Changes in H reflex and neuromechanical properties of the trapezius muscle after 5 weeks of eccentric training: a randomized controlled trial

Steffen Vangsgaard,¹ Janet L. Taylor,² Ernst A. Hansen,¹ and Pascal Madeleine¹

¹Center for Sensory-Motor Interaction, Department of Health Science and Technology, Aalborg University, Aalborg, Denmark; and ²Neuroscience Research Australia and the University of New South Wales, Sydney, Australia

Submitted 19 February 2014; accepted in final form 30 April 2014

Vangsgaard S, Taylor JL, Hansen EA, Madeleine P. Changes in H reflex and neuromechanical properties of the trapezius muscle after 5 weeks of eccentric training: a randomized controlled trial. J Appl Physiol 116: 1623–1631, 2014. First published May 1, 2014; doi:10.1152/japplphysiol.00164.2014.—Trapezius muscle Hoffman (H) reflexes were obtained to investigate the neural adaptations induced by a 5-wk strength training regimen, based solely on eccentric contractions of the shoulder muscles. Twenty-nine healthy subjects were randomized into an eccentric training group (n = 15) and a reference group (n = 14). The eccentric training program consisted of nine training sessions of eccentric exercise performed over a 5-wk period. H-reflex recruitment curves, the maximal M wave (Mmax), maximal voluntary contraction (MVC) force, rate of force development (RFD), and electromyographic (EMG) voluntary activity were recorded before and after training. H reflexes were recorded from the middle part of the trapezius muscle by electrical stimulation of the C3/4 cervical nerves; Mmax was measured by electrical stimulation of the accessory nerve. Eccentric strength training resulted in significant increases in the maximal trapezius muscle H reflex (Hmax) (21.4% for the eccentric training group; 0.57; P < 0.01), MVC force (26.4% [15.0–37.7]; P < 0.01), and RFD (24.6% [3.2–46.0]; P = 0.025), while no significant changes were observed in the reference group. Mmax remained unchanged in both groups. A significant positive correlation was found between the change in MVC force and the change in EMG voluntary activity in the training group (r = 0.57; P = 0.03). These results indicate that the net excitability of the trapezius muscle H-reflex pathway increased after 5 wk of eccentric training. This is the first study to investigate and document changes in the trapezius muscle H reflex following eccentric strength training.

monosynaptic reflex; shoulder; strength training; human

THE TRAPEZIUS MUSCLE is an important muscle in the upper body (24). This superficial muscle is involved in supporting the body posture and in scapular movements (24, 47) and is often mentioned in musculoskeletal disorders of the upper limbs (43). Interestingly, its motor and sensory innervation is separated into the accessory nerve and the C3/4 cervical nerves, respectively (37). Thus it is possible to evoke Hoffman (H) reflexes in the trapezius muscle with minimal influence of M waves (5, 44, 45). In other muscles, like the soleus muscle, stimulation of a mixed nerve causes the amplitude of the H reflex to increase with stimulation intensity until a number of motor axons are also activated. Hereafter the amplitude decreases until it reaches zero. This is due to collision between action potentials of the evoked reflex response and antidromic action potentials in the motor axons from the electrical stimulation. Consequently, the use of the maximal H reflex as a measure of reflex excitability is questionable (33). This is especially problematic in muscles with a low discrepancy between the threshold for activating Ia afferents and the threshold for activating motor axons (e.g., flexor carpi radialis and quadriceps). Therefore, studying the trapezius muscle H reflex may allow special insight into the modulation of the monosynaptic circuit in different conditions, e.g., following strength training (30).

It is well established that the increases observed in maximal voluntary contraction force (MVC) and maximal rate of force development (RFD) following strength training are not only related to changes in muscle tissue but also to adaptations in the central nervous system (1). However, the underlying neural changes responsible for this are not fully understood (9). Measuring changes in the H reflex may give insight into neural changes at a segmental level. In several studies, the H reflex has been investigated following strength training (4, 15, 16, 20). Although it has been well documented for the soleus muscle that no change occurs in resting H reflexes following strength training, the results regarding H reflexes elicited during voluntary contraction are somewhat contradictory (9). Some studies reported increases in H-reflex amplitudes (4, 9, 15, 20) while others did not observe any differences (12, 16). Increased H-reflex amplitude following training has been suggested to be mediated by changes in either the excitability of the motoneurons or in presynaptic inhibition of Ia afferent synapses (1, 4, 30). However, the specific mechanisms still remain unknown (9).

