

The Location of Peak Upper Trapezius Muscle Activity During Submaximal Contractions is not Associated With the Location of Myofascial Trigger Points: New Insights Revealed by High-density Surface EMG

Barbero, Marco; Falla, Deborah; Mafodda , L; Cescon, Corrado; Gatti, Roberto

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1
2 **THE LOCATION OF PEAK UPPER TRAPEZIUS MUSCLE ACTIVITY**
3 **DURING SUBMAXIMAL CONTRACTIONS IS NOT ASSOCIATED WITH**
4 **THE LOCATION OF MYOFASCIAL TRIGGER POINTS: NEW INSIGHTS**
5 **REVEALED BY HIGH DENSITY SURFACE EMG**
6

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8 Barbero M¹ , Falla D^{2,3} , Mafodda L⁴ , Cescon C¹ , Gatti R⁴

9
10 ¹Department of Health Sciences, University of Applied Sciences and Arts of Southern Switzerland,
11 SUPSI, Manno, Switzerland.

12 ²Pain Clinic, Center for Anesthesiology, Emergency and Intensive Care Medicine, University
13 Hospital Göttingen, Göttingen, Germany

14 ³Institute for Neurorehabilitation Systems, Bernstein Focus Neurotechnology (BFNT) Göttingen,
15 Bernstein Center for Computational Neuroscience, University Medical Center Göttingen, Georg-
16 August University, Göttingen, Germany

17 ⁴Rehabilitation Department, San Raffaele Hospital, Milan, Italy
18

19 Corresponding author:

20 Marco Barbero, Rehabilitation Research Laboratory, Department of Business Economics, Health
21 and Social Care. University of Applied Sciences and Arts of Southern Switzerland (SUPSI), Via
22 Violino, Stabile Piazzetta, 6928 Manno, Switzerland.

23 Phone: +41(0)58 666 64 35

24 Mobile: +41(0)78 737 58 70

25 E-mail: marco.barbero@supsi.ch

26
27 The authors certify that they have NO affiliations with or involvement in any organization or entity
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31 **ABSTRACT**

32 **AIM:** To apply topographical mapping of the electromyography (EMG) amplitude recorded from
33 the upper trapezius muscle to evaluate the distribution of activity and the location of peak activity
34 during a shoulder elevation task in subjects with and without myofascial pain and trigger points
35 (MTrP) and compare this location with the site of the MTrP.

36 **METHODS:** Thirteen subjects with myofascial pain and MTrP in the upper trapezius muscle and
37 12 asymptomatic subjects participated. High-density surface EMG was recorded from the upper
38 trapezius muscle using a matrix of 64 surface electrodes aligned with an anatomical landmark
39 system (ALS). Each subject performed a shoulder elevation task consisting of a series of 30 s
40 ramped contractions to 15% or 60% of their maximal voluntary contraction (MVC) force.
41 Topographical maps of the EMG average rectified value were computed and the peak EMG
42 amplitude during the ramped contractions was identified and its location determined with respect to
43 the ALS. The location of the MTrP was also determined relative to the ALS and Spearman's
44 correlation coefficients were used to examine the relationship between MTrP and peak EMG
45 amplitude location.

46 **RESULTS:** The location of the peak EMG amplitude was significantly ($p < 0.05$) different between
47 groups (subjects with pain/MTrP: -0.32 ± 1.2 cm at 15% MVC and -0.35 ± 0.9 cm at 60% MVC
48 relative to the ALS; asymptomatic subjects: 1.0 ± 1.3 cm at 15% MVC and 1.3 ± 1.1 cm relative to
49 the ALS). However, no correlation was observed between the position of the MTrP and peak EMG
50 amplitude during the ramped contractions at either force level (15%: $r_s = .039$, $p = .9$; 60%: $r_s = -$
51 $.087$, $p = .778$).

52 **CONCLUSION:** People with myofascial pain and MTrP displayed a caudal shift of the distribution
53 of upper trapezius muscle activity compared to asymptomatic individuals during a submaximal
54 shoulder elevation task. However, for the first time, we show that the location of peak muscle
55 activity is not associated with the location of MTrP.

56

57 **INTRODUCTION**

58 Myofascial trigger points (MTrP) are considered to be a common cause of primary or
59 secondary muscle pain. Local or referred pain elicited by active MTrP can contribute to pain
60 symptoms in people with several different musculoskeletal conditions [1-5]. Although several
61 factors, such as muscle trauma, repetitive low-intensity muscle overload, intense muscle
62 contraction, or psychological stress, have been suggested to play an important role in the activation
63 of MTrP, the etiology remains speculative [6-8].

