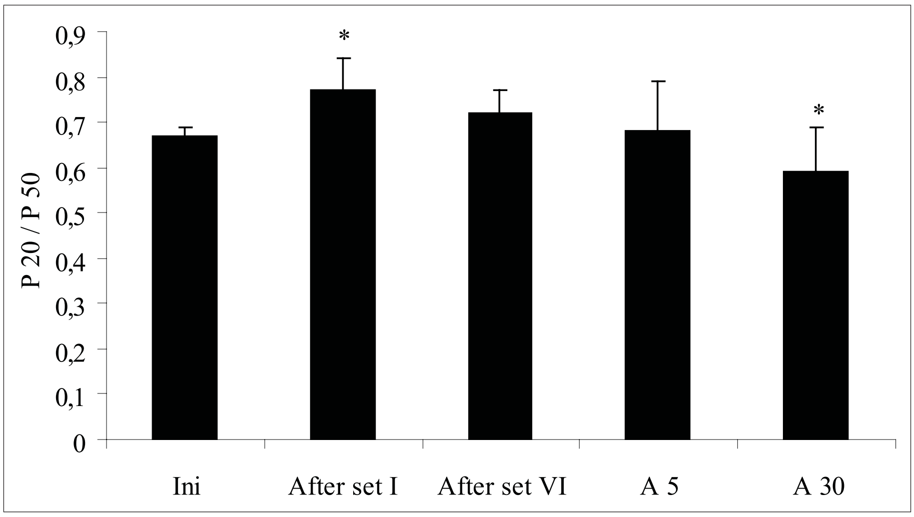


Figure 6. **The torque ratio P 20 / P 50 of quadriceps muscle before the experiment (Ini), and after first (set 1) and sixth (set VI) sets, and following 5 and 30 minutes of recovery (A 5 and A 30, respectively)**

Note. Values are means ± SD; * — significant ($p < 0.05$) compared to the initial mean level, ($n = 11$).



$MVC_{0\text{-}100ms}$ during the training session showed, that potentiation was effective in fast "ballistic" performance. It was also observed that potentiation counteracted LFF, therefore signs of fatigue during and after explosive strength training session were not observed while potentiation was present.

Enhancement of MVC during the explosive strength training session can be attributed to neural potentiation. Trimble and Harp (1998) indicated, that maximal neural facilitation can be achieved with short and strong contractions. At the spinal level, A. Guillich and D. Schmidtbleicher (1996) attributed the short-term increase in explosive force following a few MVCs to an improved neuromuscular activation. Evidence of this postcontraction neural potentiation is provided by increased H-reflex amplitudes (Guillich, Schmidtbleicher, 1996; Hodgson et al., 2005) which may persist for 10 minutes following the contractions (Trimble, Harp, 1998). An additional consideration is that, when the performance is a series of contractions, the contractions themselves have a cumulative effect in mobilizing the PAP mechanisms (Gossen, Sale, 2000).

With the exercise protocol employed in this study, potentiation was clearly indicated in P 1 (Fig. 3) and P 20 (Fig. 5) observed after the first and the sixth explosive strength training sessions. Twitch potentiation is attributed to regulatory light chain phosphorylation (Houston, Grange, 1990; Sweeney et al., 1993), which increases the number of force producing cross-bridges under conditions of suboptimal Ca^{2+} activation (Sweeney et al., 1993). Likewise P 20 potentiation occurs because myosin light-chain phosphorylation is thought to alter the sensitivity to Ca^{2+} (MacIntosh, Willis, 2000). Potentiation also involves an increase in the rate constant of cross-bridge attachment (Metzger et al., 1989), thus the overall increase in $MVC_{0\text{-}100ms}$ (Fig. 2) as well as a significantly shorter CT of P 1 during 30 minutes of recovery can be explained (Fig. 4).

We provided 5 min rest periods between sets to dissociate PAP from metabolic fatigue. Metabolism usually recovers within several minutes post-exercise, with a parallel regain of muscle force and relaxation rate (Bogdanis et al., 1995). Typically, recovery or rest periods between sets of repetitions are between 30 seconds and 3 minutes (Fleck, Kraemer, 2003). A 5-minute recovery period between sets was sufficient to fully restore creatine phosphate, as nearly full restoration has been reported to occur in approximately 4 minutes (Casey et al., 1996). Consequently signs of fatigue during and immediately after the explosive strength training session were not observed possibly due to short duration of action time and long time period between sets.

