Transfer Mechanisms of Eccentric Training
- The effects of EMG-biofeedback in training

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Abstract

Aim: The aim of this study was to investigate how neural mechanisms operate during maximum strength training in the Quadriceps Femoris muscle group. One of the main objectives is to investigate the effects of five weeks unilateral maximum eccentric strength training on contralateral neural adaptations. The second is to investigate the effects of adding electromyographic (EMG) biofeedback into the training intervention.

Method: 20 healthy, recreationally active men and women had to undergo five weeks (three training sessions per week, resulting in 15 sessions in total) of maximum isokinetic unilateral eccentric strength training of the Quadriceps femoris muscle, with EMG biofeedback; FBG, n=10 five women and five men, or without EMG biofeedback; RTG n=10 five women and five men. The study was performed at the Laboratory of Biomechanics and Motor control, BMC Laboratory, Stockholm Sweden.

Results: The results demonstrated an increase in concentric strength development in the trained leg; before 130 ± 43 Nm and after training 148 ± 46 Nm, (p=0.006). No significant increase in strength was detected for the untrained leg. Further, post hoc tests showed a tendency towards an increase in level of activation (LOA) of the trained leg in the FBG; from 69 ± 15 % before to 81 ± 13 % after training (p=0.097). No significant differences in the ecc:con EMG-ratio or in antagonist co-activation after the training intervention were shown.

Conclusion: No significant difference in strength development was shown, whether training occurred with or without EMG biofeedback. However, eccentric training tended to induce transfer of neural activation to a maximum voluntary contraction (MVC) in the trained leg only in the group training with EMG biofeedback. In addition, the results revealed that eccentric strength training improved concentric strength in the trained leg but induced no transfer to the contralateral untrained leg. The benefits and prospects with incorporating feedback into training remains somewhat unknown and requires further research to obtain deeper understanding of the neural mechanisms affected by biofeedback.
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1. Introduction

By investigating neural mechanisms involved in resistance training, one can achieve a greater understanding of how the neural system acts in conjunction with maximum resistance training. Findings might then work as a guideline for how to design exercise programs, and thereby optimize exercise performance. The information that this study provides may also be used for issues in the field of rehabilitation, etc.

Factors affecting strength development are usually divided into two parts: muscular (local) factors as well as neuronal (central) factors (Enoka 2008, p. 363). There is ongoing research trying to determine how and to what extent these two factors affect the muscle activity. One way to measure muscle activity, which in turn reflects neuronal activation, is by measuring the EMG activity (Gabriel, Kamen & Frost 2006, Konrad 2005 and Aagaard & Thorstensson 2002, p.74). There are different possible explanations for enhanced strength caused by neural mechanisms, which is either an enhanced and firing frequency in already active motor units, or an increase in the number of activated motor units, or both of these explanations. Another possible reason is the improved synchronization among the involved motor units acting together (Aagaard & Thorstensson 2002, p.73 + 74, Enoka 2008, p. 115 + 223, Gabriel, Kamen & Frost 2006 and Wilmore, Costill & Kenney 2008, p.206)

Muscular actions are usually classified into three different types depending on the ongoing length changes of the muscle, where isometric is when the muscle stays the same length while activated, concentric is when the muscle shortens, and eccentric is when the muscle lengthens while activated. The discussions of eccentric versus concentric exercise are many and there is a lot of research done in the subject as an attempt to identify these two forms of exercise, ranging from the advantages, disadvantages, optimal execution, affecting parameters, etc. The literature indicates that eccentric training is superior to concentric training, but at the cost of being more specific to the action type, compared to concentric training. Eccentric exercise has previously been shown to induce significantly greater increase in both total and eccentric strength (Higbie, Cureton, Warren & Prior 1996, Hortobágyi, Barrier, Beard, Braspenninex, Koons, Devita, Dempsey & Lambert 1996, Roig, O'brien, Kirk, Murray, McKinnon, Shadgan & Reid 2008,
Friedmann, Kinscherf, Vorwald, Müller, Kucera, Borisch, Richter, Bärtsch & Billeter 2004, Enoka 2008, p. 365 and Aagaard & Thorstensson 2002, p.73), than concentric training does on total and concentric strength. On the contrary, some have failed to prove that eccentric training would be superior to concentric training in terms of increases in muscle strength (Roig et al. 2008). However, it seems that the superior increase in muscle strength and mass after eccentric training is strongly associated with specificity of contraction mode, higher loads and high intensity. In contrast, the strength development after concentric exercise has been shown to be more universal but at a lower degree (Higbie et al. 1996 and Roig et al. 2008). In fact all training responses, either acute or chronic, are specific adaptations to the nature of training performed (even if the extent of specificity might vary). The response could be specific to the energy expenditure, the volume or intensity of training, to the motion path that is trained, the specific muscles to be trained etc. Consequently, training of specific nature, can not induce greater responses to another mode than to itself, however, some training response can be transferred, for example, positive responses in short-term endurance due to resistance training have been shown, also the existence of cross-education effects (increase in neural activity within an untrained limb due to unilateral training of the contralateral limb), is another evidence of transferred training responses(Wilmore, Costill & Kenney 2008, p.190 + 248-9). Furthermore, eccentric exercise performed with high intensity appears to be more effective for increases in muscle cross-sectional area (Roig et al. 2008).