64 Hubbard and Berkoff conducted the first needle electromyography (EMG) investigation of
65 MTrP in the upper trapezius muscle and described two abnormal patterns; a low amplitude
66 persistent activity of 50 μ V and intermittent higher amplitude spike-like activity of 100-700 μ V [9].
67 Such spontaneous and persistent background EMG activity of the MTrP were supported by further
68 investigations [10-13]. However, the origin of such activity has been debated. Possible explanations
69 include dysfunctional endplates located nearby the MTrP [14-16].

70 More recently, Chung et al measured EMG from seven subjects with MTrP in the trapezius
71 muscle. Needle EMG was recorded from the tender area and control sites at various depths for a
72 prolonged time. All subjects exhibited a reliable resting EMG signal identified at subject-specific
73 depths which were not associated with general muscle activation [17]. The atypical electrical
74 activity was interpreted as motor unit action potentials and their prevalence closely correlated with
75 the pressure pain threshold of the MTrP [13]. Furthermore, a study evaluating people with latent
76 MTrP in the upper trapezius muscle documented early myoelectric manifestations of fatigue of the
77 upper trapezius during sustained isometric contractions, and notably the muscle fibers close to the
78 latent MTrP exhibited an anticipated and significant increase in surface EMG amplitude [18]. An
79 increase of the intramuscular EMG amplitude of the trapezius muscle has also been observed in
80 subjects with latent MTrP during synergistic muscle activation [19].

81 Based on these observations, it may be expected that the distribution of activity of the upper
82 trapezius muscle would be different in people with MTrP and that the location of the peak activity

83 may even be located at the site of the MTrP. However, until now, methodological limitations have
84 prevented this investigation.

85 High-density, two-dimensional surface EMG provides a measure of the electric potential
86 distribution over a large surface area during muscle contraction [20-22]. Unlike classic bipolar
87 EMG applications, this method provides a topographical representation of EMG amplitude, and can
88 identify the intensity of activity within regions of a muscle and the location of the peak EMG
89 amplitude across a large region of the muscle. High-density EMG studies have confirmed that either
90 acute experimental muscle pain [23] or chronic clinical pain [24, 25] may alter the distribution of
91 muscle activity and may cause a shift of the peak muscle activity. Considering these findings, it
92 may be speculated that a long-lasting nociceptive irritant, such as a MTrP, could induce a spatial
93 reorganization of muscle activity however this has never been evaluated.

94 In this study we extracted topographical maps of the upper trapezius surface EMG amplitude
95 to evaluate the distribution of muscle activity and the location of peak activity during a submaximal
96 shoulder elevation task in subjects with and without myofascial pain and MTrP within the upper
97 trapezius muscle. For the first time, we examined the relationship between the location of the MTrP
98 spot tenderness and the location of the peak EMG amplitude. We hypothesized that the distribution
99 of upper trapezius muscle activity and therefore the location of the peak activity during a shoulder
100 elevation task would be different in people with MTrP compared to those without and that the
101 location of the peak may correspond to the location of the spot tenderness.

102

103 **METHODS**

104 Experimental sessions were conducted between May and June 2012 in the Laboratory of
105 Movement Analysis at Vita-Salute San Raffaele University, Milan, Italy. The study was approved
106 by the Internal Ethics Committee and conducted in accordance with the Declaration of Helsinki. All
107 participants signed an informed consent form before enrolling in the study.

108

109 *Participants*

110 A convenience sample of twelve asymptomatic subjects (seven men; age, mean \pm SD: 21.8 \pm
111 1.4 years) and 13 (six men; age: 22.8 \pm 3.5 years) individuals with myofascial pain and the
112 presences of at least one MTrP in right upper trapezius muscle participated in the study following
113 advertisement at the Vita-Salute San Raffaele University. The inclusion criteria for asymptomatic
114 subjects were no sign or symptom of musculoskeletal pain in the cervical region, thoracic region
115 and upper limb, and the absence of a clinically relevant MTrP in the right upper trapezius muscle.
116 The inclusion criteria for the symptomatic group was at least one clinically relevant MTrP [26] in
117 the right upper trapezius muscle and reported pain over the upper trapezius muscle in the last 2
118 weeks. All subjects in both groups were right hand dominant. The exclusion criteria for both groups
119 were: history of neurological or rheumatic disorders, cervical radiculopathy or radicular pain in the
120 previous 6 months, whiplash injury in the previous 6 months, the presence of mental or emotional
121 disorders, the presence of scars or moles in the area of the upper trapezius muscle, pregnancy, and a
122 body mass index of 30 or higher.

