

# Concurrent EMG feedback acutely improves strength and muscle activation

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**Abstract** The purpose of this study was to investigate the acute effects of electromyographic (EMG) feedback on muscle activation and strength during maximal voluntary concentric and eccentric muscle actions. 15 females performed two sets of three lengthening and three shortening maximal voluntary isokinetic knee extensions at  $20^\circ \text{ s}^{-1}$  over  $60^\circ$  range of motion. After the first set, subjects were randomized to either a control group ( $n = 8$ ) or a feedback group ( $n = 7$ ). In the second set, the control group performed tasks identical to those in the first set, whereas the feedback group additionally received concurrent visual feedback of the EMG rms from Vastus Medialis (VM). Knee extensor strength and EMG activation of VM, Vastus lateralis (VL) and hamstrings (HAM) were measured during the MVCs. Analyses were performed separately in a 1 s preactivation phase, a 1 s initial movement phase and a 1 s late movement phase. EMG feedback was associated with significantly higher knee extensor strength in all phases (20.5%  $p < 0.05$ , 18.2%  $p < 0.001$  and 19%  $p < 0.001$ , respectively) for the eccentric MVCs and in the preactivation phase (16.3%,  $p < 0.001$ ) and initial movement

phases (7.2%,  $p < 0.05$ ) for concentric MVCs. EMG feedback from VM further improved activation in VM and HAM but not VL. These findings suggested that concurrent visual EMG feedback from VM could acutely enhance muscle strength and activation. Before recommending implementation of EMG feedback in resistance training paradigms, the feedback parameters needs to be optimized and its long-term effects needs to be scrutinized.

**Keywords** Myofeedback · Eccentric · Concentric · Strength training · Activation · Biofeedback

## Introduction

In some muscle groups, such as the plantar flexors and knee extensors, strength is limited by a non-optimal neural activation despite maximal effort (Behm et al. 2002). This deficit is especially evident for eccentric muscle actions (Westing et al. 1990, 1991).

Strength training has been shown to improve neural activation of muscles in maximal voluntary contractions (MVC) (Aagaard et al. 2000, 2002; Duclay et al. 2008; Ekblom 2010). Neural improvements are usually seen early on in the MVC, typically with an improved rate of force development, possibly since increases in net excitation of the motor units induce increased frequencies of motor unit firing, increased synchronization and prevalence of doublet firing of motor units (Andersen et al. 2010; Gabriel et al. 2006; Oliveira et al. 2010). Although, an understanding of the mechanisms of improvements in neural activation with strength training is beginning to emerge, few attempts have been made to design training interventions that focus on improving the ability to achieve high voluntary activation of muscles during MVC.

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A recent review of 20 articles trying to acutely improve vastus medialis (VM) activation showed discouraging results with no effects of altering lower limb orientation or adding a co-contraction (Smith et al. 2009). One potential means by which muscle activation of the quadriceps (parts or the whole muscle) could be acutely improved is using feedback of electromyographic activation (EMG). This method was not included in the review by Smith et al. (2009). EMG feedback has been used in many studies for relearning sub-maximal muscle activation patterns after musculoskeletal injuries. It has been shown to be effective in improving strength after meniscectomy (Kirnap et al. 2005) and activation of VM in sub-maximal tasks (Ng et al. 2008), but seems to have no additive effects in osteoarthritis (Yilmaz et al. 2010). Studies on the effects on EMG feedback on strength and activation in healthy individuals without painful conditions are not commonly reported. However, the studies by Lucca and Recchiuti (1983) and Croce (1986) approached this issue. Lucca and Recchiuti (1983) found that isometric strength training with EMG feedback was more efficient for improving muscle strength and muscle activation as measured by EMG. The validity of the EMG method has, however, been questioned when used in training studies to compare muscle activation levels over separate days (Stock et al. 2010). Moreover, in the study by Luca and Recchiuti, no strength improvements were achieved in the control group that trained without feedback, questioning the validity of the study design. The study by Croce (1986) also showed promising results of dynamic training with EMG feedback, but the training was only evaluated with EMG over separate days. Further, the action types were not specified.