In practice, most human movements consist of both eccentric and concentric action types and therefore it is highly relevant to study the ability of the muscles to take advantage of the strength gains from eccentric resistance training, into the strength development used in concentric actions. Consequently, it is interesting to examine the potential crossover effects between eccentric and concentric actions. The research done in this area provides ambiguous results obtained from eccentric and concentric training, most likely due to differences in study design and method applied. Common for some of the results obtained after eccentric training is that it induces a cross-education effect of strength development from eccentric to concentric actions. The extent of this cross-education effect is however diverse.
Cross-education is not only interesting between action types, thus several researches have tried to investigate the effects of unilateral strength training on the contralateral limb. Previous studies have presented results indicating that increased neural activation of a muscle contributes to increases in strength of the contralateral agonist muscle and thereby reinforce the effects of cross-education. Meta-analysis and original research confirms the existence of a cross-education effect subsequent to contralateral strength training (Carroll, Herbert, Munn, Lee & Gandevia 2006, Gabriel, Kamen & Frost 2006, Shields, Leo, Messarus & Somers 1999, Lagerquist, Zehr & Docherty 2006 and Fimland, Helgerud, Solstad, Iversen, Leivseth & Hoff 2009). Eccentric training might induce greater cross-education of strength compared to concentric training, probably due to the greater increases in strength achieved by eccentric training (Aagaard & Thorstensson 2002, p.82 and Gabriel, Kamen & Frost 2006). Furthermore, higher intensities and dynamic contractions seem to be beneficial in terms of increased cross-education effect due to contralateral strength training (Gabriel, Kamen & Frost 2006 and Fimland et al. 2009). It should be mentioned that most of the studies that have focused on cross-education related inquiries includes investigation of the upper body, thus fewer results have been established for the lower part of the body.

New training methods and tools are constantly tested and evaluated in order to improve and optimize training results, leading to performance at a higher level. The utilization of biofeedback is generally applied to the field of rehabilitation, such research demonstrated improvements of muscular control due to training with biofeedback. The advantages of feedback-induced training is therefore interesting to examine in the field of exercise and performance as well, as muscular control is essential to achieve good performance. However, biofeedback is relatively new as training equipment and only few studies have investigated the benefits of resistance training performed with biofeedback (Ekblom & Eriksson 2011, Lucca & Recchiuti 1983 and Croce 1986).

There are different kinds of feedback e.g. visual or auditive, which provides information to the subject through different approaches e.g. rate of- muscle activity, force and velocity (Figoni & Morris 1984, Kellis & Baltzoupoulos 1996 and Randell, Cronin, Keogh, Gill & Pedersen 2011), and there is ongoing research to determine the magnitude of success due to different feedback...
methods applied. One main factor of the total outcome of the studies is the differences in test method, for example; one study found that training with feedback induced greater strength development during $150^\circ \text{s}^{-1}$ speed of action whereas no significant increase was found for $300^\circ \text{s}^{-1}$ speed of action (Figoni & Morris 1984), however another research demonstrated increases during both of the investigated velocities ($30^\circ$ versus $150^\circ \text{s}^{-1}$) (Kellis & Baltzoupoulos 1996). The difference in velocities chosen to evaluate is probably the main source of the different outcomes between these two. One biofeedback method that is available today is based on EMG activity, where the ability to directly be aware of the muscle activation is given. Hopefully, one can learn to activate different muscles during different time intervals and to a different extent, thus providing a greater self-control of body movement.

In a study parallel to the current, effects from eccentric training performed with or without EMG biofeedback were investigated (Larsson 2011). It was shown that the trained leg increased significantly in eccentric strength development and that the level of activation increased more in the group training with feedback than in the group training without. The current study aims to investigate if there is any cross-education effect to the contralateral untrained leg subsequent to eccentric isokinetic resistance training. In addition, is there any cross-education effect of action type (eccentric training to concentric performance) of both the trained and untrained leg? Furthermore, is there any difference if the training is performed with or without EMG biofeedback? As a complement to the parallel study mentioned above, it is thought that the main purpose of this study only will concern various transfer effects of eccentric strength training performed with or without EMG biofeedback.

Consequently, the aim of this study is to investigate how neural mechanisms operate during maximum strength training in the Quadriceps Femoris muscle group. One of the main objectives is to investigate the effects of five weeks unilateral maximum eccentric strength training on contralateral neural adaptations. The second is to investigate the effects of adding EMG biofeedback into the training intervention.
2. Method

2.1. Subjects
20 healthy, recreationally active men and women, without previous knee injuries and no previous experience in strength training of the lower extremities, were used as subjects in the study. Subjects were paired in two by age and gender and subsequently randomized into two training groups; resistance training performed with EMG biofeedback (FBG; n=10, 5 women, 5 men, (mean ± SD) age 22.5±2.2 years, height 175.0±10.0 cm, weight 75.8±19.1 kg) or to resistance training performed without any feedback (RTG; n=10, 5 women, 5 men, age 22.1±2.2 years, height 175.1±7.5 cm, weight 72.9±11.9 kg). All participants received written information concerning the study and provided their written consent to participate before the experiment (see appendix 1). Recruitment of subjects took place by advertising (see appendix 2). They could at any time terminate their participation without any reservations, and after completion of the study they received a financial compensation. The study was approved by the local ethics committee and all procedures adhered to the declaration of Helsinki.

Subjects were tested twice; one week before and one week after a training intervention of five weeks, which consisted of eccentric training of the Quadriceps muscle. The angular velocity and range of motion was the same during exercise as for testing (see Measures; Torque).

2.2. Training intervention
The training procedure was performed as follows:
The workout was performed either by using EMG biofeedback through the entire training session (FBG) or no feedback at all (RTG). All training consisted of unilateral isokinetic eccentric actions of the Quadriceps femoris muscle, and the training intervention lasted for five weeks with three training sessions per week, resulting in 15 sessions in total. Exercise could be performed two days in a row, but not three days in a row. All training sessions were supervised.