In this study potentiation probably increased P 20 / P 50 ratio after the first set of the explosive strength training (Fig. 6) by increasing Ca^{2+} sensitivity, which would counteract the effects of the reduced Ca^{2+} release, which causes LFF. Therefore, when muscles are potentiated, it may seem as if no LFF is present. The subsequent decline (after 30 min of recovery) in P 20 / P 50 ratio was an outcome of diminishing influence of potentiation on the background of persistent LFF. LFF was most likely caused by a decrease of sarcoplasmic reticulum Ca^{2+} release (Westerblad et al., 1993; Hill et al., 2001), which may be related to an impaired coupling between the dihydropyridine receptors and the ryanodine receptors in the muscle fibres (Allen et al., 1992). It has been shown (De Ruiter et al., 2005) that LFF may have large effects on *in vivo* performance and important consequences for muscle control.

Chiu with co-authors (2004) sectioned the rise phase of the force-time curve into various components. They found that a high intensity exercise acutely impaired the ability to rapidly produce force from 0—25% of maximum but not from 50—100% of maximum. It was concluded, that an impairment of calcium release because of LFF is a mechanism that may have resulted in the decreased initial rate of force development and this decrease may in part be responsible for the decrease in peak force (Chiu et al., 2004).

Summing-up, the present study showed that potentiation probably decreases LFF during and after explosive strength session by increasing Ca^{2+} sensitivity, which would counteract the effects of the reduced Ca^{2+} release. Therefore, when muscles are potentiated, it may seem as if no LFF is present. The characterization of potentiation and fatigue effects following a training session are important for prescribing subsequent training bouts for optimal adaptations (Chiu et al., 2004).

CONCLUSION

The present study showed that postactivation potentiation increases P 20 / P 50 ratio during the explosive strength training session, however the subsequent (after 30 min of recovery) decline in P 20 / P 50 ratio is an outcome of diminishing influence of potentiation on the background of persistent LFF. This is critical to consider for athletes who perform two or more training sessions per day.

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POSTAKTYVACINĖ POTENCIACIJA NEAUTRALIZUOJA MAŽŲ DAŽNIŲ NUOVARGĮ STAIGIOSIOS JĖGOS TRENIRUOTĖS METU

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SANTRAUKA

Raumenų susitraukimo metu konkuruoja du mechanizmai — slopinantys (nuovargis) ir aktyvinantys (postaktyvacinė potenciacija (PAP)) raumenų funkciją. Nėra aišku, kuris iš šių procesų vyrauja staigiosios jėgos ugdymo metu. Tyrimo tikslas — nustatyti keturgalvio šlaunies raumens susitraukimo savybių kaitą staigiosios jėgos treniruotės metu.

Buvo tiriami 22—35 metų sveiki aktyviai nesportuojantys vyrai (n = 11). Tiriamieji atliko šešias serijas po penkis izometrinius raumenų susitraukimus, kai kampas per kelio sąnarį 90 laipsnių. Prieš treniruotę (Ini) po pirmos ir šeštos serijos, bei praėjus 5 ir 10 min po treniruotės buvo registruojama keturgalvio šlaunies raumens susitraukimo jėga, sukelta 1 Hz (P 1), 20 Hz (P 20) ir 50 Hz (P 50) stimuliavimo dažniu, raumens susitraukimo (CT) bei atsipalaidavimo iki pusės jėgos P 1 (RT) trukmė, maksimalioji valinga keturgalvio šlaunies raumens susitraukimo jėga (MVJ) ir jėga, išugdyta per pirmąsias 100 ms ($MVJ_{0\text{-}100ms}$).

Gauti rezultatai parodė, kad MVJ (pagal SPSS: kartojimų efektas — p = 0,045; serijų efektas — p = 0,807) ir $MVC_{0\text{-}100ms}$ (kartojimų efektas — p = 0,012; serijų efektas — p = 0,998) atliekant krūvį statistiškai patikimai padidėjo. Labai mažų (1 Hz) ir mažų (20 Hz) stimuliavimo dažnių sukelta jėga statistiškai patikimai padidėjo po pirmos serijos ir išliko padidėjusi visos treniruotės metu ($p < 0,05$). P 20 / P 50 santykis reikšmingai padidėjo po pirmos serijos, po šeštos serijos ir praėjus 5 min po treniruotės nesiskyrė nuo pradinės reikšmės, tačiau praėjus 30 min po treniruotės sumažėjo ($p < 0,05$). Tyrimo rezultatai parodė, kad PAP padidina P 20 / P 50 santykį staigiosios jėgos treniruotės metu. Tačiau atsigavimo metu aktyvinančių veiksnių įtaka raumenų funkcijai mažėja, o slopinančių didėja, todėl praėjus 30 min po krūvio išryškėja MDN. Taigi galima klaidingai manyti, kad esant raumenų PAP raumenų MDN nepasireiškia.

Raktažodžiai: staigiosios jėgos treniruotė, mažų dažnių nuovargis, maksimalioji valinga jėga, postaktyvacinė potenciacija.

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