Activation EMG pattern during isokinetic knee flexion-extension assessment: comparison between healthy subjects and chronic pain patients

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Introduction

Isokinetic testing has been increasingly used to assess muscle performances in patients suffering from chronic pain [7,11,13,14]. Surface electromyography (EMG) is a common scientific tool allowing an objective assessment of muscular fatigability [1,3,15,17,18,26]. Impaired maximal isometric and isokinetic muscle performances have been reported in several studies dealing with fibromyalgia and chronic low back pain patients (FM and CLBP patients) [7,10,11,13,20]. The respective influence of physiological, psychological and deconditioning factors still remains controversial [16]. EMG pattern activity during isokinetic efforts appears little documented [12,24]. According to Robertson et al., isokinetic torque values appeared correlated to the agonist muscle activation. Tesch et al. [24] described an increase of vastus lateralis (VL) and rectus femoris (RF) integrated EMG activity during an endurance knee extension test performed in concentric mode at 180°/s. EMG has been extensively used to explore muscle function in patients with chronic pain. Nevertheless, to our knowledge, no study has yet compared FM and CLBP patients with regard to muscle performances and EMG patterns.

Hence the aims of this study were as follows:

(1) evaluate the isokinetic concentric strength and fatigue of knee flexors and extensors in sedentary healthy women and in women suffering from fibromyalgia or CLBP,
(2) measure in these populations the EMG activity patterns during the isokinetic strength and fatigue assessments.

Material and methods

Populations

All subjects received a complete explanation of the investigation purposes and gave their consent. This study was approved by the Ethical Committee of the University of Liege Medical Center.

Control group

The control subjects were fifteen women (45 ± 10 years old, 66 ± 11 kg) without joint or muscle injury. They performed on average 0.7 hour of recreational sport activities per week.

FM patients Group

Ten women (50 ± 5 years old, 71 ± 11 kg) meeting American College of Rheumatology Criteria for FM syndrome were included. The duration of symptoms ranged from 1 to 6 years and 3 patients were in paid jobs. The mean time spent in physical activities only reached 0.5 hour per week on average.

Chronic low back pain patients group

Ten women (45 ± 10 years old, 66 ± 6 kg) suffering from chronic low back pain (without pain irradiation in the leg or diffuse pain history) participated in this study. The symptom duration ranged from 1 to 5 years. Only 4 patients were in paid jobs and the mean time spent in physical activities was on average 0.6 hour per week.

Methods

After a warming-up consisting in 5 minutes of unload stationary cycling at 50 rotations per minute (rpm) followed by static stretching of quadriceps and hamstrings, subjects performed a concentric isokinetic test on their dominant leg by means of a Cybex Norm dynamometer (Henley Healthcare, Sugerland, Texas, USA). The range of motion during testing consisted in 100 degrees of flexion from the full active (0°) extension. Each subject was seated with the trunk and the dominant leg fixed. The dynamometer axis of rotation was aligned with the knee center of rotation (in 90° flexed position).

Submaximal efforts of knee flexors and extensors (at 120°/s angular velocity) was allowed in order to familiarize with the isokinetic exercises. Three preliminary submaximal repetitions preceded each test speed.

The testing protocol started with the strength assessment by means of 3 maximal repetitions at 60°/s and 5 maximal repetitions at 180°/s. The analysis was based on peak torques (PT in N.m) and bodyweight normalized peak-torques (NPT in N.m/kg). Thereafter, subjects performed the fatigue assessment consisting in 30 maximal-intensity knee flexion and extension at the angular velocity of 180°/s. Fatigue was expressed by the cumulative work (CW in J) and the bodyweight normalized cumulative work (NCW in J/kg) determined by summing up the work developed by both muscle groups.

EMG activity was recorded from the vastus medialis (VM), rectus femoris (RF), internal hamstring (IH) and external hamstring (EH). The ground reference electrode was secured over the tibia. Prior to electrode placement, the skin was rigorously cleaned with alcohol wipes. In order to locate electrodes (silver / silver chloride surface) accurately, we identified muscle areas thanks to a maximal voluntary isometric effort from the seated (VM and RF) and prone (IH and EH) positions. The distance between the centers of the recording electrodes was 20 mm. EMG data and torque were sampled at 1000 Hz and recorded using a Noraxon Myosystem Software. All EMG signals were rectified and smoothed (RMS 50). The average root mean square (RMS) was used as a measure of muscular activity. Agonist and antagonist EMG activities (e.g. flexor muscles recruitment respectively during flexion and extension) were expressed in absolute (µV) and peak torque (PT) normalized values (µV/N.m).