Eccentric training is associated with a greater improvement in strength compared with concentric training (2, 38). Furthermore, eccentric contractions compared with concentric or isometric contractions at a set load or force require lower levels of electromyographic (EMG) activity, i.e., lower motor unit activation (7). The gain in strength observed in the early phase of training (first 4–8 wk) is primarily due to neural adaptations leading to increased muscle activation (15, 22). In line with this, larger increases in surface EMG activity have been observed after eccentric training compared with concentric training, indicating a greater neural flow in eccentrically trained muscles (23). Neural adaptations at the spinal level have rarely been investigated following eccentric training (15, 16). Moreover, the results from these studies are unclear; Duclay et al. (15) reported an increase in H reflex while Ekblom et al. (16) did not observe any changes. Thus a better understanding of the neuromuscular adaptations to pure eccentric training is needed (25). For effective rehabilitation and exercise training, it is important to understand the extent to which the nervous system adapts to a specific intervention (48).

As previous H-reflex studies, except the early studies by Sale and colleagues (39, 40), have only investigated muscles...
that act around the ankle joint (primarily plantar flexors) (9), information regarding the mechanisms underlying neural adaptation to strength training of the upper body is lacking. Therefore, the main purpose of this randomized controlled study was to obtain measurements of evoked H reflexes from the trapezius muscle, a muscle with separate sensory and motor innervations, in relation to strength training. We hypothesized that the amplitude of the trapezius muscle H reflex would increase following a 5-wk strength training regimen, based solely on eccentric contractions of the shoulder muscles.

METHODS

Subjects

Twenty-nine healthy subjects volunteered to participate in the study (19 women and 10 men). All subjects were right-handed. The following exclusion criteria were applied: 1) previous neurological, musculoskeletal, or mental disorders; 2) regular strength training within 12 mo before the study; 3) pregnancy; 4) addictive or previous addictive behavior defined as the abuse of cannabis, opioids, or other drugs; or 5) inability to cooperate. All participants gave their written informed consent before inclusion in the study. The study was conducted in accordance with the declaration of Helsinki and approved by the local Ethics Committee of North Denmark Region (protocol N-20120036). The study was registered in the International Standard Randomized Controlled Trial Number Register: ISRCTN16080194. Table 1 shows the baseline characteristics of the subjects in the eccentric training group (ECC) and the reference group (REF).

Study Design

All subjects participated in a familiarization session where they were informed about the purpose of the study and the applied methods. Further, participants generated MVC of the right shoulder in isometric condition. The participants were matched in pairs based on the generated MVC force at the familiarization session, and from each pair one participant was randomly allocated into an eccentric training group (ECC) and one to a reference group (REF). Eccentric training was performed for 5 wk. Both groups were tested at baseline (PRE) and after 5 wk of training (POST). The first laboratory session (PRE) was performed 3–7 days before the first training session. The last laboratory session (POST) was performed 3–7 days after the last training session. REF subjects received no training and were asked not to perform any strength training during the study.

Eccentric Training

The eccentric training regimen consisted of nine training sessions of eccentric exercise performed over a 5-wk period (2 training sessions per week for weeks 1, 2, 4, and 5, and 1 training session for week 3). This period was chosen as increased neural activation has been observed following 4 wk of eccentric training (6). All training sessions were supervised by an investigator of the study to ensure full compliance. Training started with a 5-min warm-up of the shoulder region (rotation of the shoulder, shrugs, and arm swings). Unilateral right-shoulder eccentric exercise was performed using the custom-built dynamic shoulder dynamometer (Aalborg University, Aalborg, Denmark). For more details regarding the dynamometer, the reader is referred to Madeleine et al. (28). The subjects were seated in an upright position with back support and no foot support. The back support was adjusted to ensure correct positioning of the shoulder with regards to the shoulder pad of the dynamometer. The participants were equipped with a console to avoid lateral bending during exercise. The range of shoulder elevation was measured using the dynamometer before eccentric exercise. The subjects elevated both shoulders bilaterally as much as possible and then lowered their shoulders again as much as possible while position values of the dominant side were saved. During the eccentric exercise, the subjects acted against the dynamometer that moved from the highest to the lowest vertical shoulder position at a force equal to 60% (training sessions 1–3), 70% (training sessions 4–6), and 80% (training sessions 7–9) of the MVC force recorded at the PRE session. Force feedback was provided using a monitor placed in front of the subjects. The shoulder pad moved with a constant speed of 5.4 mm/s. The number of repetitions was 10, 8, or 6 (training sessions 1–3, 4–6, and 7–9, respectively), performed over 3 sets. The subjects relaxed for ~3 s between contractions and ~2 min after each set. The subjects were encouraged verbally throughout the training sessions.

EMG Recordings

EMG was recorded from the middle section of the trapezius muscle on the right side via a pair of pregelled surface electrodes (20-mm interelectrode distance; Ambu Neuroline 7200k, Ballerup, Denmark) placed on shaved abraded ethanol-cleaned skin (44). EMGs were amplified and band-pass filtered (16–1,000 Hz; 2nd order Butterworth filter) and amplified 1,000 times (CED 1902, quad-system; Cambridge Electronic Devices, Cambridge, UK). Data were sampled at 2 kHz and stored on a computer via a 16-bit A/D converter (CED 1401, Signal 5.07 software; Cambridge Electronic Devices). EMGs were digitally band-pass filtered (10–1,000 Hz; Butterworth, 4th order). All recordings were done in a quiet and temperature-controlled environment.