123 The clinical examination to detect the presence of MTrP was performed by an expert
124 physiotherapist with more than 10 years of experience in the diagnosis and management of
125 myofascial pain syndromes. Diagnostic criteria for a clinically relevant MTrP were: the presence of
126 a palpable taut band, the presence of spot tenderness within the taut band, and the elicitation by
127 manual palpation of either one or a combination between pain recognition and referred pain [26].
128 Pain recognition was defined as the reproduction of a familiar pain by manual compression of the
129 MTrP spot tenderness. If more than one MTrP was detected, the MTrP which elicited a familiar
130 pain was considered. If the subject was not able to distinguish between two MTrPs and they
131 reported familiar pain at both sites, the examiner asked the subject to identify the most painful
132 MTrP on palpation.

133

134

135 *Procedure*

136 The subject was seated with their back supported, knees and hips flexed to 90° and their arms
137 by their side in a relaxed position. An operator marked a standardized anatomical landmark system
138 (ALS) over the right shoulder region of all subjects while they were seated [27]. The ALS consisted
139 of a line between the spinous process of the seventh cervical vertebrae and the acromial angle (X-
140 axis), and a second line perpendicular to the first passing through its midpoint (Y-axis). The
141 distance between the spinous process of the seventh cervical vertebrae and the acromial angle was
142 measured using a measuring tape.

143 A palpation examination was performed on all subjects. For the subjects with myofascial
144 pain, the examination was performed to confirm the presence of a clinically relevant MTrP, while
145 for asymptomatic subjects it was performed to exclude the presence of any MTrP and specifically
146 any spot tenderness within any taut band of the upper trapezius muscle. For the subjects with
147 myofascial pain and MTrP, the examiner marked the location of the MTrP on the skin using a
148 custom designed stamp (1 cm² circle with a dot in the centre). The dot in the centre was overlapped
149 with the spot tenderness, and its distance from the X- and Y-axes of the ALS was measured with a
150 measuring tape. Pain pressure threshold (PTT) over the spot tenderness was recorded using an
151 algometer (Wagner Instruments, Greenwich, CT, USA). The contact area of the algometer tip was 1
152 cm² and the application rate was approximately 1 kg/s. PPT was measured three times over 10 s
153 intervals, and the average value was recorded as the PPT.

154 Two adjustable straps connected to the load cells were positioned over the acromion of both
155 shoulders (Figure 1). The subject was instructed to keep their trunk against the back of the chair and
156 both the straps were tensioned to avoid any shoulder movements. The subject was then instructed
157 to perform a shoulder elevation task that consisted of pushing up both shoulders towards the ceiling.
158 Two maximal voluntary contractions (MVCs) of shoulder elevation were performed, each lasting
159 ~4 sec with 2 min rest in between. The subjects were asked to reach their maximum force gradually
160 and were verbally motivated by the investigator. For each of the two MVC contractions, the average

161 value around the maximum force was considered and the highest of the two values was taken as the
162 reference MVC. After ~2 min of rest the subject performed a series of 6 ramped contractions from
163 0-15-0% and 0-60-0% MVC each of 60 sec duration. The order of the ramp contractions was
164 alternated (15%, 60%, 15%, 60%, 15%, 60%). Visual feedback was provided by means of a moving
165 arrow and two moving bars on a screen positioned ~1 m in front of the subject. EMG and force
166 signals were acquired during each contraction.

167

168 *Electromyography*

169 Surface EMG was detected in a monopolar referenced configuration with a semidisposable
170 adhesive grid of electrodes (model ELSCH064, OT-Bioelettronica, Torino, Italy). The grid
171 consisted of 13 rows and 5 columns of electrodes with one electrode absent at the lower left corner.
172 The diameter of each electrode is 2 mm and the inter-electrode distance 8 mm in both directions.