Generally, eccentric training is associated with higher forces (Westing et al. 1991) and larger strength improvements (Hortobágyi et al. 1996) than isometric or concentric training. The importance of high muscle tension for stimulation of muscle growth was elegantly demonstrated by Eliasson et al. (2006) who found that one single session of maximal voluntary eccentric knee extensor training was more effective than a similar concentric session at stimulating protein synthesis. Since, as mentioned above, voluntary activation is often low in maximal voluntary eccentric muscle actions, an intervention that could acutely increase voluntary activation in the eccentric actions might also prove helpful in improving the effects from strength training, since it will increase the training intensity (force).

The aim of the current study was to investigate the acute effects of concurrent visual feedback of VM EMG activity on muscle activation and knee extensor strength in maximal voluntary lengthening (eccentric) and shortening (concentric) knee extensions.

The main hypothesis was that feedback from VM would induce increased knee extensor strength and enhanced

activation of both VM and Vastus Lateralis (VL), but not hamstrings (HAM).

We further hypothesized that the acute feedback-related improvements in strength and activation of knee extensors would be larger in eccentric muscle actions as compared to concentric muscle actions and larger in the earlier phases of the MVC than the late.

## Methods

### Subjects

15 female recreationally active healthy subjects without previous experience of regular strength training ( $23.4 \pm 5.9$  years,  $1.69 \pm 0.03$  m,  $64.4 \pm 8.1$  kg) volunteered to participate in the study. All procedures were approved by the regional ethics board in Stockholm and the study was conducted according to the declaration of Helsinki.

### Procedures

After a 10 min warm-up on a cycle ergometer, subjects performed three isometric knee-flexion MVCs. After that, 10 sub-maximal concentric and eccentric knee extensions of increasing intensity (20 to 90% of 1RM) were performed for the subjects to get used to the test equipment. Subsequently, two sets of maximal voluntary concentric and eccentric knee extensions were completed. In each set, three MVC trials at  $20^\circ \text{ s}^{-1}$  over  $60^\circ$  range of motion were performed for each action type. MVC trials were separated by 45 s, action types by 5 min and sets by 5 min of rest. Subjects were not verbally encouraged during the MVC trials but instructed before each trial to do their absolute best in every single trial. After the first set, subjects were randomized to either a control group ( $n = 8$ ,  $25.1 \pm 7.8$  years,  $1.70 \pm 0.02$  m,  $64.1 \pm 10.3$  kg) or a feedback group ( $n = 7$ ,  $21.4 \pm 1.1$  years,  $64.7 \pm 5.4$  kg). The age, length and mass of the two groups were not significantly different ( $p = 0.89$ ,  $p = 0.14$  and  $p = 0.22$ , respectively). In the second set, subjects in the control group performed tasks identical to those in the first set, whereas the feedback group performed the same tests as in the first set but this time with concurrent feedback of the EMGrms from VM allowing them to continuously compare the activation of VM in the ongoing MVC trial with that of the prior. Before the second test, subjects in the intervention group performed ten trials (five concentric and five eccentric) at increasing intensity in order to get familiarized to the feedback system. Subject in the control group also performed ten trials at the same increments, but without feedback.

## Strength measurements

The subjects were seated in an isokinetic dynamometer (Isomed 2000<sup>®</sup>, D&R, Hemau, Germany) with 90° hip flexion, with a seat belt securing the horizontal position of the pelvis and the shoulders tightly strapped to the back rest. The right knee joint was aligned with the center of rotation of the torque motor and the dynamometer lever arm was secured to the lower leg using a Velcro strap. Torque signals were analog to digital converted at 5 kHz using CED 1401 data acquisition system and Signal software (Cambridge Electronic Design, Cambridge, UK). Knee extensor strength was measured in three different phases, the first being the 1-s period prior to the onset of dynamometer movement (preactivation phase), the second being in the 1-s period prior to passing the mid position, (initial phase) and the third phase being in the 1-s-period directly after passing the mid position (late phase). Knee extensor torque was calculated as the mean of the three trials for each phase, action type and set.

