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# Experimental muscle pain changes the spatial distribution of upper trapezius muscle activity during sustained contraction

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**Abstract**

*Objective:* To investigate the effect of local excitation of nociceptive muscle afferents on the spatial distribution of muscle activity.
*Methods:* Surface electromyographic (EMG) signals were recorded from the upper trapezius muscle of 10 healthy volunteers with a $5 \times 13$ electrode grid during 90-s isometric contractions before, during, 15 and 30 min after intramuscular injection of hypertonic (painful) or isotonic (non-painful) saline. From the multi-channel EMG recordings, two-dimensional maps of root mean square and mean power frequency were obtained. The centre of gravity of the root mean square map was used to quantify global changes in the spatial distribution of muscle activity.
*Results:* During sustained contractions, average root mean square increased, average mean frequency decreased and the centre of gravity moved cranially. During experimental muscle pain, compared to before injection, the average root mean square decreased and there was a caudal shift of the centre of gravity. Fifteen minutes after the painful injection the centre of gravity returned to its original position.
*Conclusions:* Short-term dynamic reorganization of the spatial distribution of muscle activity occurred in response to nociceptive afferent input.
*Significance:* The study furnishes an extension of the pain adaptation model indicating heterogeneous inhibition of muscle activity.


*Keywords:* Surface EMG mapping; Two-dimensional arrays; Muscle plasticity

## 1. Introduction

Afferent peripheral inputs modulate muscle activation pattern, e.g., motor unit recruitment and discharge rates (Enoka, 1995). Small diameter groups III and IV muscle afferents are sensitive to noxious mechanical and chemical stimuli (Mense and Meyer, 1985). Bolus or continuous intramuscular injection of algogenic substances, e.g., hypertonic saline is a well-established method to induce pain in a localized part of the muscle (Stohler and Lund, 1994; Arendt-Nielsen et al., 1997).

When nociceptive afferents are excited, maximal voluntary contraction force is reduced (Graven-Nielsen et al., 1997a). Moreover, nociceptive input causes a complex functional reorganization of muscle synergies that depends on the motor task (Arendt-Nielsen et al., 1996; Madeleine et al., 1999a,b). Within the reorganization of muscle coordination, most studies showed reduced electromyographic (EMG) activity in the painful muscle, which was interpreted as an inhibitory mechanism reflecting adaptation to pain (Lund et al., 1991; Arendt-Nielsen et al., 1996; Graven-Nielsen et al., 1997a; Madeleine et al., 1999a,b; Farina et al., 2004). Motor unit studies provided evidence of

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decreased motor unit discharge rates with muscle pain without changes in muscle fiber membrane properties (Sohn et al., 2000; Farina et al., 2004, 2005b), in agreement with the reduction of global muscle activity.

Both intramuscular and classic single-channel surface EMG techniques provide information on a relative small portion of the muscle and do not allow the investigation of the spatial distribution of activity within a single muscle. The extension of the classic bipolar surface EMG technique to one- or two-dimensional electrode arrays (Masuda and Sadoyama, 1987; Prutchi, 1995; Kleine et al., 2000) provides topographical mapping of muscle activity (Kleine et al., 2000; Lapatki et al., 2004; Holtermann et al., 2005). The technique has been termed high-density surface EMG since it detects EMG signals from a number of closely located points over the same muscle (Staudenmann et al., 2005; Lapatki et al., 2004, 2006), thus providing a spatial sampling of the skin surface electric potential due to muscle activation. High-density surface EMG disclosed heterogeneities in muscle activation during both short and sustained contractions (Holtermann et al., 2005), thus indicating possible spatial adaptation of activation within individual muscles during, e.g., muscle pain or fatigue.

We hypothesized a spatial, within-muscle reorganization of activation in response to excitation of nociceptive muscle afferents. Under this hypothesis, we expected global changes in the high-density surface EMG mapping in response to pain, which would demonstrate for the first time functional muscular plasticity mediated by nociceptive afferent input.

## 2. Methods

### 2.1. Subjects

Ten right-handed male volunteers, without any histories of neck–shoulder pain, participated in the study [means ± SD, age 23.9 ± 1.9 years, body mass 71 ± 4.7 kg, height 1.78 ± 0.06 m, body mass index 20.2 ± 7.3]. The Local Ethics Committee approved the study (approval number VN 2004/56) and the subjects gave their informed consent prior to inclusion.

### 2.2. Experimental muscle pain

One 0.5-ml bolus of hypertonic saline (5.8%) was injected into the belly of the right or left upper trapezius muscle with a 27 G × 3/4 in. cannula over 15 s. The injection point was 2-cm lateral to the halfway point between the spinous process of the seventh cervical vertebra (C7) and the lateral edge of the acromion. Saline mostly spreads along the muscle fiber direction and minimally in the transversal direction (Graven-Nielsen et al., 1997b), thus after the injection it was mostly concentrated along the C7-acromion line. Contralateral injection of isotonic saline, used as a control, was administered in the same quantity and location as hypertonic saline. The administration of hypertonic or isotonic saline was randomized for shoulder side and order of injection and subjects were blinded as to the sequence applied. Rating of perceived pain intensity was assessed after each contraction on a 100-mm visual analogue scale defined as 0: 'no pain' and 100: 'most pain imaginable'.

### 2.3. General procedures

Each subject attended a single experimental session in which both hypertonic (painful) and isotonic (non-painful) saline were injected into the left and right upper trapezius muscle (randomized order). The subjects were seated upright in a comfortable chair with their hip and knee joints flexed at 90°. The recordings session started 5 min after the placement of EMG electrodes (see below). The session consisted of four recordings before, during (30 s after injection), 15 and 30 min after injection of either hypertonic or isotonic saline separated by 15-min rest. The subjects were asked to hold both arms at 90° abduction for 90 s, with elbows fully extended and forearms 90° pronated with palm facing toward the ground without hand load corresponding to 15–20% of the maximum voluntary contraction of the trapezius muscle (Mathiassen et al., 1995). Two flexible bars placed at shoulder level were used to provide tactile position feedback to the subject. Moreover, two templates placed behind and on the side of the subject were used by the experimenter to ensure the same position of the neck and head in all contractions. At the end of each contraction, the subject rated the perceived exertion on a 100-mm visual analogue scale defined as 0: 'no perceived exertion' and 100: 'maximal perceived exertion' (corresponding to the endurance). Room temperature was kept constant at 24 ± 1 °C during the entire experimental session.

### 2.4. Surface EMG recording and analysis

Surface EMG signals were detected with a semi-disposable adhesive grid of 64 electrodes (LISiN-Spes Medica, Italy, model ELSCH064; Fig. 1). The grid consists of 13 rows and 5 columns of electrodes (2-mm diameter, 8-mm inter-electrode distance in both directions) with a missing electrode at the upper right corner. The missing electrode was considered the origin of the coordinate system to define electrode location. The silver–silver chloride electrode surfaces in the grid are separated from the skin by a small cavity (~1-mm thick) filled with electrolyte gel. The EMG signals were bipolarly amplified 5000 times (64-channel surface EMG amplifier, SEA64, LISiN-OT Bioelectronica, Torino, Italy; 3-dB bandwidth, 10–500 Hz), sampled at 4096 Hz, and A/D converted in 12 bits (National Instrument® acquisition board, Austin, USA).

Before placement of the grid, the main innervation zone of the upper trapezius muscle along the C7-acromion line was identified in a few test contractions with a linear array of 8 electrodes (silver bars, 5-mm long, 1-mm diameter,