Force Recordings

The force was recorded with a load cell (SHBxR-200 Kg-C3-SC; Revere Transducers Europe, Hadsund, Denmark). The load cell signal was amplified with a strain gauge amplifier (LAU 73.1; Sensor Techniques, Cowbridge, UK). The force signal was sampled at 2 kHz and digitized via a 12-bit A/D converter (National Instruments PCI-MIO-16-E4, Austin, TX) using LabView (National Instruments) and digitally low-pass filtered at 5 Hz with a second order Butterworth filter.

Percutaneous Stimulation

The present study followed the recommendations for H-reflex recordings proposed by Brinkworth et al. (8) and Zehr (49); acquisition of full recruitment curves, normalization for the size of the reflex, as well as the use of a submaximal level of muscle activity. The latter was also necessary as it was not possible to obtain clear trapezius muscle H reflexes at rest. Maximal M wave (Mmax) was used to account for potential changes in the location of recording electrodes between the two recording days enabling normalization of the size of the H reflex.

During all electrical stimulation, the subjects were seated on an office chair with feet on the floor and their right arm on a supporting bench with ~70° shoulder abduction and 90° of elbow flexion. As differences in body posture affect the H reflex (49), the position of the subjects was carefully noted. The level of muscle contraction was
controlled to ensure a similar level of motoneuron excitability across measures of H reflexes (49). Therefore, before any stimulation maximal EMG was obtained from the middle part of the trapezius muscle over three trials of 3 s of isometric maximal shoulder abduction by lifting the arm against a horizontal bar located just above the supporting bench. A ~30 s rest was given after each trial. The subjects received visual feedback of the root mean square (RMS) EMG computed over 250-ms nonoverlapping epochs (LabView 8.2; National Instruments). A target range was preset to 20 ± 5% of the maximal EMG. When the target range was reached, a trigger signal was sent to the stimulator (Digitimer DS7A; Digitimer, Hertfordshire, UK), allowing the next electrical stimulus to be delivered. Electrical pulses were delivered at intervals no faster than 5 s to minimize postactivation depression (8, 49).

Electrical Stimulation of the Accessory Nerve

Percutaneous electrical stimulation was applied to the accessory nerve. Single electrical pulses of 1-ms duration were delivered at intervals of no less than 5 s with the anode positioned over the mastoid process and the cathode fixed over the accessory nerve. The exact location for the cathode was determined using a hand-held electrode to find the location eliciting the largest M wave in trapezius. The area of search was behind the sternocleidomastoid muscle and between the level of the jaw and the upper border of trapezius. A self-adhesive Ag/AgCl surface electrode was stuck to the skin over the nerve once the location was found.

Electrical Stimulation of the C3/4 Cervical Nerve

Percutaneous electrical stimulation was also applied to the C3/4 cervical nerve. Single electrical pulses (same stimulation as above) were delivered with the anode positioned just below the midpoint of the clavicle and the cathode fixed over the C3/4 cervical nerve. A hand-held electrode was again used to determine the exact location for the cathode, which was placed where an H-reflex could most easily be elicited in the trapezius muscle. The search area was over the anterior surface of the upper fibers of trapezius above the clavicle. A self-adhesive Ag/AgCl surface electrode was stuck to the skin over the nerve once the location was found.

Experimental Procedures

After placement of the surface electrodes, the following measures were collected in the stated order.

Recruitment curves of the M waves and H reflexes. Recruitment curves of the M waves were performed to obtain the maximal trapezius M wave. Accessory nerve stimulus intensity was gradually increased by ~0.5-mA steps until three consecutive recordings showed no further increase in M-wave amplitude despite an increase in stimulus intensity. All recordings of the M wave were done while the subjects were relaxed.

Recruitment curves of the H reflex from the middle part of the trapezius muscle were obtained by gradually increasing C3/4 cervical nerve stimulus intensity by ~0.2-mA steps during the standardized voluntary contraction (20% maximal EMG). Ten stimuli were delivered at each current intensity. The recruitment curve was continued until no further increase in amplitude was detected despite increasing stimulus intensity. The subjects were allowed to take a pause at any time if they reported fatigue.

Maximal muscle force. Immediately after the collection of recruitment curves, the subjects were comfortably seated in the dynamometer. The position of the subjects in the dynamometer was carefully noted to maintain similar conditions across the experimental sessions. Thereafter, the subjects did a warm-up consisting of submaximal isometric elevations of the shoulder (10 repetitions at ~70%, 8 repetitions at ~80%, and 6 repetitions at ~90% of the self-estimated MVC). After a 3-min break, the subjects performed three maximal isometric shoulder elevations of a 5-s duration. Verbal encouragement was given during the MVC. The subjects rested for ~2 min between MVCs. The subjects were instructed to contract as fast and hard as possible. Force feedback was provided by means of a moving bar on a computer screen.