FBG: Initially, subject went through the necessary preparations required before the training session (see subject preparation). The subject then performed three sets of five maximal isokinetic eccentric contractions of the Quadriceps, with each set separated by four minutes rest.
RTG: The same training procedure as above, except for feedback during the exercise and thus electrode placement.
Each training session took about a total of 30 minutes to complete.

2.3. Experimental procedures

2.3.1. Subject preparation

The same subject preparation was used during testing and training sessions, except for the electrical stimulation preparations, which was only applied during the test interventions. Also the local warm up differed slightly, to better adapt it to the next element (training or testing).

Subjects came to the laboratory under the same conditions regarding sleep and diet on pre and post-test. Initially, they warmed up for 10 minutes on an exercise bicycle (Monark 829, Varberg, Sweden) at their own pace. Thereafter the skin was prepared by shaving and washing the electrode area, on which the electrodes for EMG registration and electrical stimulation were then applied and secured by taping (see EMG and Electrical stimulation). Circles were painted around the electrodes to ensure the same positioning during pre and post-test. Subjects were then seated in the dynamometer, positioned with the knee joint axis corresponding to the axis of the leverarm. Position and settings were documented to be re-used in the training sessions and for the posttest. While seated in the dynamometer subjects were strapped on to the dynamometer by a seatbelt over their pelvis. Belts were firmly strapped over the shoulders and the waist, see figure 1. To Hamstrings maximal voluntary contractions (MVCs), an extra strap was attached on to the thigh, close to the knee joint, to make sure the knee would not elevate during the movement.

After the general warm up and practical preparations, subject began with either a local warm up for testing; three submaximal repetitions for a local warm up for each action type. Thereafter the search for the supramaximal stimulation intensity by evoking stimulation of the femoral nerve took place. Once this was completed, the measurements could start. Or with a local warm up for training; two Hamstrings concentric submaximal actions and one Hamstring MVC after which two eccentric Quadriceps submaximal actions and one Quadriceps MVC was performed,
followed by two minutes rest before the training session started. These repetitions were also used for calibration of the feedback unit for the FBG.

Figure 1. Subject seated in the dynamometer with surface-electrodes visible on VL, VM and RF muscles of the dominant leg (right leg). At the left picture the feedback-screen is shown.

2.3.2. Test procedure

Initially, the pretest started with subjects undergoing the necessary preparations required before the measurements (see subject preparation). Subjects then had to perform three concentric Quadriceps MVCs of which the first one was performed without stimulation, and the last two with a supramaximal stimulation inducing a superimposed twitch. After each concentric Quadriceps MVC, the torque motor returned the relaxed leg to the start position. In between the two last MVCs the leg was also passively moved into knee extension (passive concentric movement) with a supramaximal stimulation inducing a resting twitch. After the concentric MVCs was performed subject had to rest five minutes before repeating the same procedure for eccentric actions. The test ends with one Hamstrings MVC concentric and eccentric, performed
without any stimulation. The procedure was first performed on the left leg and then the right leg, between legs there was five minutes of rest allowed. To minimize confounding factors and to maintain a high reliability and reproducibility at each MVC attempt, instructions, feedback and verbal encouragement for each subject was standardized. Subjects were told to contribute with their absolute maximum effort, further verbal encouragement was not allowed during the trials. This was applied in both pre and post-test and also during the training sessions. Post-testing: The same procedure as in the pre-test was used in the post-test. Each testing session took about a total of two hours to complete.

2.4. Electrical stimulation

Supramaximal stimulation was applied to the femoral nerve by a constant current stimulator (Digitimer DS7A, Digitimer Ltd, Hertfordshire, UK). Stimuli were delivered via a gel-coated surface electrode, acting like a cathode, placed in the inguinal triangle and a gel coated coal rubber electrode, acting like an anode, (carbon rubber electrode, 100x50mm, CEFAR medical, Malmö, Sweden) placed between the trochanter major and the iliac crest. This placement of the electrodes was chosen for the current to access the femoral nerve without activating the sciatic nerve. The placement of electrodes was secured with tape to maintain the right placement trough the whole test procedure. After placement of the electrodes, the stimulus intensity started at 10mA and was then gradually increased by 30mA at a time until a further increase in stimulus intensity did not result in an increase in the amplitude of the twitch recorded in the torque data channel. This maximum intensity was then further increased by 30 mA to reach the supramaximal intensity used in the subsequent protocol. In the test protocol, two pulses at 100Hz were always delivered at a supramaximal intensity as the leg moved through the mid position of the range of motion. These stimuli induced resting twitches and superimposed twitches in the torque signal, which were then used for subsequent calculations of level of activation (see torque recordings).
2.5. Feedback

The signal from the four EMG channels were sent to an AD-card (Proreflex), where each signal was digital to analogue converted. The digital signal was then further sent (in 100 Hz) to the USB port on a laptop (Dell Latitude E6500), which read off all channels. The information from each channel was then filtered for mean values. The window length used in the filtration process could be adjusted through a graphical user interface. A too short window gave a "jerky" signal, while a too long window generated a long delay. By testing different window sizes in the pilot tests it was found that a window length of one second was seen as the most intuitive.

Feedback was provided visually on a computer screen indicating in real-time the activation of the Vastus medialis (VM), Vastus lateralis (VL), Rectus femoris (RF) and Hamstrings muscles. The muscle activation was presented on the screen in a circle which represented a "cross section" of the leg. A “wedge” in the circle represented each muscle. The outline region of the circle represented the subjects last maximum performance whereas the length of each slice was proportional to the filtered muscle activation.