Immediately after the isokinetic assessment, participants completed a 10 cm visual analogue scale (VAS) for pain intensity estimate: the distance was scored from 0 to 10 arbitrary units (a.u.), 0 a.u. corresponding to the absence of pain and 10 a.u. to the maximum pain.

Data analysis

An analysis of variance (ANOVA) was used for each variable in order to examine the difference between the 3 populations. Student's paired t-test allowed to compare results recorded at both speeds. An ANOVA test was used to examine fatigue effects on agonist and antagonist EMG activities of each muscle group throughout the thirty repetitions.

Results

Isokinetic strength and fatigue

The PT, NPT, CW and NCW parameters were significantly lower in FM patients comparatively to the control group but also to the patients suffering from chronic low back pain. Impairment affected more knee flexors than knee extensors (Table I).

By contrast, the isokinetic muscle profile did not differ significantly between the control group and the low back pain patients

EMG pattern during isokinetic strength assessment

The agonist electrical activity (expressed in absolute and normalized values) of VM, RF, IH and EH was recorded during the isokinetic strength assessment at 60°/s and 180°/s angular velocities. No significant difference was observed between the control group and both groups of chronic pain patients (Table II).

We determined a specific EMG pattern for knee extensors and flexors, based on EMG activities recorded respectively from VM and RF and from IH and EH. The agonist recruitment of both muscle groups was significantly influenced by velocity in the control group in contrast to the chronic pain populations (Table III).

The normalized EMG activity Ext/Fl ratio calculated in the 3 groups of subjects appeared significantly lower at low velocity (60°/s) than at high velocity (180°/s).

EMG pattern during isokinetic fatigue assessment

We determined the agonist and the antagonist EMG activities of VM, RF, IH and EH during the isokinetic fatigue assessment. Four sequences consisting in 3 consecutive flexion-extension movements were compared: 1st to 3rd repetitions, 9th to 11th repetitions, 18th to 20th repetitions and 28th to 30th repetitions.

Whatever the sequence, the agonist and antagonist EMG activities did not significantly differ between the three populations. By contrast with the steady agonist EMG activity of the knee flexors (IH and EH), we observed a moderate agonist EMG activity increase of VM and RM in the control group and in the chronic pain patients (Figures 1 and 2). The antagonist EMG activities increase at the end of the fatigue assessment reached + 2 % to + 29 % depending on the muscle and the population studied (no significant difference).

The curve profiles of agonist (Figures 1 and 2) and antagonist (Figures 3 and 4) EMG activities were similar in control group and chronic pain patients.

Discussion

In this study, we compared muscle performances and EMG patterns in a control group and in two groups suffering from chronic pain: fibromyalgia and chronic low back pain patients. Variables reflecting isokinetic strength and muscle fatigue resistance were significantly lower in the FM group compared to the control group and the CLBP patients.

The FM patients muscular performances impairment is well documented [7,11,13]. It could be related to the anticipation of pain, pain itself, central alterations or mechanisms induced by a deconditioning syndrome. The predominant reduction of isokinetic strength on knee flexors may be explained by our testing procedure which requires successive repetitions of knee flexions and extensions without period of rest. In contrast to other studies, knee muscle performances did not differ between healthy women and CLBP patients. Lee et al. [10] found a significant reduction in knee flexors and extensors strength in CLBP patients. Schipplein et al. [21] and Trafimow et al. [25] suggested that quadriceps muscle performance limits the CLBP patients' ability to lift with their knee flexed. In our study, the similar isokinetic performances in the control and CLBP groups may be explained partly by our exclusion criteria (absence of leg irradiation). Furthermore, the populations were drastically paired for age, weight and daily physical activities.

To our knowledge, no comparative study of muscle performances in FM and CLBP patients appears in the literature. The comparison of both populations suffering from chronic pain showed higher isokinetic strength and muscle fatigue resistance in CLBP patients. The diffuse pain in FM patients may explain these observations. At the end of the isokinetic assessment, VAS pain score reached respectively 0.68 a.u. and 2.7 a.u. in control and CLBP groups (non significant difference). By contrast, the VAS pain score in FM averaged 5.3 a.u. ($p < 0.05$).