Primary Outcome Measures

H-reflex parameters. Peak-to-peak amplitudes were measured for individual H reflexes and M waves. Before any analysis of the H reflexes, an average was calculated from the amplitude of the 10 individual responses collected at each stimulus intensity. Maximal amplitudes of the M waves and H reflexes (Mmax and Hmax) were identified from the recruitment curves from each nerve. Hmax contains information on the number of motor units reflexly activated; Mmax represents activation of the entire motoneuron pool (33). Thus the Hmax to Mmax amplitude ratio (Hmax/Mmax) was calculated for each subject as it provides information on the proportion of the motoneuron pool being activated in the H reflex. The ascending limb of each H-reflex recruitment curve was fitted using a general least square model of a custom three parameter sigmoid function (26). From the fitted curves, the following H-reflex parameters were identified and analyzed: the slope of the ascending limb of the recruitment curve at 50% of the Hmax value (Hslp) to examine the threshold differences between motoneurons; the current at H-reflex threshold (current at HTH) to examine the excitability of the motoneurons with the lowest threshold values; the current at 50% of Hmax (current at 50%Hmax) to examine the excitability of motoneurons with intermediate threshold values; and the current at Hmax (current at 100%Hmax) to examine the excitability of the motoneurons with the highest threshold values (Fig. 1).

Furthermore, the stimulus intensities associated with the H-reflex parameters from the PRE session were used as inputs to the equations describing the POST recruitment curves (H1/TH, H1/50, and H1/Hmax). With this procedure, the amplitudes of the H-reflex responses were

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Fig. 1. Hoffman (H)-reflex parameters of interest derived from the fitted curves. Example data from 1 test in 1 subject. The analyzed parameters were as follows: maximal amplitude of the normalized H reflex (H1,Hmax; A); 50% of the maximal normalized reflex amplitude (H1,50; B); normalized reflex amplitude at the current at H-reflex threshold (H1,TH; C); the slope of the ascending limb (Hslp, D); current intensity at H-reflex threshold (current at HTH; E); current intensity at 50% of Hmax (current at 50%Hmax; F); and the current at the maximal normalized reflex response (current at Hmax; G).

- Average of 10 reflex responses evoked at a given stimulus intensity. The solid line represents the fitted curve.
compared on a basis of equal current intensities across sessions. Thus the presence or absence of shifts in the recruitment curve at different stimulus intensities, delineating changes in H-reflex excitability, could be investigated (14, 26).

Secondary Outcome Measures

**MVC force.** The MVC force was determined as the maximal value of the force-time curve for each MVC trial. For the statistical analysis the average of the three MVC force values was used.

**Rate of force development.** The RFD was also calculated from the force-time curve for each MVC trial to investigate the early phase of the contraction (20). The RFD was calculated as the slope of the force-time curve (Δforce/Δtime) from contraction onset over an epoch of 500 ms. The contraction onset was set to the time point where the generated force exceeded 10 N. The time epoch was chosen as >500 ms from contraction onset were required to reach MVC force. For the statistical analysis, the average of the three RFD values was used.

**EMG voluntary activity.** For each MVC, RMS values were estimated from the EMG over overlapping 250-ms epochs moving in steps of 100 ms. The maximal RMS (RMS\textsubscript{max}) was extracted from each MVC for the middle part of the trapezius muscle, as an index of efferent neural drive. For the statistical analysis, the average of the three RMS\textsubscript{max} values was used.

All data were analyzed with MATLAB software (The MathWorks, Natick, MA) version 7.13.

Adverse Effects

Eccentric exercise can produce muscle soreness and pain affecting the H-reflex amplitude (45). Therefore, pain in the shoulder region was evaluated using a visual analog scale (VAS) before each testing session. The VAS consisted of a 10-cm line ranging from 0 (no pain) to 10 (worst pain imaginable). The subjects rated the pain intensity felt during daily life activity.

Statistical Analysis

The required sample size was based on the H\textsubscript{max}/M\textsubscript{max} ratios and aimed at detecting a mean difference between the groups in relative change score of 20% with a standard deviation of 15%. With the use of a desired statistical power of 90%, the estimated minimum sample size was nine subjects per group (G*Power 3.1.3; Kiel University, Kiel, Germany). To account for expected dropouts or inability to measure the H reflex (44, 45), 15 and 14 subjects were included in the ECC and REF groups, respectively.