## EMG measurements

EMG was recorded from VM, VL and HAM, using pairs of surface electrodes (Ag–AgCl, Blue M-00-A, electrode sensor area 13.2 mm<sup>2</sup>, Ambu, Ølstykke, Denmark). After shaving and cleaning with alcohol, pairs of surface electrodes were placed over the muscle bellies of the VM and the VL aligned with the fiber directions. A pair of electrodes was also placed centrally over the bulk of the HAM (likely recording a mixture of Biceps Femoris and Semimembranosus activation). Signals were low pass filtered at 650 Hz amplified 2 times, and analog to digital converted at 1.5 kHz with a wireless EMG system (TeleMyo 2400 G2, Noraxon, Scottsdale, U.S.A.). Signals were then sampled together with the torque using a Power 1401 and Signal Software (Cambridge Electronic Design, Cambridge, UK). The root mean square for each muscle was measured in the same three phases as the strength (preactivation, initial phase, late phase). As for the strength, EMG root mean square was calculated as the mean of the three trials for each phase, action type and set.

## EMG feedback

The raw EMG of the VM was sent to a root mean square integrator (Neurolog 705, Digitimer, Hertfordshire, UK) before being presented to the subjects. In the first trial with feedback, the subjects could see their ongoing activation together with a horizontal line indicating the highest VM activation achieved in the first set in any of the trials and in any of the phases. In the 2nd and 3rd trials the ongoing trial was overlaying the previous, so that they were able to

instantly compare their ongoing VM to that of the previous (Fig. 1.)

## Statistics

Shapiro Wilks *W* test was used to check data for normality and since data were found to be normally distributed, repeated measures ANOVAs were used for knee extensor strength, VL EMGrms, VM EMGrms and HAM EMGrms with the dependent factors *time* (1st or 2nd set), *action type* (concentric or eccentric) and *phase* (preactivation, initial phase or late phase) and the independent factor *group* (feedback group or control group). Where an interaction was found between group, time and action type of phase, post hoc analyses were performed using Fischer LSD test. All statistical analyses were performed using Statistica (StatSoft, Tulsa, USA). The results are presented as means  $\pm$  standard deviations (SD) and a difference of  $p < 0.05$  was considered as statistically significant.

## Results

### Effects of EMG feedback on strength

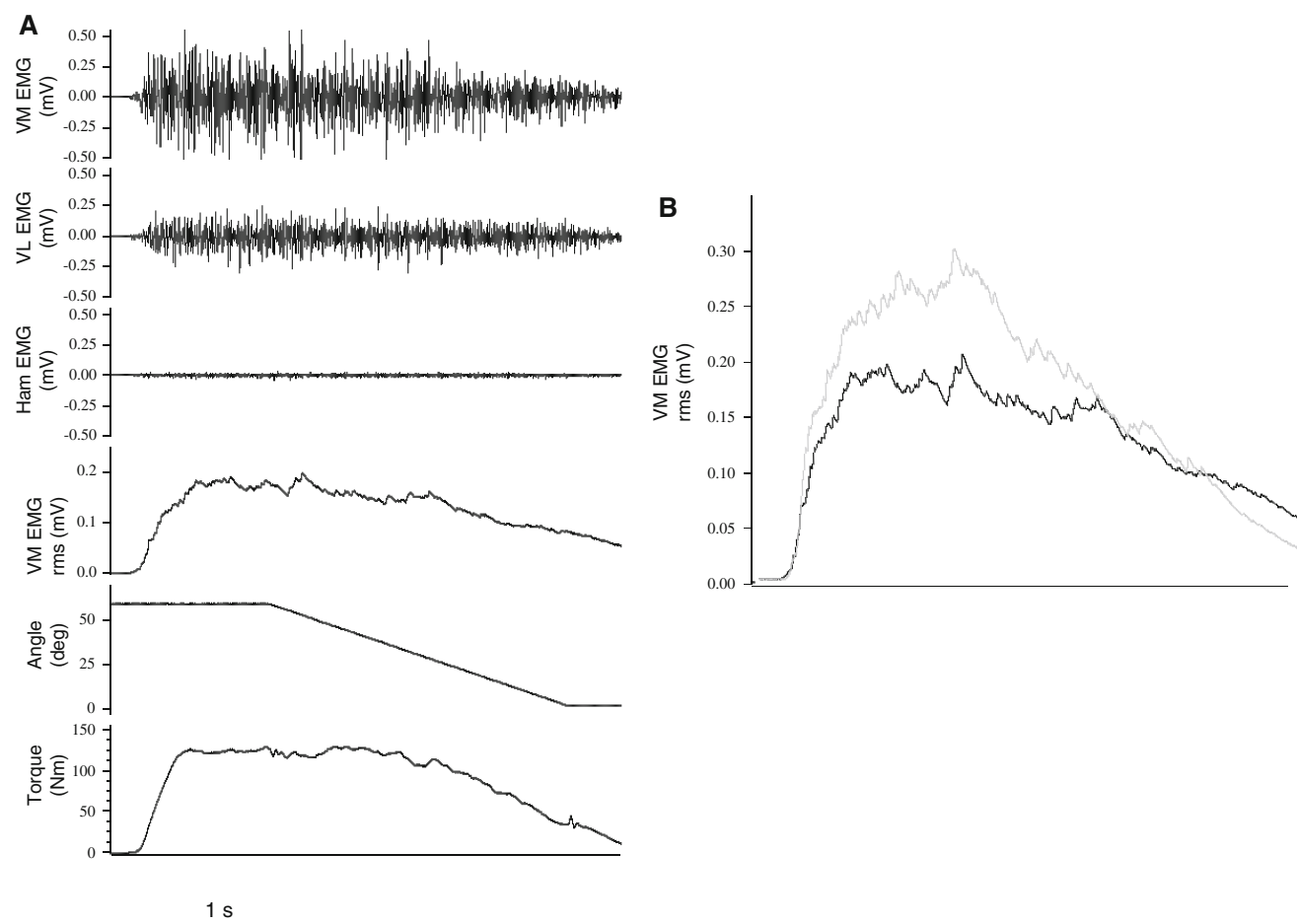
The effect of EMG feedback on strength depended on action type and phase ( $F_{2,26} = 17.5$ ,  $p < 0.001$ ). For concentric MVCs, EMG feedback was associated with significantly higher knee extensor strength in the preactivation phase (by 16.3%,  $p < 0.001$ ) and the initial movement phase (by 7.2%,  $p < 0.05$ ), but not in the late phase (Fig. 2a). For the eccentric MVCs, EMG feedback was associated with significantly higher knee extensor strength in all phases (by 20.5%  $p < 0.05$ , 18.2%,  $p < 0.001$  and 19.0%,  $p < 0.001$ , respectively)(Fig. 2b).