173 Firstly, the innervation zone of the upper trapezius was identified using a linear electrode
174 array and the electrode grid was then positioned medial to this point, with the fourth row along the
175 X-axis of the ALS (Figure 2). The rows of the electrode grid were positioned parallel to the line
176 between C7 and the acromion. The grid was fixed to the skin with double adhesive tape following
177 skin preparation by gentle local abrasion with abrasive paste and cleansing with water. The
178 electrode cavities were filled with conductive paste to ensure a proper electrode-skin contact.

179 The EMG signals were amplified (EMG-USB2 amplifier, OT-Bioelettronica, Torino, Italy),
180 sampled at 2048 Hz and stored on a PC after 16 bit A/D conversion. A reference electrode was
181 placed around the right wrist.

182

183 *Force*

184 Shoulder elevation force was measured with two load cells that operated linearly in the
185 range 0–1000 N (Mod. TF2/S, CCT Transducers, Torino, Italy). The load cells, fixed on a wooden
186 plate on the ground, were secured over the subject's shoulders (over the acromion) with two

187 adjustable straps. The force signals were amplified (MISO-II, OT-Bioelettronica, Torino, Italy,
188 bandwidth 0–80 Hz) and stored on a PC (sampling rate 2048 Hz; 12 bit A/D converter). The force
189 signal was presented as visual feedback to the subjects during the shoulder elevation tasks.

190

191 *Signal processing*

192 For each of the two force levels, the force and EMG signals of the three ramp contractions
193 were visually inspected, and the best of the three (in terms of EMG signal quality and precision of
194 the force with respect to the target) was selected and used for further analysis. Single differential
195 (SD) signals were computed for each pair of adjacent electrodes by differentiating the monopolar
196 signals of the adjacent columns (SD longitudinal along the direction of the muscle fibers). The last
197 row of channels (13th) was excluded from further analysis because of the absent electrode in the
198 lower left corner, in order to have a rectangular grid of 12x4 SD channels. The SD signals were
199 digitally filtered with a 4th order Butterworth noncausal filter (20– 450 Hz) in order to reduce
200 instrumentation noise and slow transients, and divided in epochs of 1 sec. Average rectified values
201 (ARV), were computed for each channel and for each epoch. The ARV computed in each channel
202 were combined to generate a 12x4 topographical map of EMG amplitude (ARV) (Figure 2). The
203 maps of ARV were computed for each epoch and the maximum value was extracted from each row
204 of each map, leading to a vertical vector of 12 elements for each epoch. The values for the 60
205 epochs were stored in a table of 12x60 elements where the rows represented the positions of the
206 electrode in the Y-axis direction and the columns represented the time instants and displayed as
207 color images (Figure 3). The peaks of the ARV maps were computed for each time instant and
208 traced over the images, in order to describe the location of EMG signal amplitude of the upper
209 trapezius muscle. The distance between EMG peaks and MTrP location was computed in the Y-axis
210 direction in order to describe the distance between MTrP and the most active muscle fibers of the
211 upper trapezius, which are assumed to be parallel to the ALS (Figure 4).

212 The error of the force with respect to the target force was computed as the mean of the
213 absolute difference between the actual force and the requested force profile (equivalent to the ARV
214 of the error). The error was normalized with respect to the instantaneous target force values and
215 expressed as a percentage (% TF). The analysis was performed separately for 15% and 60% ramps
216 and also for the two portions of the ramps (*up and down slope*). The force error provides an
217 indication of the accuracy of task performance.

218

219 *Statistical analysis*

220 A Shapiro-Wilk test for normality was performed ($p < 0.05$) on all dependent variables and
221 indicated the need to use non-parametric statistical methods. Mann-Whitney U test was used to test
222 for a differences in the accuracy of force between groups and to test for a difference between groups
223 in EMG amplitude, normalized with respect to the ARV computed during MVC (ARV_n), at
224 different force levels (5-10-15 % MVC or 20-40-60 % MVC) Friedman test was used to determine
225 if there were differences in the position of peaks of the EMG signal amplitude during the ramps at
226 different force levels (5-10-15 % MVC or 20-40-60 % MVC) in both subject groups. Mann-
227 Whitney U test was used to test for a difference in the position of peaks of EMG signal amplitude
228 during both ramps between groups.

229 Descriptive statistics were used to determine the location of the peaks of EMG signal
230 amplitude according to the ALS, and their distances along the Y-axis from the MTrP location
231 during both ramp contractions. In the subjects with pain and MTrP, Spearman correlation analysis
232 was carried out to test whether there was any significant relationship between the location of the
233 peak of EMG signal amplitude and the MTrP location during both ramp contractions.