Before statistical comparison, all data were tested for normal distribution by a Shapiro-Wilk test. For normally distributed data, Student’s independent t-test was used to compare PRE and POST values. For data violating the Shapiro-Wilk test, a Mann-Whitney rank sum test was performed. A paired-samples t-test with Bonferroni correction was applied to test changes from PRE to POST in each group. For data violating the Shapiro-Wilk test, a Wilcoxon signed-rank test was performed to compare PRE and POST values. Pearson’s correlation coefficient (r) was used to test for associations between percentage changes in MVC force and RMS\textsubscript{max} and H\textsubscript{max} from PRE to POST in the ECC group. Effect size was calculated for all experimental measures (Cohen’s d). Intraclass correlation coefficients (ICC2,1 for absolute agreement) were used to estimate test-retest reliability for MVC force, RFD, M\textsubscript{max}, H\textsubscript{max}, H\textsubscript{max}/M\textsubscript{max}, and RMS\textsubscript{max} values from the middle part of the trapezius muscle. The ICC values were calculated from the subjects in the REF group.

All statistical calculations were performed in SPSS version 20.0 (IBM, Armonk, NY). Results are reported as mean [95% confidence interval (CI)]. P < 0.05 was considered significant.

RESULTS

At baseline, the ECC and the REF groups were similar with regard to demographics (Table 1), MVC force (see Fig. 5A), RFD (see Fig. 5B), RMS\textsubscript{max}, and H-reflex parameters (Table 2).

Two subjects (1 each group) dropped out after the PRE test. Thus these are not included in the current analysis. Further, four subjects (2 in each group) were excluded from the H-reflex analysis, since H reflexes could be obtained with the hand-held cathode but not with adhesive electrode. Additionally, three subjects (2 from ECC group and 1 from REF group) were excluded from the analysis involving M\textsubscript{max} due to saturation of the responses. Thus 10 participants were included in each group for the analysis of the H\textsubscript{max}/M\textsubscript{max} recruitment curves. Concerning adverse events, no pain during daily life activity following training was reported by the subjects before the testing sessions (VAS was equal to 0).

Reliability

The ICCs between the PRE and POST tests of the REF group were 0.97 for MVC force, 0.97 for RFD, 0.69 for M\textsubscript{max}, 0.85 for H\textsubscript{max}, 0.76 for H\textsubscript{max}/M\textsubscript{max}, and 0.86 for RMS\textsubscript{max}.

Table 2. Mean [95% CI] of the H-reflex parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ECC Group (n = 10)</th>
<th>POST</th>
<th>REF Group (n = 10)</th>
<th>POST</th>
</tr>
</thead>
<tbody>
<tr>
<td>M\textsubscript{max}, mV</td>
<td>6.2 [4.9–7.5]</td>
<td>6.3 [4.7–7.7]</td>
<td>5.8 [4.2–7.3]</td>
<td>7.0 [5.7–8.3]</td>
</tr>
<tr>
<td>H\textsubscript{max}, mV</td>
<td>2.5 [1.7–3.3] *</td>
<td>3.0 [2.0–4.1]</td>
<td>2.4 [1.6–3.3]</td>
<td>2.6 [1.6–3.7]</td>
</tr>
<tr>
<td>H\textsubscript{max}/M\textsubscript{max}</td>
<td>0.33 [0.25–0.40] †</td>
<td>0.42 [0.30–0.53]</td>
<td>0.33 [0.26–0.40]</td>
<td>0.31 [0.20–0.42]</td>
</tr>
<tr>
<td>H\textsubscript{ap}</td>
<td>0.19 [0.09–0.29]</td>
<td>0.16 [0.09–0.23]</td>
<td>0.13 [0.08–0.18]</td>
<td>0.15 [0.06–0.24]</td>
</tr>
<tr>
<td>Current at H\textsubscript{TTH}, mA</td>
<td>1.4 [1.2–1.7]</td>
<td>1.7 [1.1–2.3]</td>
<td>1.2 [0.6–1.7]</td>
<td>1.3 [0.8–1.9]</td>
</tr>
<tr>
<td>Current at 50% H\textsubscript{max}, mA</td>
<td>2.6 [2.0–3.1]</td>
<td>3.5 [2.2–4.7]</td>
<td>2.5 [2.0–3.0]</td>
<td>2.8 [2.3–3.2]</td>
</tr>
<tr>
<td>Current at H\textsubscript{m}, mA</td>
<td>3.8 [2.9–4.6]</td>
<td>5.2 [3.7–4.1]</td>
<td>3.9 [3.4–4.4]</td>
<td>4.2 [3.5–4.8]</td>
</tr>
<tr>
<td>H\textsubscript{TTH} normalized to M\textsubscript{max}</td>
<td>0.04 [0.03–0.05]</td>
<td>0.06 [0.03–0.09]</td>
<td>0.04 [0.03–0.05]</td>
<td>0.03 [0.01–0.05]</td>
</tr>
<tr>
<td>H\textsubscript{SO} normalized to M\textsubscript{max}</td>
<td>0.16 [0.12–0.19]</td>
<td>0.14 [0.08–0.21]</td>
<td>0.16 [0.12–0.19]</td>
<td>0.13 [0.07–0.18]</td>
</tr>
<tr>
<td>H\textsubscript{Hmax} normalized to M\textsubscript{max}</td>
<td>0.28 [0.21–0.34]</td>
<td>0.24 [0.16–0.31]</td>
<td>0.27 [0.20–0.34]</td>
<td>0.25 [0.15–0.35]</td>
</tr>
</tbody>
</table>