For the control group, the 2nd set was associated with significantly lower strength in the preactivation (by 6.0%,  $p < 0.05$ ) and initial phases (by 5.5%,  $p < 0.05$ ) for the concentric MVCs but remained unchanged in the late concentric phase (Fig. 2c) and all of the eccentric phases (Fig. 2d).

### Effects of EMG feedback on EMGrms

The effect of EMG feedback on VM EMGrms depended on phase ( $F_{2,26} = 4.99$ ,  $p < 0.05$ ). In the preactivation and initial phases, EMG feedback was associated with significantly higher VM EMGrms [by 14.3 ( $p < 0.001$ ) and 7.5% ( $p < 0.05$ ), respectively], whereas in the late phase the 2nd set with EMG feedback was instead associated with significantly lower VM EMGrms [by 9.2% ( $p < 0.05$ )] (Fig. 3a).

For the control group, the 2nd set was associated with significantly lower VM EMGrms in all three phases [by 7.3



**Fig. 1** **a** Raw data from a single subject in a concentric MVC without feedback. These data were not displayed to the subject. **b** An example of the visual feedback provided to the feedback group in the second set for the same subject as in **a**. The *black line* represents the

VM EMGrms achieved in the previous trial and the *grey line* is the ongoing VM EMGrms. The subjects were instructed to, throughout the MVC, try to make the *grey line* exceed the *black line*

( $p < 0.05$ ), 8.0 ( $p < 0.05$ ) and 9.5% ( $p < 0.001$ ), respectively] (Fig. 3b).

VL EMGrms did not change between the 1st and the 2nd sets either for the feedback group or the control group, but there was an interaction between time (set 1 or 2) and action type ( $F_{1,13} = 5.50$ ,  $p < 0.05$ ). In concentric MVCs, the VL EMGrms was significantly lower in the 2nd trial as compared to the 1st (by 10.7%,  $p < 0.05$ ). In eccentric trials though, there was no such change in VL EMGrms.

