BMC Complementary and Alternative Medicine

BioMed Central

Research article

Open Access

The effect of massage on localized lumbar muscle fatigue

Tim Hideaki Tanaka*[1,3], Gerry Leisman[2], Hidetoshi Mori[3] and Kazushi Nishijo[3]

Address: [1]The Pacific Wellness Institute, Toronto, Ontario, Canada, [2]Department of Cognitive Neuroscience, Rensselaer Polytechnic Institute, Troy, New York, USA and [3]Tsukuba College of Technology, Ibaragi, Japan

E-mail: Tim Tanaka* - ttanaka@sympatico.ca; Gerry Leisman - drgersh@yahoo.com; Hidetoshi Mori - hmori@k.tsukuba-tech.ac.jp; Kazushi Nishijo - nishijo@a.tsukuba-tech.ac.jp

*Corresponding author

Published: 14 October 2002

BMC Complementary and Alternative Medicine 2002, **2**:9

This article is available from: http://www.biomedcentral.com/1472-6882/2/9

Received: 25 August 2002
Accepted: 14 October 2002

Abstract

Background: There is not enough evidence to support the efficacy of massage for muscle fatigue despite wide utilization of the modality in various clinical settings. This study investigated the influence of massage application on localized back muscle fatigue.

Methods: Twenty-nine healthy subjects participated in two experimental sessions (massage and rest conditions). On each test day, subjects were asked to lie in the prone position on a treatment table and perform sustained back extension for 90 seconds. Subjects then either received massage on the lumbar region or rested for a 5 minute duration, then repeated the back extension movement. The median frequency (MDF), mean power frequency (MNF), and root mean square (RMS) amplitude of electromyographic signals during the 90 second sustained lumbar muscle contraction were analyzed. The subjective feeling of fatigue was then evaluated using the Visual Analogue Scale (VAS).

Results: MDF and MNF significantly declined with time under all conditions. There was no significant difference in MDF, MNF or RMS value change between before and after massage, or between rest and massage conditions. There was a significant increase in fatigue VAS at the end of the 2nd back extension with rest condition. There was a significant difference in fatigue VAS change between massage and rest condition.

Conclusions: A significant difference was observed between massage and rest condition on VAS for muscle fatigue. On EMG analysis, there were no significant differences to conclude that massage stimulation influenced the myoelectrical muscle fatigue, which is associated with metabolic and electrical changes.

Background

Localized muscle fatigue is defined as the fatigue that is localized to the muscle or group of synergistic muscles performing contraction [1]. Localized muscle fatigue can be induced by sustained muscular contractions and is associated with such external manifestations as inability to maintain a desired force output, muscular tremor, and localized pain [2].

In a clinical and sports setting, massage is utilized widely and believed to be efficacious in the recovery from muscular fatigue [3,4]. Previous studies [5–7] that investigated the effect of massage on muscle fatigue evaluated the loss of force generating capacity by measuring the rate of decline based on maximal voluntary contraction. However, it has been indicated that the results of muscle fatigue assessed by this method tend to be influenced by subjective qualities, such as personal motivation and current level of pain [8]. More objective and reliable measures are necessary to evaluate the possible efficacy of massage against muscle fatigue.

The myoelectric signal (ME) can be considered as an index of motor unit recruitment and the electrical representation of the neuromuscular activity of a contracting muscle. The development of fatigue can be revealed by amplitude and spectral analysis of electromyographic (EMG) recordings. The root mean square (RMS) value of ME is commonly utilized as a parameter of EMG amplitude. The RMS has a variable response during fatiguing contraction that appears to be reflective of the force of the contraction [9].

In recent years, many investigators have employed power spectrum analysis of EMG as an index of muscle fatigue. It has been demonstrated that in local muscle fatigue, the myoelectric frequency shifts towards a lower frequency band with both static and dynamic contractions [10]. The mean power frequency (MNF) or median frequency (MDF) is calculated in order to quantify the EMG spectra and is used as an index of muscle fatigue.

The study tested the hypothesis that massage application on low back influences the degree of low back muscle fatigue caused by muscle fatiguing contraction. The amplitude and power spectrum analysis of EMG signals and the Visual Analog Scale were utilized to evaluate and estimate the degree of muscle fatigue.