M\textsubscript{max}, maximal M wave; H\textsubscript{max}, maximal H reflex; H\textsubscript{ap}, slope of the ascending limb of the recruitment curve at 50% H\textsubscript{max}; H\textsubscript{TTH}, current intensity at H reflex threshold; H\textsubscript{SO}, H\textsubscript{Hmax}, normalized reflex peak-to-peak amplitude at the intensity associated with H\textsubscript{TTH}, 50% of H\textsubscript{max}, and H\textsubscript{max} obtained before training (PRE). For H\textsubscript{max}, n = 12 in the ECC group and n = 11 in the REF group. *P < 0.05, when comparing PRE to after training (POST). †P < 0.05, when comparing relative change score from PRE to POST between the groups. Numbers in italics are significantly different from each other.

J Appl Physiol • doi:10.1152/japplphysiol.00164.2014 • www.jappl.org
H-reflex parameters. The amplitude of the maximal H reflex increased significantly in the ECC group from 2.5 mV (1.7–3.3) to 3.0 mV (2.0–4.1) ($P = 0.01$; Cohen’s $d = 0.32$; Fig. 2A; Table 2), which corresponds to an average relative increase of 21.4% [5.5–37.3] after the eccentric training. No significant change in $H_{\text{max}}$ amplitude (17.5% increase [−17.2–52.1]) was observed in the REF group ($P = 0.45$; Cohen’s $d = 0.13$). The relative change in $H_{\text{max}}$ amplitude from PRE to POST was not significantly different between the groups ($P = 0.84$; Fig. 2B).

In contrast to the increase in $H_{\text{max}}$ amplitude, no significant changes were observed in the $H_{\text{max}}/M_{\text{max}}$ ratio from PRE to POST in either of the two groups ($P = 0.10$ and $P = 0.60$ for the ECC group and REF group, respectively; Fig. 3A). However, the relative change in $H_{\text{max}}/M_{\text{max}}$ ratio from PRE to POST was significantly larger in the ECC group (32.5% [3.4–61.6]; Cohen’s $d = 0.58$) compared with the REF group (−9.4% [−30.0–11.3]; Cohen’s $d = 0.11$; $P = 0.039$; Fig. 3B).

No significant differences were observed in any of the other H-reflex parameters (see Table 2 and Fig. 4). No significant correlation between the change in MVC and the change in $H_{\text{max}}$ of the ECC group ($r = 0.39$; $P = 0.21$) was found.

**Secondary Outcomes**

**MVC force.** Eccentric neck-shoulder training resulted in a significant increase in MVC force of 26.4% [15.0–37.7] from PRE to POST test in the ECC group ($P < 0.01$; Cohen’s $d = 0.44$). No significant change in MVC force was found in the REF group of −7.3% [−14.5 to −0.1] ($P = 0.07$; Cohen’s $d = 0.15$). Furthermore, the relative change in muscle force from PRE to POST between the groups was significantly different ($P < 0.01$; Fig. 5A).

**Rate of force development.** In accordance with the increase in force, the RFD increased significantly (24.6% [3.2–46.0]) in the ECC group ($P = 0.025$; Cohen’s $d = 0.37$; Fig. 5B) after eccentric training and did not change in the REF group (9.0% [−11.7–29.6]; $P = 0.37$; Cohen’s $d = 0.06$). The relative change in RFD from PRE to POST test between the groups was not significantly different ($P = 0.30$).

**EMG voluntary activity.** At baseline, RMS$_{\text{max}}$ was 185.5 $\mu$V [138.6–232.4] for the ECC group and 212.2 $\mu$V [140.7–283.7] for the REF group ($P = 0.54$). In contrast with the increase in MVC force and RFD, the RMS$_{\text{max}}$ recorded during MVC did not significantly change in either group ($P = 0.12$ and $P = 0.68$ for, respectively, the ECC and REF groups). Similarly, the relative change in EMG activity from PRE to POST between the groups (ECC group: 9.8% [−1.9–21.5] and REF group: 2.0% [−13.9–17.9]) was not significantly different ($P = 0.41$).

A significant positive correlation between the relative change in MVC force and relative change in RMS$_{\text{max}}$ of the ECC group ($r = 0.57$, $P = 0.03$) was found.
The main purpose of this randomized controlled study was to investigate changes in the trapezius muscle H reflex to delineate neural adaptations following 5 wk of eccentric strength training. This was the first study to investigate these changes in a muscle with separate sensory and motor innervations. Eccentric training caused a significant increase in the amplitude of the maximal trapezius muscle H reflex (H_max), while all other H-reflex parameters remained unchanged. Furthermore, the eccentric training resulted in significant increases in MVC force (26.4%) and RFD (24.6%) whereas no change was observed in the REF group. The increase in MVC force was positively correlated with the increase in RMS_max from the middle trapezius. However, there was no correlation with the increase in H_max. Finally, the reliability of the investigated parameters was found to be substantial to extremely high.