There was a significant effect of EMG feedback on HAM EMGrms ( $F_{1,13} = 12.9$ ,  $p < 0.05$ ). EMG feedback was associated with increased HAM EMGrms (by 21.6%,  $p < 0.05$ ) from 9.3 to 11.4% (normalized to HAM activation during maximal voluntary isometric knee flexion). No such change was seen in the control group (Fig. 4).

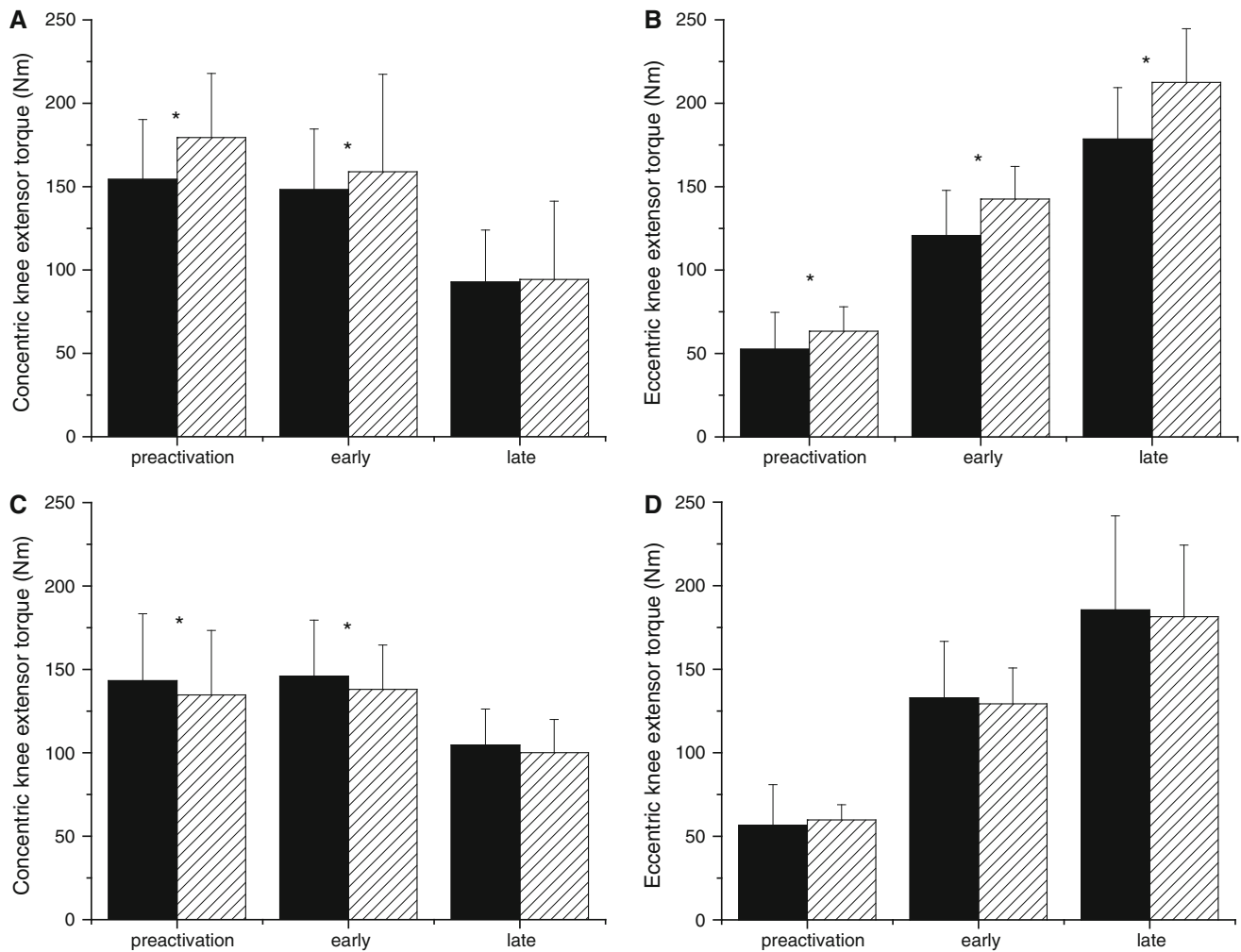
## Discussion

The main finding of the current study was that EMG feedback from VM could be used to acutely enhance knee

extensor torque production and VM activation in maximal voluntary knee extensions. The improvements in strength were more pronounced in eccentric actions and in the preactivation and initial phase of the MVC.