Agonist electrical activities of VM, RF, IH and EH recorded during the isokinetic strength assessment were not significantly different among our populations. Simons and Mense [23] reported absence of rest EMG activity increase in patients suffering from chronic pain. Sihvonen et al. [22] described trunk flexors and extensors activity decrease, in CLBP patients, when they have an agonist function in dynamic movements.

In the control group, we demonstrated a significant influence of velocity on agonist EMG activity of knee flexors and extensors. According to Robertson et al. [19], torque production is strongly related to EMG activity in the biceps femoris and vastus lateralis. These authors observed that increased torque was associated with increased EMG activity. Croce et al. [2] found that knee flexors PT was higher when the ankle was fixed in dorsiflexion compared to plantarflexion. This increased PT was not combined with concomitant EMG activity increase. However, according to these authors, the results were not in contradiction with Robertson's study. Croce et al. [2] suggested that the higher knee flexors PT was due to a greater gastrocnemius contribution as knee flexors, which explains the absence of repercussion in hamstring EMG activity. In our study, no significant relation between PT (which were significantly reduced at 180°/s compared to 60°/s) and EMG activity was observed in the two populations suffering from chronic pain. These results suggested that chronic pain syndrome may influence the motor units recruitment.

We determined the knee flexors and extensors EMG pattern. The normalized Ext/Fl ratio of EMG activity increased significantly with speed in the 3 groups. This observation may be related to the muscular typology; Garret et al. [5] demonstrated a higher proportion of fast twitch motor units in hamstrings than in the quadriceps. Faulkner et al. [4] suggested that, at high contraction velocities, slow twitch motor units were less able to contribute to power than at slow contraction velocities. Therefore, FT motor units contribution may be more important at 180°/s. This fact may also explain that knee flexors EMG activity increases less than quadriceps muscle EMG activity (composed of a higher number of ST motor units) when speed gets higher. Results of the present study indicated an

Normalized EMG activity Ext/Fl ratio of inferior to 1 in the control group. This observation may also be related to the different fiber types proportions in knee flexors and extensors. In fact, Gerdle et al. [6] reported a positive correlation between RMS and the percentage of type II muscle fibers during 100 maximal dynamic knee extensions at 90°/s. The higher ratio found in our chronic pain populations may be explained by a modified typology consecutive to a deconditioning syndrome or a reduction of daily physical activities.

In the isokinetic fatigue assessment, we examined the agonist and antagonist EMG activities throughout 4 serials of contractions. The signal amplitude (RMS) reflects the recruitment of motor units. The literature describes a RMS increase during prolonged static submaximal contractions [8]. EMG pattern during repeated dynamic movements is less documented. Larsson's study showed good reproducibility for maximal isokinetic knee extension PT and RMS during three sets of 10 contractions [9]. Lindström and Gerdle [12] investigated the interrelationships between RMS and peak torque throughout 100 successive maximal isokinetic contractions of both knee flexors and extensors. They reported a RMS increase during the initial 20 contractions, followed by relatively stable RMS levels throughout the subsequent contractions [12]. At the end of the test, a tendency towards decreased levels appeared [12]. According to these authors, no significant difference in EMG behavior between extensor and flexor muscles existed. Contrarily, our study revealed that unlike the knee flexors activity (IH and EH activities), the agonist EMG activity of VM and RM moderately increased. Our results may differ from those of Lindström and Gerdle, due to our specific protocol. Several mechanisms may be responsible for changes in the RMS and it remains difficult to interpret the EMG activity measured during maximal dynamic effort. Unexpectedly, agonist and antagonist activites of the chronic pain groups did not differ from those of the control group for each repetitions serial investigated in the present study.

Curve profiles of agonist or antagonist EMG activites were similar in the control group and the chronic pain patients. Consequently, the chronic pain syndrome appears to be not related to the EMG pattern during isokinetic fatigue assessment.

Conclusion

FM patients isokinetic muscular performances were significantly decreased in comparison with the control and the CLBP groups. Results of these last two populations did not differ significantly. Agonist electrical activities recorded during the isokinetic strength assessment were similar in the 3 studied groups. In the control subjects, we demonstrated a significant influence of velocity on agonist EMG activity of knee flexors and extensors. The normalized EMG activity Ext/Fl ratio increased significantly with speed in the 3 populations. During the isokinetic fatigue assessment, the curve profiles of agonist and antagonist EMG activities were identical in the control group and the chronic pain groups. In contrast with the knee flexors agonist EMG activity, we observed a moderate agonist EMG activity increase of VM and RF.