Reliability

This study demonstrates, for the first time, that the trapezius muscle H reflex can be reliably measured between weeks in healthy young adults. Only one study has previously investigated the trapezius muscle H reflex between days (45). In line with findings from the present study, Vangsgaard et al. (45) observed no significant differences between two sessions before eccentric exercise. However, this is the first study to investigate the trapezius muscle H reflex over an extended period of time. The value of the ICC found in this study for the trapezius H_max (0.85) was “almost perfect” (27). Still, this value is at the lower end of ICC values reported for H_max in other muscles. For the soleus, peroneal, and tibialis anterior muscles, Palmieri et al. (34) found ICCs to be 0.99, 0.99, and 0.86, respectively. For the quadriceps muscle, Hopkins and Wagie (21) reported an ICC of 0.79 between days. In the upper extremity, Stowe et al. (42) reported ICCs for H_max in the extensor carpi radialis longus and flexor carpi radialis muscles to be 0.94 and 0.99, respectively. In muscles like soleus and tibialis anterior, the M wave accompanying the H reflex is typically used to control for constant axonal stimulation and, hence, constant synaptic input to the alpha motoneurons (41, 49). However, as the motor and sensory innervations are divided into the accessory nerve and the C3/4 cervical nerves, respectively, this is not possible for the trapezius muscle. Similarly, normalization of the stimulation intensity with respect to the stimulation intensity used for M_max (14, 46) is rendered impossible for the trapezius muscle. The reported ICC values and the lack of significant changes in any of the experimental parameters in the control group suggest that the observed increases in MVC force, RFD, and H_max amplitude were related to eccentric training.

![Fig. 4. Recruitment curves calculated from the average parameters (Table 2) obtained before (PRE) and after (POST) eccentric training.](image-url)
Changes in MVC Force, RFD, and EMG Voluntary Activity

After 5 wk of eccentric training, the MVC force increased on average by 26.4%. This is in line with previous findings (11, 15, 35). Although no significant changes were observed in \( \text{RMS}_{\text{max}} \) after the eccentric training, the variation in \( \text{RMS}_{\text{max}} \) in the ECC group corresponded with the increase in strength and accounted for 33% of the variation in MVC force. This suggests that neural adaptations contribute to the increase in MVC force (1). In line with the increase in maximal strength, the RFD increased on average by 24.6% following the training. This is the first study to report an increase in isometric RFD following pure eccentric training of the shoulder region. An increase in RFD has previously been explained by increases in efferent neural drive (3, 20). However, fiber-type composition has also been proposed to affect the RFD (19). As eccentric training has been suggested to recruit more type II fibers than concentric contractions (23, 31), altered motor unit recruitment in combination with neural changes may have contributed to the increased RFD observed following training. All in all, these results underlined that substantial strength improvement can be achieved following pure eccentric training.

Increase in Maximal H Reflex Following Eccentric Training

For the first time, measurements of the trapezius muscle H reflex were obtained to investigate neural adaptations in the shoulder region following pure eccentric strength training. The maximal H-reflex amplitude (H\(_{\text{max}}\)) increased, suggesting that neural adaptations occur in the initial phase of a strength training program focused on the shoulder region (4, 9). The finding of an increase in H\(_{\text{max}}\) following strength training is in line with most previous findings (4, 9, 15, 20). Additionally, an increase in H-reflex amplitude of the soleus and medial gastrocnemius muscles has previously been observed following pure eccentric strength training as investigated in the present study (15). In other muscles, like the soleus muscle, H\(_{\text{max}}\) represents the point where a further increase in stimulation intensity either does not yield a further increase in net excitatory input to the motoneurons or reduces the H reflex size due to collision of action potentials from the reflex response with antidromic impulses in the motor axons (29). The latter makes interpretation of H\(_{\text{max}}\) difficult. However, as previously reported, M\(_{\text{max}}\) does not usually limit H\(_{\text{max}}\) in the trapezius muscle (44). Hence, the plateau reached at H\(_{\text{max}}\) is assumed to represent the maximal net excitation to the motoneurons in the trapezius muscle. That is, either 1) all Ia afferents are recruited by the H-reflex stimulus, or 2) enough Ib afferents are recruited such that disynaptic inhibition counteracts any extra Ia excitation brought about by increasing stimulus intensity, or 3) there is a large gap in recruitment threshold to the next motoneuron to be recruited and, therefore, potential additional excitation is not effective. Thus the increase observed in H\(_{\text{max}}\) amplitude after the eccentric training either reflects an increase in net excitation to the trapezius motoneurons and/or more excitability of the subliminal fringe motoneurons (9, 29, 30). Moreover, the increase in net excitation may arise from 1) an increase in excitatory input, i.e., more group Ia (or group II) input; and/or 2) a decrease in inhibitory input (presumably group Ib afferents). In this study, all H reflexes were collected with a controlled background level of EMG, which was set at 20% of the maximal EMG in each session. This was done to control the motoneuron output and thereby minimize changes in motoneuron excitability. It is notable that no changes were observed in threshold or slope of the H-reflex recruitment curve. This possibly argues against 1) a change in the recruitment gain of the motoneuron pool and, hence, a change in the excitability of motoneurons in the subliminal fringe; and 2) a blanket increase in excitatory input at all stimulus intensities, as might be expected if presynaptic inhibition of the Ia fibers was reduced. Thus a differential effect on higher threshold motoneurons or their inputs, or a change in the balance of excitatory and inhibitory inputs as additional afferents are activated with higher stimulus intensities, is postulated to explain the observed increase in maximal H-reflex amplitude.