### Effects of EMG feedback on strength

The effect of EMG feedback on strength was somewhat more pronounced during eccentric muscle actions as compared to concentric muscle actions. This was expected, since eccentric muscle actions are associated with lower voluntary activation levels in maximal voluntary actions as compared to concentric muscle actions (Duchateau and Enoka 2008). Therefore, the potential for improving activation level and torque production is greater in eccentric muscle actions. This effect is further accentuated when subjects are not experienced strength trainers (Amiridis et al. 1996). The subjects participating in the current study were students from the Swedish School of Sports and Health Sciences who were recreationally active but who



**Fig. 2** Mean  $\pm$  SD. **a** Concentric and **b** eccentric knee extensor strength in the first set (black bars, without feedback) and second set (striped bars, with feedback) for the feedback group in the preactivation, initial and late phases, respectively. **c** Concentric and

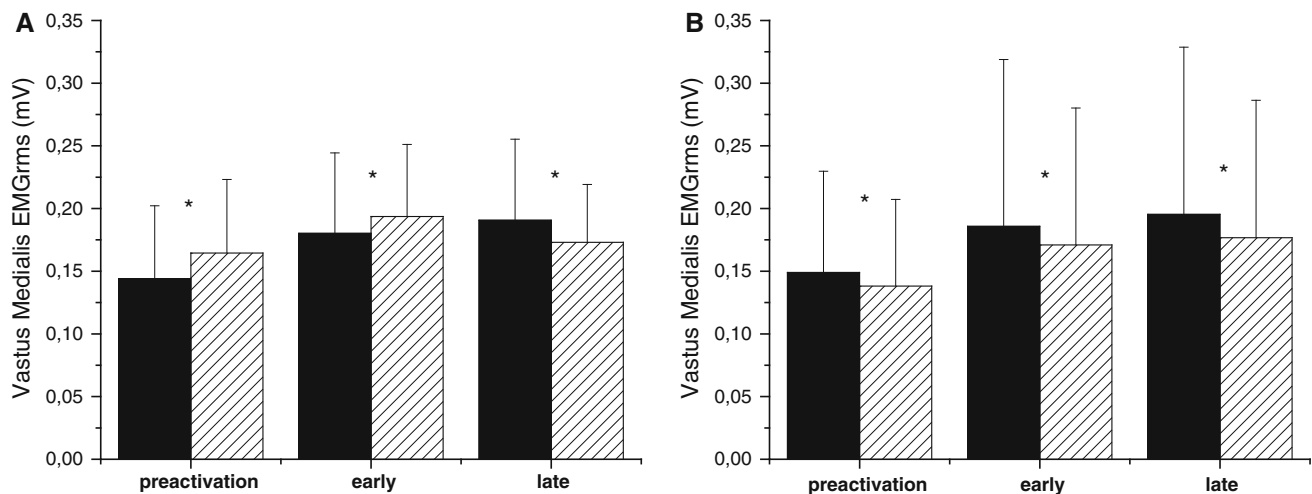
**d** eccentric knee extensor strength in the first set (black bars, without feedback) and second set (striped bars, also without feedback) for the control group in the preactivation, initial and late phases, respectively. \*Denotes a significant difference between the first and second set

had not had previous experience of regular strength training.

#### Effects of EMG feedback on activation

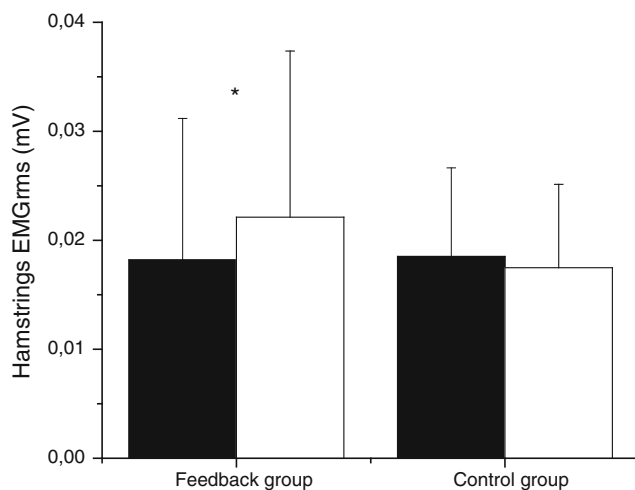
The current study showed acute effects from EMG feedback on the activation of VM. This supports the notion that biofeedback can be used to enhance the voluntary activation in dynamic muscle actions. In a recent study by Oliveira et al. (2010), a single training session yielded larger activation improvements in VL than in VM. In our study, feedback from VM activation was associated with improved activation of VM but not of its agonist VL, indicating that the activation levels of the individual heads in the quadriceps to some extent can be regulated independently on one another. A selective improvement of VM activation after feedback training has also been found in