References

1. B. Bigland-Ritchie, EMG/force relations and fatigue of human voluntary contractions, In: *Exercise and sport sciences reviews*, Miller D, ed, Philadelphia: Franklin Institute Press, 1981, pp. 75-117.

2. R.V. Croce, J.P. Miller and P. St. Pierre, Effect of ankle position fixation on peak torque and electromyographic activity of the knee flexors and extensors, *Electromyogr. Clin. Neurophysiol.* **40** (2000), 365-373.

3. C. De-Luca, Myoelectric manifestations of localised muscular fatigue in humans, *Crit. Rev. Biomed. Eng.* **11** (1984), 251-279.

4. J.A. Faulkner, D.R. Clafin and K.K. McCully, Power output of fast and slow fibers from human muscles. In: *Human muscle power Human Kinetics*, N.L. Jones, N. McCartney, A.J. McComas, eds, Champaign IL., 1986, pp. 81-94.

5. W. Garrett, J. Califf and F. Basett, Histochemical correlates of hamstring injuries, *Am. J. Sports Med.* **12** (1984), 98-103.

6. B. Gerdle, S. Karlsson, A.G. Crenshaw et al., The influences of muscle fibre proportions and areas upon EMG during maximal dynamic knee extensions, *Eur. J Applied Physiol.* **81** (2000), 2-10.

7. S. Jacobsen, G. Wildschiodtz and B. Danneskold-Samsoe, Isokinetic and isometric muscle strength combined with transcutaneous electrical muscle stimulation in primary fibromyalgia syndrome, *J. Rhematol.* **18** (1991), 1390-1393.

8. K.C. Jurell, Surface EMG and fatigue, *Electromyography* **9** (1998), 933-946.

9. B. Larsson, B. Mansson, C. Karlberg et al., Reproducibility of surface EMG variables and peak torque during three sets of ten dynamic contractions, *J. Electromyogr. Kinesiol.* **9** (1999), 351-357.

10. J.H. Lee, Y. Ooi and K. Nakamura, Measurement of muscle strength of the trunk and the lower extremities in subjects with history of low back pain, *Spine* **18** (1995), 1994-1996.

11. M.H. Lindh, L.A. Johansson, M. Hedberg et al., Studies on maximal voluntary muscle contraction in patients with fibromyalgia, *Arch. Phys. Med. Rehabil.* **75** (1994), 1217-1222.

12. B. Lindström and B. Gerdle, The interrelationships between EMG, peak torque and perceived fatigue during repeated maximum isokinetic knee flexion with and without active knee extension, *Physiother. Theory Prac.* **10** (1994), 17-25.

13. D. Maquet, J.L. Croisier, C. Renard et al., Muscle performance in patients with fibromyalgia, *J. Bone Spine* **69** (2002), 293-299.

14. A.M. Mengshoel, O. Forre and H.B. Komnaes, Muscle strength and aerobic capacity in primary fibromyalgia, *Clin. Exp. Rheumatol.* **8** (1990), 475-479.

15. T. Oberg, Muscle fatigue and calibration of EMG measurements, *J. Electromyogr. Kinesiol.* **5** (1995), 239-243.

16. N.J. Olsen and J.H. Park, Skeletal muscle abnormalities in patients with fibromyalgia, *Am. J. Med. Sci.* **315** (1998), 351-358.

17. J. Potvin and L. Bent, A validation of techniques using surface EMG signals from dynamic contractions to quantify muscle fatigue during repetitive tasks, *J. Electromyogr. Kinesiol.* **7** (1997), 131-139.

18. J.A. Psek and E. Cafarelli, Behavior of coactive muscles during fatigue, *J Appl Physiol* **74** (1993), 170-175.

19. R.N. Robertson, L.R. Osternig, J. Hamill et al., EMG-torque relationships during isokinetic dynamometer exercise, *Sports Training Med. Rehab.* **2** (1990), 1-10.

20. S.H. Roy, C.J. De Luca and D.A. Casavant, Lumbar muscle fatigue and chronic lower back pain, *Spine* **14** (1989), 992-1001.