234 Statistical analyses were performed with SPSS Version 22.0 (IBM Corp., Armonk, NY,
235 USA). Statistical significance was set to $\alpha = .05$.

236

237

238 **RESULTS**

239 Clinical features of the individuals with myofascial pain and MTrP in right upper trapezius
240 are summarized in Table 1. None of the asymptomatic subjects showed the presence of spot
241 tenderness within their right upper trapezius.

242 All subjects completed the submaximal shoulder elevation tasks. The groups were similar at
243 modulating shoulder elevation force according to the visual feedback during both ramped
244 contractions, and there was no significant difference in task performance between groups. The force
245 errors are presented in Table 2 and confirm that both groups were able to perform the task with the
246 same degree of accuracy. Moreover no significant differences were observed between the force
247 errors computed in the two portions of the ramps or between the different force levels (15% and
248 60% MVC).

249 Values of ARVn obtained during the ramped contractions for both groups are summarized
250 in Figure 5a and 5b. A significant difference between groups was detected at 15% MVC ($p = .046$)
251 and 5% MVC (down slope, $p = .040$). The position of the peak EMG amplitude did not differ across
252 the different force levels of the 15% MVC ramped contractions for either group (Friedman's test:
253 asymptomatic, $p = .644$; pain and MTrP; $p = .140$), whilst it did change significantly across the
254 different force levels of the 60% MVC ramped contraction for both groups (Friedman's test:
255 asymptomatic, $p = .008$; pain and MTrP; $p = .001$). The position of the EMG peak amplitude was
256 significantly different between groups for the ramped contractions at 15% MVC ($p = .010$), 10%
257 MVC (down slope, $p = .016$), 5% MVC (down slope, $p = .007$), 60% MVC ($p = .019$) and 40%
258 MVC (down slope, $p = .026$) (Figure 5c and 5d).

259 The location of the peak EMG amplitude in the participants with pain and MTrP was $-0.32 \pm$
260 1.2 cm at 15% MVC and -0.35 ± 0.9 cm at 60% MVC relative to the ALS. In the asymptomatic
261 subjects, the peak EMG amplitude was 1.0 ± 1.3 cm at 15% MVC and 1.3 ± 1.1 cm at 60% MVC
262 relative to the ALS. The distance between the peak EMG amplitude and the location of the MTrP
263 along the Y-axis was 1.51 ± 1.19 cm and 1.34 ± 1.00 cm at 15% and 60% MVC respectively

264 (Figure 6). No correlation was observed between MTrP and the peak EMG amplitude position
265 during the ramped contractions at either force level (15%: $r_s = .039$, $p=.9$; 60%: $r_s = -.087$, $p=.778$).

266

267 **DISCUSSION**

268 This study evaluated the topographical distribution of upper trapezius muscle
269 activation in people with and without myofascial pain and MTrP in the upper trapezius muscle
270 during a shoulder elevation task. The results showed that the two groups were similar at
271 modulating shoulder elevation force according to the visual feedback during both ramped
272 contractions, and there was no significant difference in task performance between groups. Upper
273 trapezius EMG amplitude was modulated with force intensity and notably the people with
274 myofascial pain and MTrP in the upper trapezius muscle showed higher activity, with this
275 becoming statistically significant at the peak of the 15% MVC ramped contraction and at the end of
276 down slope of the 15% MVC ramp (i.e. 5% MVC). Importantly, a difference in the location of peak
277 upper trapezius muscle activity was also noted between groups both at the peaks of the ramps (15%
278 MVC and 60% MVC) and during the down slope which partially supports our hypothesis.
279 Specifically, the data showed that the peak EMG amplitude was located at a more caudal location in
280 the subjects with myofascial pain and MTrP compared to the asymptomatic controls. The MTrP
281 were located in a well-defined area of the upper trapezius muscle as previously observed [15].
282 However, novel to this study, we showed that there was no spatial correlation between the location
283 of the MTrP and the position of the peak EMG amplitude. MTrPs are typically defined as a
284 peripheral pain generator that may induce central sensitization. Proposed treatments such as dry
285 needling and ischemic compression are passive and usually active exercise to address motor control
286 are not considered. The present results support previous findings of altered muscle activation in
287 people with myofascial pain during shoulder abduction [28] and provide the basis for future
288 research on the role of active exercise in the treatment of myofascial pain.