rehabilitation of patellofemoral pain (Ng et al. 2008). A systematic review recently concluded that there was no evidence that VM could be preferentially activated by different positioning interventions (Smith et al. 2009), indicating that the selective improvement of VM activation seen in the current study was an effect of voluntarily directing increased excitation to the VM motoneurone pool, rather than just twisting the leg into a position that would be more beneficial for VM activation. On the other hand, Aagaard et al. (2000) showed greater adaptations in VM than in VL after 12 weeks of strength training without feedback. One possible reason for the selective improvements in the current study may, therefore, be that the VM was more susceptible for increased activation. While, it cannot be excluded that training with feedback from one muscle, if continued over a longer time would induce improved activation of all agonists, if the objective is to



**Fig. 3** Mean  $\pm$  SD. Changes in VM EMGrms for **a** the feedback group and **b** the control group between the first (black bars, without feedback for both groups) and the second set (striped bars, with

feedback for the feedback group) in the preactivation, initial and late phases, respectively. Values are collapsed over action types. \*Denotes a significant difference between the first and second set



**Fig. 4** Mean  $\pm$  SD. Changes in HAM EMGrms between the first set (black bars) and second set (white bars) in the feedback group and the control group. Values are averaged over action types and phases. \*Denotes a significant difference between the first and second set

improve strength in the entire quadriceps, it may prove useful to provide feedback from multiple parts of the muscle group.

An adverse effect of the EMG feedback provided was a slight increase in the HAM activation (from 9.3 to 11.6% of MVC). By providing feedback from HAM, it would be interesting to investigate if it is possible to reduce activation in the antagonist and at the same time increase activation in the agonist.

#### Phase specific effects of EMG feedback

Grabiner and Owings (2002) showed that already in the preactivation phase, i.e. the isometric phase before onset

of muscle length changes, eccentric actions are associated with lower muscle activation as compared to concentric actions. In our study, strength was improved by EMG feedback in this phase both in eccentric and concentric MVCs, suggesting that the activation level without feedback was sub-maximal in both action types and that the feedback was especially successful in achieving improved activation in this phase. A common finding in training studies is an increase in activation in the initial phase of the muscle action, typically measured as a rise in the rate of force development (Andersen et al. 2010; Oliveira et al. 2010). It is believed that, due to the “catch-like” properties of muscle fibres, an increased activation early in the muscle action can increase the torque later on in the muscle action (Gabriel et al. 2006).

#### Practical implications

While verbal encouragement can sometimes have similar acute effects on muscle strength to those demonstrated here (Ikai and Steinhaus 1961), training situations where peer or personal trainer assistance is not available might benefit from EMG feedback interventions. Recent advances in electronic textiles have made it possible to develop clothes with EMG-electrodes woven into the fabrics (Finni et al. 2007). Combined with techniques in pervasive computing and wireless technology, EMG feedback can thus be provided to a person by means of visual and/or auditory modalities. Thus, this type of training is not limited to a laboratory setting, but can be carried out in a regular strength training setting.

## Conclusions

Feedback of VM EMG acutely enhanced strength and VM activation in dynamic knee extensions. This response was most pronounced in eccentric actions and in the isometric preactivation phase and the initial movement phase. EMG feedback should, therefore, be considered as a viable tool by which the training load can be increased. In this study, concurrent visual feedback was based only on the activation of VM. In future approaches, more complex visualizations of the muscle activation representing the activity of multiple parts of the muscles may be interesting. Before recommending implementation of EMG feedback in resistance training paradigms, its long-term effects needs to be scrutinized.

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