21. O.D. Schipplein, J.H. Trafimow, G.B. Andersson et al., Relationship between moments at L5/S1 level, hip and knee joint when lifting, *J. Biomech.* **23** (1990), 907-912.

22. T. Sihvonen, J. Partanen, O. Hänninen et al., Electrical behaviour of low back muscles during lumbar pelvic rhythm in low back pain patients and healthy controls, *Acta Phys. Med. Rehab.* **72** (1991), 1080-1087.

23. D.G. Simons and S. Mense, Understanding and measurement of muscle tone as related to clinical muscle pain, *Pain* **75** (1998), 1-17.

24. P.A. Tesch, G.A. Dudley, M.R. Duvoisin et al., Force and EMG signal patterns during repeated bouts of concentric or eccentric actions, *Acta Physiol. Scand.* **138** (1990), 263-271.

25. J.H. Trafimow, O.D. Schipplein, G.J. Novak et al., The effects of quadriceps fatigue on the technique of lifting, *Spine* **18** (1993, 364-367.

26. J. Viitasalo and P. Komi, Signal characteristics of MEG during fatigue, *Eur. J. Appl. Phys.* **37** (1977), 111-121.

Table I: NPT (N.m/kg), CW (J) and NCW (J/kg) developed by knee flexors and extensors (means and SD): comparison between control subjects, FM patients and CLBP patients

Variables	Test modalities	Control group	FM group	CLBP group
Strength measurements				
FLE				
NPT (N.m/kg)	C60°/s	0.97 (0.27) [a]	0.64 (0.21) [b]	0.88 (0.25) [a]
	C180°/s	0.71 (0.18) [a]	0.49 (0.15) [b]	0.7 (0.14) [a]
EXT				
NPT (N.m/kg)	C60°/s	1.77 (0.37) [a]	1.34 (0.23) [b]	1.68 (0.37) [a]
	C180°/s	1.07 (0.2) [a]	0.86 (0.2) [b]	1.14 (0.28) [a]
Fatigue measurements				
FLE + EXT				
CW (J)	C180°/s	3058 (839) [a]	2278 (394) [b]	2755 (564) [a]
NCW (J/kg)	C180°/s	47 (12) [a]	33 (7) [b]	42 (9) [a]

Difference in letters represents a significant difference ($p < 0.05$); C, concentric

Table II: Agonist electrical activities of VM, RF, IH and EH recorded during the isokinetic strength assessment (means and SD): comparison between control subjects, FM patients and CLBP patients.

Muscles	EMG activities	Control group	FM group	CLBP group
VM				
C 60°/s	Absolute (µV)	177 (58) [a]	172 (86) [a]	169 (111) [a]
	Normalized (µV/N.m)	1.61 (0.69) [a]	1.83 (0.79) [a]	1.5 (0.75) [a]
C 180°/s	Absolute (µV)	167 (56) [a]	180 (72) [a]	171 (104) [a]
	Normalized (µV/N.m)	2.45 (0.92) [a]	3.03 (1.15) [a]	2.23 (0.94) [a]
RF				
C 60°/s	Absolute (µV)	158 (48) [a]	135 (57) [a]	132 (75) [a]
	Normalized (µV/N.m)	1.41 (0.49) [a]	1.45 (0.64) [a]	1.2 (0.55) [a]
C 180°/s	Absolute (µV)	137 (46) [a]	137 (56) [a]	131 (85) [a]
	Normalized (µV/N.m)	2.02 (0.78) [a]	2.34 (1.1) [a]	1.73 (0.73) [a]
IH				
C 60°/s	Absolute (µV)	228 (108) [a]	155 (63) [a]	167 (82) [a]
	Normalized (µV/N.m)	3.66 (1.56) [a]	3.55 (1.11) [a]	2.94 (1.41) [a]
C 180°/s	Absolute (µV)	191 (69) [a]	157 (62) [a]	153 (65) [a]
	Normalized (µV/N.m)	4.26 (1.61) [a]	4.63 (1.36) [a]	3.44 (1.57) [a]
EH				
C 60°/s	Absolute (µV)	177 (83) [a]	202 (94) [a]	177 (104) [a]
	Normalized (µV/N.m)	2.8 (1.08) [a]	4.77 (2.28) [a]	3.15 (1.85) [a]
C 180°/s	Absolute (µV)	161 (72) [a]	208 (108) [a]	172 (88) [a]
	Normalized (µV/N.m)	3.51 (1.43) [a]	6.23 (2.88) [b]	3.86 (2.14) [a]