With the help of the graphical user interface, the experimenter could normalize the size of each wedge, so that when a wedge reached the edge of the circle, the "new value" became equal to the greatest muscle activation of the day. The system was implemented in C++ where the graphics were generated using OpenGL.

2.6. Measures

2.6.1. Torque

-Maximum strength (torque)

The measurement of strength about the knee was recorded from an isokinetic dynamometer (IsoMed 2000 Basic, D. & R. Ferstl, Hemau, Germany), which also controlled the angular velocity of the lower leg to 20°·s⁻¹. The range of motion was 60°, and stopped when the knee was fully extended, approximately at 180°. The dynamometer measured two signals; the torque-signal
and the angular-signal, both then, were analog to digital converted using a CED power 1401 data acquisition system and collected into Signal software program (Signal 2:16, Cambridge Electronic Design, Cambridge, UK), see figure 2 and 3.

MVC torque was determined from the mean torque throughout the range of motion, from the MVC performed without stimulation. Resting value (to estimate the load of the leg) was calculated by the mean torque throughout the range of motion, from a passive motion. (Lengthening or shortening depending on evaluated action type). The resting value was subsequently subtracted from the MVC torque before statistical analysis. Values are expressed in Nm.

Figure 2. Overview of the data acquisition; the first four channels demonstrates the EMG signals from VM, VL, RF and Hamstrings. The last two channels are corresponding to the angle degree and the strength, in this case measured as torque (Nm). The cursors made it possible to determine the range of motion during the data analysis.
2.6.2. Level of activation (LOA)

In the current study level of activation in dynamic contractions was investigated, which has not been done to a large extent. Voluntary activation was assessed by using the twitch interpolation technique, making it possible to determine the level of activation. The voluntary activation (%) was calculated as 100 x (1-IT/RT), where IT stands for the interpolated twitch and RT the resting twitch. To achieve the interpolated twitch from the superimposed MVC, the mean torque obtained during the 50ms just before the electric stimulation (figure 4, vertical line 1) was subtracted from the peak torque appearing within 150ms from when the electrical stimulation was applied (figure 4, vertical line 2). Resting twitch was estimated as the peak torque appearing within 150ms from when the electrical stimulation was applied, measured from a passive contraction, see figure 5. This was done for each action type.
Figure 4. Data acquisition from a superimposed MVC performed with electrical stimulation, interpolated twitch (IT). IT was used to calculate LOA. The cursors made it possible to determine the range for which the calculation of IT would take place within.

Figure 5. Data collection from a superimposed passive motion performed with electrical stimulation, resting twitch (RT). RT was used to calculate LOA. The cursors made it possible to determine the range for which the calculation of RT would take place within.
2.7. **EMG**

2.7.1. EMG activity

EMG activity was recorded from Vastus medialis (VM), Rectus femoris (RF), Hamstrings (H) and Vastus lateralis (VL) using surface electrodes (Ag-AgCl, Ambu Blue Sensor M, M-00-S, electrode sensor area: 13.2 mm², Ambu AB, Ballerup, Denmark). The electrodes were placed according to recommendations by Konrad, 2005 Noraxon, and along the assumed muscle fibre direction. EMG signals were recorded by a wireless device (Noraxon TeleMyo 2400), and transferred to (TeleMyo 2400 RG2). The signals were then analog to digital converted using a CED power 1401 data acquisition system and collected into Signal software program (Signal 2:16, Cambridge Electronic Design, Cambridge, UK) with a sampling frequency of 1500Hz and filtered between 10 and 500hz. Signal amplitude was then measured by the Root mean square RMS method, which was measured for each muscle leg and action type in the MVCs performed without electrical stimulation, and over the whole range of motion. Values are expressed in mVs.

2.7.2. EMG-ratio and antagonist co-activation

EMG-ratio between eccentric-concentric strength development is measured for the MVCs without electrical stimulation, and performed for the Quadriceps muscles. For further information on how this is calculated, see statistics. A modification in the ecc:con EMG-ratio could be an indicator of changes in muscle activity, that is, changes in neural functional patterns.

Co-activation of Hamstrings was calculated by EMG measurements normalized to MVC. A modification in Hamstrings co-activation could be an indicator of either changes in agonist muscle strength (Quadriceps), or changes in the neural patterns controlling Hamstrings activation. Calculation of Hamstrings co-activation contributes further understanding concerning increases in strength and possible underlying causes i.e. increased activation in the quadriceps, or decreased activation of the hamstrings.
2.8. Statistics

Initially the normal distribution of the data was checked by Shapiro Wilks W-test, thereafter three four way repeated measures ANOVA was used for the independent variables (strength, LOA, EMG-ratio) with the factors; group, time, leg, type and muscle. Repeated measures ANOVA was performed for strength and LOA with the factors group (FBG or RTG), time (before and after), leg (trained and untrained) and type of action (eccentric and concentric). Repeated measures ANOVA for EMG-ratio was performed with the factors group (FBG or RTG), time (before and after), leg (trained and untrained) and muscle (VM, VL and RF). Repeated measures ANOVA was also used to calculate co-activation of Hamstrings normalized to MVC.

In case of significance, Tukey HSD post hoc tests were calculated to detect where the differences existed. P-values were considered significant at $p < 0.05$, and values between $p > 0.05$ up to $p < 0.1$ were considered to be tendencies. Unless otherwise indicated, data is presented as mean values ± standard deviation (SD). All statistic analyses were executed using Statistica software program (Statistica package, version 8.0, Stat-soft).
3. Results

The main interest in this study lies in the transfer mechanisms followed by eccentric resistance training, consequently, the reported results relate only to this area. For further details regarding other outcomes from the study, see the parallel study performed by Larsson, 2011.