The sensory Ib afferents from the Golgi tendon organs have previously been suggested to inhibit muscle activity at high force levels to preserve muscles and connective tissues from injury (2, 13). Strength training has previously been proposed to reduce the neural inhibition and thereby increase the generated MVC (2). Interestingly, Hortobágyi et al. (23) suggested that eccentric training downscaled inhibition more effectively than concentric training. However, as no experimental data yet support this idea, it has been considered speculative (10). Here, neural modulation following eccentric exercise was only observed at H\(_{\text{max}}\), suggesting a change in the recruitment of the higher threshold motoneurons or the balance of input from higher threshold afferents. Thus it may be possible that the increased H reflex observed in the current study is mediated by decreased inhibition from Ib afferents and, hence, an altered balance between Ia input (monosynaptic excitation) and Ib input (disynaptic inhibition).

According to the Henneman size principle, motoneurons are recruited by Ia synaptic input in an orderly fashion from the smallest to the largest (36). The investigation of the entire recruitment curves has been recommended as this allows different levels of stimulus intensities, and thereby motor units of different thresholds, to be compared between sessions (49). To the best of our knowledge, only two previous studies have investigated changes in the entire H-reflex recruitment curve following strength training (14, 46). In contrast to the findings from the present study, Vila-Chã et al. (46) reported a decrease in the current intensity to elicit a threshold H reflex of the plantar flexors, suggesting that the excitability only changed for the low-threshold motor units. Similar results have been presented by Dragert and Zehr (14), who reported an increase in amplitude of the threshold H reflex following high-intensity isometric training of the dorsiflexors. However, this was accompanied with a decrease of the maximal H reflex. The conflicting results may be explained by the different methodologies applied to record the H reflexes (e.g., differences in the level of contraction) and/or the differences in training modalities. However, it might also be possible that different neural adaptations to training are present in upper and lower limbs as differences in neural activation have been suggested (18, 32).

Methodological Considerations

The strengths of the present study include a robust design (a randomized, controlled trial) and the reliable methodology used to record trapezius muscle H reflexes. All training sessions were supervised leading to 100% compliance to the training program. Further, the focus of the training was spe-
cifically on the trapezius muscle. These elements suggest that it was possible to assess genuine effects of the intervention. A limitation of the study may be that only neural changes in the H reflex were investigated. In a recent study, Fouré et al. (17) reported specific changes in muscles and tendons involved in plantar flexion following an eccentric strength training program. Thus insight into the mechanical properties of the muscle tendon complex following the training program may have increased the practical implications of the findings. Further studies investigating the effects of eccentric training on the trapezius muscle H reflex in patients with, e.g., rotator cuff injury are needed.

Conclusion
The findings from the present study suggest that the net excitability of the trapezius muscle H-reflex pathway increased after 5 wk of eccentric training. Moreover, the increase in strength was associated with an increase in RMS$_{max}$ and RFD suggesting a general increase in efferent neural drive. We propose that the increased H reflex following eccentric training could be explained by decreased Ib inhibition of motoneurons. This is the first study to investigate and document changes in trapezius muscle H reflex following strength training consisting of pure eccentric contractions of the muscles from the shoulder region.

ACKNOWLEDGMENTS
We are grateful to Dr. Afshin Samani, Center for Sensory-Motor Interaction (SMI), Aalborg University for providing a visual feedback interface.

GRANTS
The study was partly supported by grants from the Ministry of Culture Committee on Sports Research in Denmark and the Danish Rheumatism Association.

DISCLOSURES
No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS
Author contributions: S.V., J.L.T., E.A.H., and P.M. conception and design of research; S.V. performed experiments; S.V., J.L.T., E.A.H., and P.M. analyzed data; S.V., J.L.T., E.A.H., and P.M. interpreted results of experiments; S.V., J.L.T., E.A.H., and P.M. prepared figures; S.V. drafted manuscript; S.V., J.L.T., E.A.H., and P.M. edited and revised manuscript; S.V., J.L.T., E.A.H., and P.M. approved final version of manuscript.

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