Difference in letters represents a significant difference ($p < 0.05$) ; C, concentric

Table III: Agonist electrical activities of knee extensors and flexors recorded during the isokinetic strength assessment (60°/s and 180°/s)

EMG activities		C 60	C 180	p
Extensors				
Control				
	agonist (µV)	168 (48)	152 (43)	**0.003**
FM				
	agonist (µV)	153 (68)	159 (61)	0.37
CLBP				
	agonist (µV)	150 (91)	151 (94)	0.79
Flexors				
Control				
	agonist (µV)	203 (92)	176 (65)	**0.01**
FM				
	agonist (µV)	179 (75)	182 (73)	0.72
CLBP				
	agonist (µV)	172 (91)	162 (74)	0.22

C, concentric

Table IV: Comparison of normalized EMG activity Ext / Fl ratio recorded during the isokinetic strength assessments (60°/s and 180°/s)

Ratio Ext / Fl	C 60	C 180	p
Control	0.55 (0.27)	0.68 (0.34)	0.003
FM	0.8 (0.1)	1 (0.16)	0.03
CLBP	0.92 (0.15)	1.12 (0.15)	0.004

Figures Legends

Figure 1: Evolution profile of RF agonist EMG activity recorded during the isokinetic fatigue assessment (control subjects, FM patients and CLBP patients).

Figure 2: Evolution profile of EH agonist EMG activity recorded during the isokinetic fatigue assessment (control subjects, FM patients and CLBP patients).

Figure 3: Evolution profile of RF antagonist EMG activity recorded during the isokinetic fatigue assessment (control subjects, FM patients and CLBP patients).

Figure 4: Evolution profile of EH antagonist EMG activity recorded during the isokinetic fatigue assessment (control subjects, FM patients and CLBP patients).

Figure 1

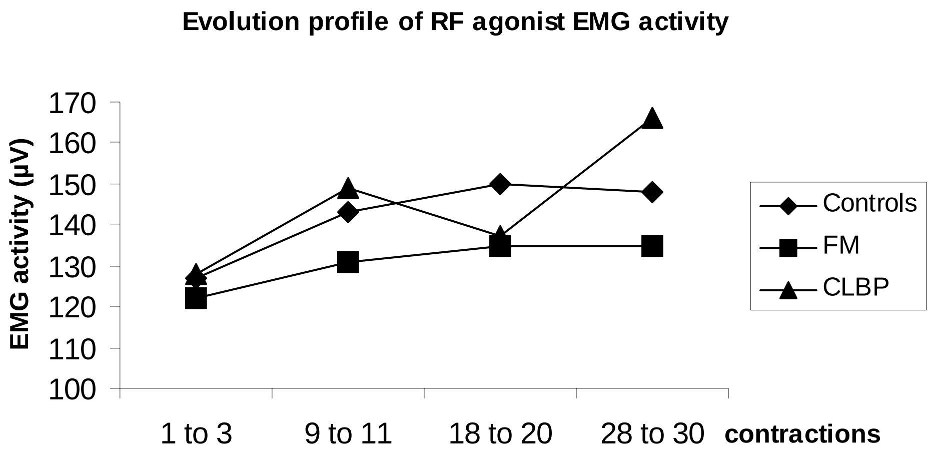
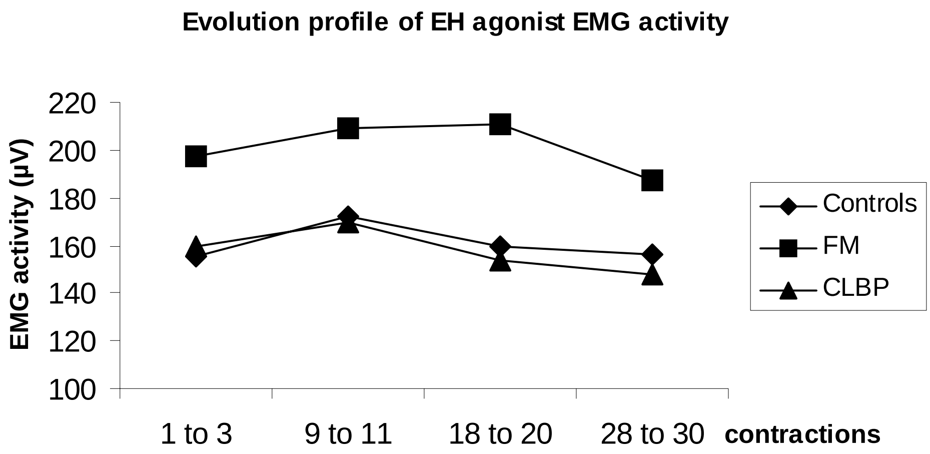
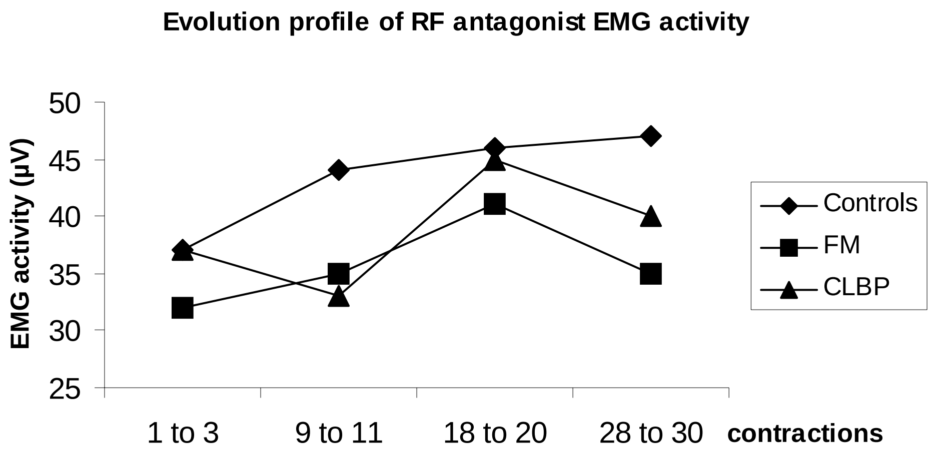