289

290 The observed change in the peak position during the course of ramped contractions reflects
291 progressive recruitment or derecruitment of motor units and/or modulation of the discharge rate of
292 motor units in different locations within the upper trapezius muscle. Previous work has shown that
293 the upper trapezius muscle shows non-uniform activation and that not all regions within the upper
294 trapezius muscle adapt in the same way to load [22, 29, 30], fatigue or pain [31, 32]. Our results
295 confirm the non-uniform activation of the upper trapezius muscle and, similar to the results
296 Holtermann and Roeleveld which showed that the activation of the upper trapezius muscle is not
297 spatially uniform during intense ramp contraction, the current data also showed variation of the
298 location of the peak EMG amplitude, but only during the 60 % MVC ramped contraction [33]. On
299 the contrary we did not detect a change in peak EMG amplitude location during the low level force
300 ramp to 15% MVC probably due the limited force modulation requested during this task.

301 The location of peak muscle activity occurred within the upper region of the upper trapezius
302 muscle where the fascicles act as an agonist for shoulder elevation and facilitate stabilization of the
303 scapula [34, 35]. However, the region of peak muscle activity was located at a more caudal location
304 for the subjects with pain MTrP. This observation is in line with previous studies investigating the
305 effects of experimentally induced muscle pain on the spatial distribution of upper trapezius activity
306 [23, 36, 37]. Specifically, it has been shown that acute muscle pain induces a caudal shift of the
307 upper trapezius muscle activity and this occurs regardless of the site of noxious stimulation within
308 the upper trapezius muscle [23]. Thus the current results provide further evidence of a change in the
309 spatial distribution of upper trapezius muscle activity in painful conditions. Considering that the
310 subjects with pain showed higher activity in regions of the muscle which would not normally be as
311 active, this change in the pattern of muscle activation can be considered as an inefficient motor
312 strategy which may even perpetuate the painful condition in the long term.

313 A main aim of the study was to examine the relationship between the location of the MTrP
314 and the location of the peak EMG amplitude. The data show that, despite the caudal shift of the
315 distribution of upper trapezius muscle activity in the subjects with pain, there was no association

316 between the location of peak muscle activity and the location of MTrP. Thus we could not confirm
317 that the muscle fibers close to the MTrP exhibit a significant increase in surface EMG amplitude, as
318 some previous reports suggest [18]. This is a novel finding which provides new insight into the
319 association between peak muscle activity and the location of MTrP. We suggest that when the
320 upper trapezius muscle is painful, the motor adaptation aims preferentially to minimize activation of
321 the cranial region; possibly because this region has higher pain sensitivity [38].

322

323 *Limitations*

324 When considering the reported results, it important to remark that we established the
325 location of each MTrP using its spot tenderness and by identifying a discrete point according to the
326 ALS. However, MTrP hyperalgesia, defined using spot tenderness, may not be limited to a discrete
327 point and may extend through the taut band. We did not collect information regarding the presence
328 of additional MTrP in the symptomatic group which may be a limitation of the study.

329 Our symptomatic group were fairly homogenous for most of the clinical features assessed
330 and only one subject didn't recognize familiar pain upon palpation of the MTrP. More than half of
331 the subjects complained of referred pain during the spot tenderness compression. The MTrP were
332 located in well-defined area of the upper trapezius muscle as already observed in two recent studies
333 that adopted the same ALS [15, 27]. Although we did not distinguish between active and latent
334 MTrP in the current study, all of the symptomatic subjects except for one, respected the criteria for
335 active MTrP [28] and showed low PPT when compared to both active and latent MTrP recently
336 observed in two clinical studies [30, 31].

337 The sample size was small and was not determined *a priori*. Rather, we recruited subjects
338 based on convenience sampling and sought to recruit a similar size which was sufficient to show
339 differences between painful and non-painful conditions in previous high-density EMG studies
340 [23,24]. Despite being small, the sample size was sufficient in this study to show group differences.
341 Nevertheless, it important to note that the enrolled subjects were highly selective (i.e. relatively

342 young with pressure-sensitive MTrP in the right upper trapezius muscle, as evidenced by their
343 relatively low PPT). Thus extrapolation of these findings to different populations should be done
344 with caution. Moreover, it should also be noted that the subjects included in this study reported
345 acute pain (onset within the previous two weeks) and different observations may be expected in
346 people with long-standing symptoms.