3.1. Strength

Repeated measures of ANOVA showed a significant interaction between time (before versus after), leg (trained versus not trained leg) and type (concentric versus eccentric).

There was no significant difference in increase in strength between the groups (FBG versus RTG). Consequently, both groups improved significantly in terms of strength development in concentric actions of the trained leg, irrespective of whether training was performed with or without EMG biofeedback.

Post hoc tests showed an increase in concentric strength development of 14%, in the trained leg after the training intervention; concentric strength before training was 130.3 ± 43.9 Nm and after training 148.3 ± 46.9 Nm (p = 0.006), see figure 6. Regarding the untrained leg, no significant increase in strength was detected after the training intervention, a result that was valid for both action types. For the concentric actions in the untrained leg, the results rather showed a decrease in concentric strength by 9 % (from 139.1 ± 45.6 Nm before to 126.6 ± 36.8 Nm after). This decrease was however not significant but can at least be considered as a tendency (p = 0.095), see figure 7. Eccentric strength in the untrained leg before and after training; 162.5 ± 58.0 Nm and 152.2 ± 49.1 Nm (p = 0.246), respectively.
Figure 6. Concentric strength development pooled between both groups in the trained □ and untrained ■ leg, before and after the training intervention, respectively. The difference in torque outcome is significant * for the trained leg and considered as a tendency ▲ for the untrained leg. Values are expressed as mean ± SD.

Figure 7. Concentric □ and eccentric ■ strength development pooled between both groups in the untrained contralateral leg before and after the training intervention. A tendency ▲ towards a decrease in concentric strength is shown. Values are expressed as mean ± SD.
3.2. Level of activation, LOA

The results from measurements of LOA did not demonstrate significant differences between action types, nor did it reveal differences of significance between legs or between the groups. However, repeated measures of ANOVA showed a tendency for an interaction between time, leg and group.

Post hoc tests showed a tendency towards an increase in LOA of the trained leg after the training intervention; with LOA improving by 16.8 %, from 69.5 ± 15.4 % before to 81.2 ± 13.1 % after training. This increase was only seen in the trained leg, in the FBG exclusively (p = 0.097). LOA of the untrained leg in the FGB before and after training; 74.9 ± 18.8 % and 72.2 ± 16.0 % (p = 0.995), respectively. In the RTG of the trained leg, before and after training; 79.6 ± 13.6 % and 84.5 ± 11.5 % (p = 0.892), respectively, and of the untrained leg before and after training; 71.6 ± 15.0 % and 76.5 ± 17.7 % (p = 0.896), respectively, see figure 8.

Figure 8. Level of activation for each group (RTG, FBG) and leg (untrained (nd), trained (d)), before (pre) and after (post) training. The trained leg in the feedback group showed a tendency towards increased LOA after training. Values are expressed as mean ± SD.
3.3. **EMG-ratio**

For eccentric EMG-ratio, the repeated measures ANOVA showed no significant interactions between the within-subject factors of group, time, leg and muscle (VM, VL and RF, respectively).

3.4. **Antagonist co-activation**

Repeated measures of ANOVA showed a significant interaction between time, leg and group regarding the co-activation of Hamstring. Post hoc tests however showed no change in co-activation over time between none of the legs or groups. No differences were detected between action types.

Antagonist co-activation in FBG, of the trained leg before and after training; $11.2 \pm 9.6 \%$ and $8.1 \pm 3.6 \%$ ($p = 0.978$), respectively, and in the untrained leg before and after training; $11.0 \pm 5.1 \%$ and $13.4 \pm 9.6 \%$ ($p = 0.994$), respectively. Antagonist co-activation in RTG, of the trained leg before and after training; $11.2 \pm 4.3 \%$ and $16.8 \pm 11.2 \%$ ($p = 0.613$), respectively, and in the untrained leg before and after training; $12.9 \pm 3.7 \%$ and $10.2 \pm 4.8 \%$ ($p = 0.999$), respectively, see figure 9.

![Antagonist co-activation graph](image_url)

Figure 9. Antagonist co-activation (Hamstring) for each group (RTG, FBG) and leg (untrained (nd), trained (d)), before (pre) and after (post) training. None of the interactions were significant. Values are expressed as mean ± SD.
4. Discussion

The current study aimed to investigate the influence of EMG biofeedback on cross-education effects. The purpose was to investigate if there are any cross-education effects subsequent to eccentric resistance training, both in terms of strength development of the contralateral untrained leg and between action types in both legs. The investigation consisted of five weeks unilateral maximum isokinetic eccentric strength training of the quadriceps femoris muscle group.

The main findings of this study were that eccentric strength training improved concentric strength in the trained leg but induced no transfer to the contralateral untrained leg. Furthermore, eccentric training tended to induce transfer of neural activation to a concentric MVC in the trained leg only in the group training with EMG feedback.