Evolution profile of RF agonist EMG activity
EMG activity (µV)
170
160
150
140
130
120
110
100
1 to 3
9 to 11
18 to 20
28 to 30
contractions
Controls
FM
CLBP

Figure 2



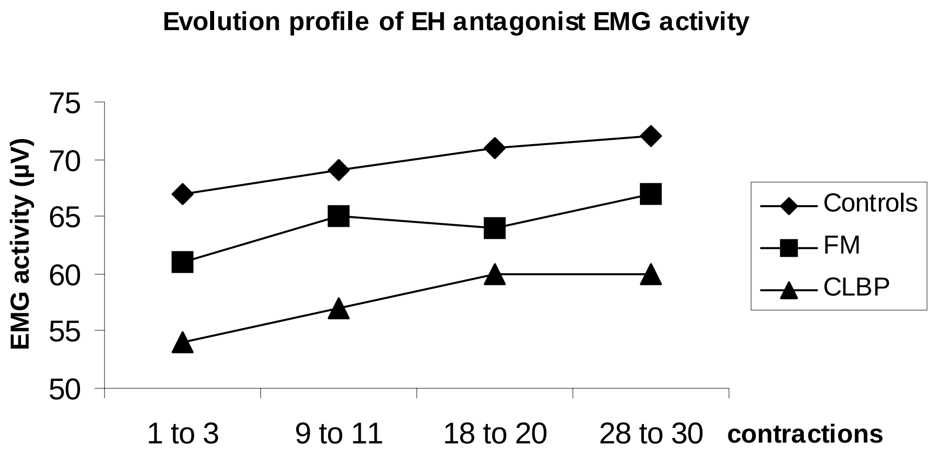
Evolution profile of EH agonist EMG activity
EMG activity (µV)
220
200
180
160
140
120
100
1 to 3
9 to 11
18 to 20
28 to 30
contractions
Controls
FM
CLBP

Figure 3



Evolution profile of RF antagonist EMG activity
EMG activity (µV)
50
45
40
35
30
25
1 to 3
9 to 11
18 to 20
28 to 30
contractions
Controls
FM
CLBP

Figure 4



Evolution profile of EH antagonist EMG activity
EMG activity (µV)
75
70
65
60
55
50
1 to 3
9 to 11
18 to 20
28 to 30
contractions
Controls
FM
CLBP