347 The EMG peak position was established during a shoulder elevation task using a
348 standardized positioning of subjects. But small changes of posture may have occurred during the
349 contractions which may have affected the peak position of upper trapezius muscle activity.
350 However, an investigator carefully monitored the subjects' posture to ensure a consistent starting
351 posture and performance during the task therefore variations in posture are unlikely to explain the
352 differences observed between groups.

353 The upper trapezius muscle is complex muscle which is activated during many movements
354 and different tasks. In this study we evaluated peak activity of the upper trapezius muscle during
355 shoulder elevation since the upper trapezius acts as an agonist during this task. However,
356 generalization of the results to different movements and tasks should be done with caution.
357 Moreover, we did not measure resting EMG, which, considering the results of earlier studies, may
358 have differed between groups.

359

360 **CONCLUSION**

361 During an isometric submaximal shoulder elevation task, the location of peak upper
362 trapezius muscle activity was located more caudal in people with myofascial pain and MTrP when
363 compared to asymptomatic individuals indicating a different motor strategy for the task. This
364 change in the topographical distribution of muscle activity may have a role in the clinical course of
365 myofascial pain. However, the location of peak muscle activity was not associated with the specific
366 location of MTrP.

367

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481

482 **TABLE LEGENDS**

483 **Table 1.** Clinical features of the enrolled individuals with myofascial pain and MTrP in right upper
484 trapezius. Third to sixth column indicates the positivity for the MTrP criteria, the 7th column
485 indicates the spot tenderness location according to the ALF, the last column reports the PPT over
486 the spot tenderness.

487

488 **Table 2.** Force errors during the ramp contractions computed for the two portions of each ramp (up
489 and down slope). The error was computed as the mean of the absolute difference between the actual
490 force with respect to the theoretical force profile requested. The error was normalized with respect
491 to the instantaneous target force values and expressed as a percentage (% TF).

492

493 **FIGURE LEGENDS**

494 **Figure 1.** Experimental setup, subjects sat in a chair with their trunk against the chair. Two
495 adjustable straps, connected to load cells (Mod. TF2/S, CCT Transducers, Torino, Italy) fixed on a
496 wooden plate, were tensioned over the acromion of both the shoulders. The subject was instructed
497 to perform a shoulder elevation task that consisted in pushing up both shoulders towards the ceiling.
498 An electrode matrix (model ELSCH064, OT-Bioelettronica, Torino, Italy) was placed on the upper
499 trapezius, and a visual feedback was provided means of a moving arrow and two moving bars on a
500 screen.

501

502 **Figure 2.** A) Position of the electrode grid over the right upper trapezius muscle. The electrode
503 grid was positioned on the anatomical reference system (ALS), medially to the innervation zone and
504 with the fourth row along the X-axis. An example of an EMG amplitude map (12x4 elements) of a
505 single epoch (1 sec.) is superimposed over the electrode grid. B) Example of single differential
506 EMG signals detected from each row (1 to 12) of the grid is shown.

507

508 **Figure 3.** Representation of average rectified values (ARV) extracted for the 60 epochs during the
509 ramp contractions at 15 and 60% MVC recorded from representative subjects: two asymptomatic
510 subjects (A,C) and two subjects with pain and MTrP in the right upper trapezius (B,D). Black
511 curves represent the location of the ARV peak along the Y-axis for each time instant.

512

513 **Figure 4.** Examples of topographical maps of the average rectified value (ARV) detected at the
514 time instant corresponding to the maximal force value during ramped contractions at 15% and 60%
515 MVC from representative asymptomatic subjects and subjects with pain and MTrP during ramped
516 contractions at (A) 15% and (B) 60% MVC. The grey circles represent the location of the MTrP
517 according to the ALS.

518

519 **Figure 5.** Mean (\pm SD) of the (A,B) normalized average rectified values (ARV) and (C,D) ARV
520 peak position recorded from asymptomatic subjects and subjects with pain and MTrP during
521 ramped contractions at 15% and 60% MVC. * = $p < 0.05$

522

523 **Figure 6.** Location of the MTrP according to the ALS (grey circles). Blue and red rectangles
524 represent the distribution (mean and SD) of the EMG amplitude peaks computed at the maximum
525 value of both ramped contractions at 15% and 60% MVC in the asymptomatic subjects and subjects
526 with pain and MTrP (blue and red respectively).

527