4.1. Strength

The results revealed from this study showed no significant difference in strength development, whether training occurred with or without EMG biofeedback. Thus, both training methods induced the same training results. Previously, the impact of biofeedback on training performance was investigated by Evetovich et al. (2007) where one have examined the influence of muscle activation due to mechanomyographic (MMG) biofeedback. It was revealed that the biofeedback group did provide lower MMG and EMG levels when told to relax the muscle, compared to the non-biofeedback group. However, the utilization of biofeedback revealed no improvements in performance. Other studies that have integrated feedback into the training however, showed that the feedback training contributed to increased performance (in terms of greater peak and average torque, respectively) when evaluating strength pre and post training with or without feedback (Lucca & Recchiuti 1983, Croce 1986 and Ekblom & Eriksson 2011) Possible explanations to the different results obtained from these studies might be due to the different procedures and study design; presentation of the biofeedback and intervention time (Ekblom & Eriksson 2011), action type specificity (Lucca & Recchiuti 1983), normalization to peak or mean (Croce 1986), etc. For instance, Ekblom & Eriksson (2011) demonstrated significant increases in strength and muscle activity when subjects were tested with feedback; however they investigated the effects of acute
feedback during a single test occasion. Perhaps, the utilization of feedback induces different effects when used over time compared to when used occasional times. To the author’s knowledge, studies investigating the potentials of feedback-induced training are few, thus, benefits and prospects with incorporating feedback into training remains somewhat unknown.

4.2. Cross-education of strength

The training intervention did not result in any strength transfer to the contralateral untrained leg, irrespective if training was performed with or without feedback. Given that many studies have previously confirmed that eccentric strength is very specific to the situation given (Ratamess, Alvar, Evetoch, Housh, Kibler, Kraeme & Triplett 2009 and Folland & Williams 2007), this may well be one possible reason for the lack of cross-education between the legs. Considering the results from this study, the theory of the specificity of eccentric training is even more reinforced. On the contrary, still in consensus with the greater specificity associated with adaptations after eccentric training, particularly in terms of velocity and contraction mode, other studies have nevertheless demonstrated a cross-education effect to the contralateral untrained limb during eccentric training (Seger, Arvidsson & Thorstensson 1998 and Seger & Thorstensson 2005). Although it appears that cross-education of strength might be action type and velocity specific, this should not have been a problem in the current study as the same velocity was used during both training and testing. On the other hand, it appears that the effect is not only velocity-specific but specific to higher velocities in particular; Farthing & Chiliback(2003) investigated the effects of eccentric training at different velocities on cross-education and found a cross-education effect of strength to the contralateral untrained limb only in the group that was training with high velocity eccentric training (180°.s⁻¹) compared to the slow-velocity group (30°.s⁻¹) where no changes in contralateral strength was found. In the studies by Seger & Thorstenssson(1998) and Seger, Arvidsson & Thorstensson (2005) respectively, where cross-education of strength to the contralateral limb was found, the applied velocity during training was 90°.s⁻¹, compared to the velocity used in the current study (20°.s⁻¹). On the contrary, Tomberlin, Basford, Schwen, Orte, Scott, Laughman & Ilstrup (1991) investigated the effect of eccentric strength training on cross-education without any significant changes in the untrained limb, despite eccentric training at a relatively high velocity (100°.s⁻¹).
Additionally, it has been shown that eccentric contractions contribute to greater cross-education of strength to the untrained limb, probably due to the greater increases in strength achieved by eccentric training compared to concentric training (Aagaard & Thorstensson 2002, p. 82, Gabriel, Kamen & Frost 2006 and Enoka 2008, p. 352+365). Furthermore, higher intensities and dynamic contractions also seem to be beneficial in terms of increased cross-education effect after contralateral strength training (Gabriel, Kamen & Frost 2006 and Fimland et al. 2009). Even though only eccentric actions performed dynamically and with high intensity was used in the training intervention no superior strength gains was found for the eccentric compared to concentric actions in the untrained limb, thus, the specificity of action type, mode or intensity was not an influencing factor in this study.

The velocity applied during exercise does not only affect the strength gains through specificity, but different velocities contribute with different outcomes of strength gains subsequent to training (Enoka 2008, p. 229 and Ratamess et al. 2009). Another possible reason for the undiscovered cross-education might be due to the somewhat slower movement velocity used during the contractions, since eccentric exercise previously has shown to produce greater increases in strength when performed at higher velocities (Roig et al. 2008). For example, Wilmore et al. describes the relationship between velocity and force production where it is shown that greater eccentric force production is attained during relative faster actions (Wilmore, Costill & Kenney 2008, p. 44 + 195). Other studies support these findings, however, not limited to eccentric actions but strength training in general, thus involving both eccentric and concentric contractions (Hatfield, Kraemer, Spiering, Häkkinen, Volek, Shimano, Spreuwenberg, Silvestre, Vingren, Fragra, Gomez, Fleck, Newton & Maresh 2006 and Enoka 2008, p. 241).

Further, it has been shown that training with high volume induces greater contralateral strength gains than does low volume (i.e. one versus three set) (Caroll et al. 2006). No significant increase in contralateral strength was detected, despite a high volume set design as in this protocol, perhaps adding further set to the training protocol could reinforce the effectiveness. Another influencing factor that could have affected the contralateral strength is the effect of familiarization of the test procedures, which have been valued up to 3.4 % (Caroll et al. 2006).
Despite a rather small influence, one might have expected some effect of familiarization at least for the trained leg, given the design of this study. However, this factor does not seem to have influenced the outcome of the cross-education effect either.

On the contrary, the results showed a tendency towards a decrease in contralateral strength for the concentric action type after the training intervention. Unfamiliarity may have contributed this result; a majority of the subjects reacted quite strongly when they, in the post test after finishing the training had to perform MVCs with the untrained leg, and in addition also perform the other action type than used to, i.e. concentric MVCs (training used eccentric actions only). Perhaps, the discomfort that occurred could be avoided by a familiarization period including performance of concentric contractions with the untrained leg before testing. Given that training only consisted of eccentric contractions the training does not seem to have been beneficial for concentric strength gains. The primary outcome of training seems determined by training mode, thus strength gains due to resistance training appears to be action type specific.

In conclusion, no cross-education strength effect of unilateral strength training to the contralateral untrained limb could be established in this study, regardless of training mode (feedback or not). Cross-education between action types was found for the trained leg only, thus indicating changes in neural adaptation. This result is very interesting and requires further research for understanding and confirming.

4.3. LOA

The results from LOA showed no significant difference between groups or action types. The fact that there was no difference in LOA between action types is interesting, considering that training was performed with eccentric actions only. Since there were differences in strength development between the action types, a difference in LOA between action types could therefore be somewhat expected. As this is not the case, it denotes that other factors beyond strength development must have had an impact on LOA.
LOA does not reflect pure strength alone, but rather provides with information about the neural mechanisms that operate during exercise. This is reinforced by the results revealed from this study, showing that subjects generated greater strength development, without showing any significant increase in LOA after training. This indicates that the progress made in the nervous system after the training intervention, is not limited to the specific training performed but also transferred and applied during strength development in general, regardless of action type used in the execution.

However, a difference in LOA between groups was detected, indicating greater LOA in the trained leg in the FBG after the training. The increase was 17 %, indicating that the use of feedback during exercise might contribute to increased activation ability, although this result failed to reach statistical levels of significance (p=0.097). As already mentioned, further investigations are required to establish the advantages of feedback utilization. However, these results imply that EMG biofeedback inducted into training may provide enhanced performance, hence emphasizing feedback into the field of research.

4.4. **EMG-ratio**

Repeated measures of ANOVA showed no significant changes in the EMG-ratio of eccentric to concentric EMG after the training intervention.

The fact that both eccentric and concentric strength increased might be an explanation to the results showing no significant difference in EMG-ratio. However, one could have expected some changes in the ratio because of the greater eccentric strength gains revealed in the parallel study by Larsson (2011), compared to those of the concentric. Thus, it appears that the differences were not great enough to affect the ratio in a greater extent, indicating that the differences in neural activation subsequent to training might not have been specific to different action types. This also corresponds with the results in LOA when associated with specificity of action types.
4.5. Antagonist co-activation

Post hoc test showed no difference in co-activation between legs or groups. The fact that both groups similarly increased in strength also explains the similar result, i.e. no changes in co-activation after the training intervention. Some studies have found a reduced co-activation as a result of improved muscle coordination after training (Osu, Franklin, Kato, Gomi, Domen, Yoshioka & Kawato 2002), other shows that a higher level of co-activation is associated with higher velocities, external forces on the joint (Osu et al. 2002) and functional multi-joint exercises (Folland & Williams 2007). Additionally, some studies suggest that increased levels of antagonist co-activation can develop as a strategy from CNS to further improve the movement by providing joint stability, hence increase movement accuracy (Gribble, Mullin, Cothros & Mattar 2003). The non-increase in co-activation is in consistent with these findings considering the somewhat slower velocity and controlled movement (fixed joint) used in this study, in addition, subjects were not able to move the joint freely during the trials; the knee joint was fixated and controlled by the dynamometer, thus, a struggle to accomplish movement accuracy does not seem to be highly required during this task.

In the feedback study by Ekblom & Eriksson (2011) the agonist and antagonist muscle activation was compared to identify differences in activation patterns and the degree of co-activation in MVCs of the knee extensors. The group that performed the task with concurrent feedback increased the level of hamstrings co-activation significantly. One possible reason for the different outcomes could be related to the disparity between the feedback model used in the current and the one used in their study; which only provided VM muscle activity (agonist) unlike the model used in the current study where also hamstrings activity was shown (antagonist).

4.6. Limitations

Even though there is a certain correlation between EMG activity and force development, determining muscle strength by measuring EMG activity is not always simple, as it may exhibit differences in EMG output depended on the characteristics of the physical activity measured, training status and condition of the muscles (Konrad 2005, Conelly, Carnahan & Vandervoort
2000 and Folland & Williams 2007). For example, EMG activity and strength measurements have shown to appear lower for bilateral compared to unilateral contractions (Gabriel, Kamen & Frost 2006), on the contrary, others have not been able to demonstrate any differences between these two (Jakobi & Cafarelli, 1998). Other findings are differences in EMG activity depending on mode of contraction, where eccentric actions are associated with a lower degree of EMG activity (Gabriel, Kamen & Frost 2006, Konrad 2005, Fauth, Garceau, Wurm & Ebben 2010 and Andersson & Behm 2004). The former factor should not have affected the results as all the measurements were applied on and compared to unilateral actions. The second factor certifies the importance of a reference value, e.g. MVC, so that action types can be compared to each other, in this study EMG was normalized to MVC.

As EMG is not always enough to determine muscle strength, we have also chosen to use electric stimulation in the strength measurements. EMG signals do not always provide a high reliability since many factors can affect the signals, such as reduced subcutaneous fat during the training period, change in body composition, undesirable signals recorded from surrounding muscles, electrical interference from nearby signals, etc. (Konrad 2005 and Aagaard & Thorstensson 2002, p. 75). With addition of electrical stimulation, the measurement of strength can therefore be better ensured (Aagaard & Thorstensson 2002, p. 75).

In few cases some subjects became ill and had to cancel workouts, this may to a certain extent affect the physiological condition of the muscles and thereby the final result. The quantity in which this may happen probably depends on differences between individuals, the amount of absence from training and medical condition.

Another factor that may have influenced the outcome of the study is whether subjects were engaged in other forms of physical activity that could affect the strength development (primarily in the legs). Subjects was recommended not to perform high intensity physical activity to a great extent, and specific resistance strength training of the leg muscles was not permitted at all during the trial.
Further on, the task was performed in a seated position that affected the EMG signals recorded from Hamstrings, as the electrodes were constantly subjected to pressure. In some case, the problem caused various disruptions in the EMG recordings that led to artifacts in the signals, thus resulting in unusable data. Consequently, the data loss from Hamstrings might have resulted in a slightly weaker result than what could have been.

Another limitation of the current study is the relatively low number of subjects tested, where only ten subjects in each group participated. In what extent this factor may have influenced the statistical level of significance remains unknown.

4.7. Future research

Posttest revealed an increase in LOA for the group that was training with EMG biofeedback; hence, a longer training period may perhaps evoke greater differences in strength development than seen over five weeks as in the current study. Consequently, an investigation of feedback-induced training may provide other results than demonstrated when evaluated under longer periods.

To continue in the same field of research, and develop the methodology and the quality of the studies, one approach would be to review and improve the feedback system. Perhaps one could make the method even more educational and easier for subjects to use and understand the provided information. The convenience with the feedback system used in this study was that subjects was given a good chance to visualize the leg and the working muscles as in a cross-section view, which was experienced as very appreciated. An improvement of already existing feedback technique might be obtained by developing the layout in a way that clearly showed the significance of each muscle activation, as the feedback model used in the study by Ekbloom and Eriksson 2011, where each activation after another were a comparison to the previous contraction through the entire movement. It may be added that their study revealed a significant increase in strength when training with EMG biofeedback.
It would have been interesting to compare how functional exercise (without a controlled rate and fixed joint movements i.e. not performed in an isokinetic dynamometer) would affect transfer mechanisms, since different training modes appears to have different effects of the outcome of performance. As mentioned earlier, external loadings, functional movement, movement velocities, training intensity etc. are all examples of parameters affecting muscle activation and thus strength development. It would therefore be interesting to examine whether training with feedback turns out to be more beneficial within different modes of training. Of course there would exist other difficulties in the measurements as many other physiological components become involved when incorporating functional motions; higher/alternating speed of movements and training intensities etc. The benefit of the approach used in this study is that other influencing factors are reduced to a greater extent, making it easier to detect whether the parameters tested truly are the ones influencing the performance, thus providing greater validity.

The effect of unilateral strength training on the contralateral limb and the effect of training with biofeedback, as investigated in the current study are both interesting fields for further physiological understanding of the human body during physical activity and optimizing performance. Consequently it would be interesting to examine the outcomes of studies with different durations and subject characteristics.
Reference list


Fauth ML., Garceau LR., Wurm BJ. & Ebben WP. (2010). Eccentric muscle actions produce 36% to 154% less activation than concentric muscle actions. *International symposium on biomechanics in sports: conference proceedings archive.;* vol.28: p.1-4


Appendix 1

Godkännande för deltagande i träningsstudie angående maximal muskelaktivering


Under både test och träning ska du tänka på att ta i maximalt varje gång. Oroa dig inte för att bli trött mot slutet. Du ska inte försöka ”spara” dig för att orka prestera maximalt hela testet. Ge gärnet varje gång.

Du kan när du vill under testet (eller träningsperioden) välja att avbryta försöket utan att uppgö något skäl för detta.

Vid avslutad studie får du en ersättning om 3000 kronor. Ersättningen är skattepliktig.

Jag är införstådd med vad studien handlar om och väljer att vara med.

Underskrift

Namnförttydligande          Datum
Kvinnliga och manliga försökspersoner sökes!

Vi söker försökspersoner till en 5 veckor lång träningsstudie. Du ska vara mellan 20 och 30 år, inga knäproblem samt inte träna styrketräning regelbundet. Som försöksperson kommer du att träna benstyrka 3 gånger i veckan under en 5veckor lång träningsperiod. Utöver själva träningen kommer vi även att mäta din maximala benstyrka före och efter själva träningsperioden. Vid dessa två mättilfällen kommer även Quadriceps att elstimuleras. Inga biopsier eller andra invasiva ingrepp kommer att utföras i studien.

När: Mitten av januari till slutav februari
Var: BMC laboratoriet för biomekanisk och motorisk kontroll
Ersättning: 3000 kronor (betalas ut först efter fullbordad träning och maxtestning)

Intresseanmälan:
Är du intresserad så anmäl dig SNARAST via mail till Alexander Ovendal. Har du några frågor så är det bara att kontakta Alexander Ovendal på LTIV eller Maria Ekblom på BMC.
Appendix 3

Litteratursökning

Syfte och frågeställningar: Transfermekanismer efter excentrisk träning utförd med eller utan EMG biofeedback.

Vilka sökord har du använt?

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Var har du sökt?

PubMed, SportDiscus

Sökningar som gav relevant resultat

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<td>PubMed: EMG concentric eccentric exercise</td>
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<td>PubMed: Co-activation hamstrings quadriceps</td>
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<td>PubMed: Hamstrings Quadriceps</td>
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<td>PubMed: Strength training and feedback</td>
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<td>SportDiscus: Eccentric concentric strength training</td>
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Kommentarer

Många artiklar som hittades undersökte skillnader vid olika sjukdomstilsstånd, dessa har av den anledningen inte relaterats till, trots att de berörde en relevant frågeställning.

Överlag gav sökningarna på PubMed flera relevanta träffar än vad de på SportDiscus gjorde. Många av de artiklar som använts i arbetet har hittats genom via ”related articles” i databaserna eller litteraturlistor, några även via min handledare.