Methods

Subjects

Subjects were recruited for this experiment according to the following criteria:

• Between 18 and 30 years of age

• No present low back pain or episodes of serious low back pain in the last five years

• No reported abnormal spinal X-ray findings

• No history of major physical or mental illness

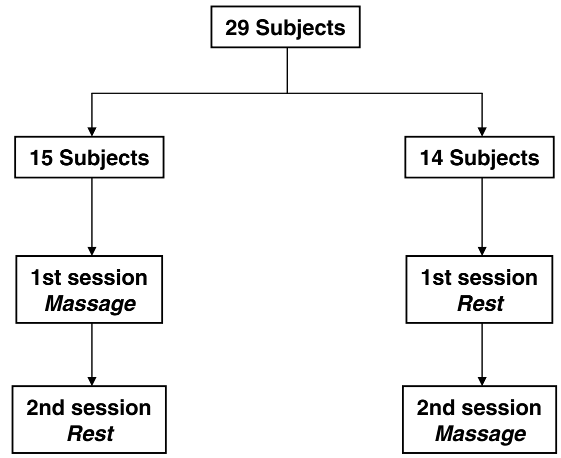

Figure 1
Study Design

Twenty-nine subjects (male: n = 16, female: n = 13) entered this study. Their mean age was 26 (SD ± 3.13). Their mean body mass index was 22.65 (SD ± 2.92).

Each subject was fully informed of the experimental procedures and had signed an informed consent statement before taking part in the experiments.

Procedure

Each of the 29 subjects participated in two experimental sessions and each session was conducted on a separate day. The interval between each session was more than one week in order to avoid carry over effect. Fifteen subjects received massage in the first experimental session and rest condition during the second session, while the remaining 14 subjects received Intervention (massage or rest) in reverse order. (See Figure 1 for the study design).

Power analysis was performed for this experimental design in order to determine a sample size, which gives a power of 70% for the test of the treatment effect. The expected effect size was assumed to be large as characterized by Cohen's standard effect sizes [11], ρ =.4. The sample size was determined to be 14 subjects per order of administration.

On each test day, subjects were asked to lie in the prone position on a treatment table with their hands crossed behind their head. After the proper attachment of electrodes was confirmed, subjects were instructed to slowly extend their trunks until the inferior portion of their rib cage no longer rested on the table. This position was held for 90 seconds and then subjects slowly returned to the resting position (Load I). Subjects then received massage on the lumbar region or rested for a 5 minute duration (see Table 1 for description of the Intervention), and then repeated

Table 1: Description of the Intervention

	INTERVENTION
Rest	The subject rested on the treatment table in the prone position for 5 minutes.
Massage	Effleurage, kneading and compression techniques were applied to the lumbar and sacrum region for 5 minutes. The massage lotion was used as a form of lubricant. The massage treatment was provided by the three registered massage therapists in Ontario. All therapists have completed a minimum of 2200 hours professional training and have written the licensing board examination. Their experience ranges from 2–8 years.

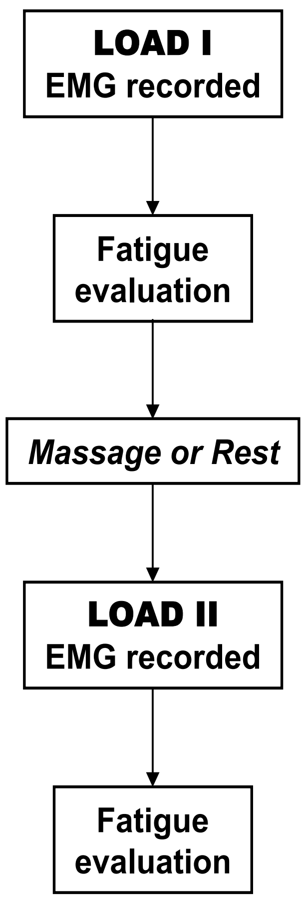

Figure 2
Experimental Procedure

the back extension movement (Load II). Immediately after each load, subjects were asked to evaluate their level of fatigue on the Visual Analogue Scale (VAS) for fatigue [12]. Subjects were specifically instructed to evaluate the level of fatigue of their lumbar area only and not to confuse it with the fatigue or discomfort of other body parts or general type of fatigue (e.g., shortness of breath). The experimental procedure is summarized in Figure 2.

EMG signal recording and analysis

EMG signals were recorded during the entire sustained back extension using Biopac MP 150 with EMG amplifiers and Acqknowledge software. Bipolar silver-silver chloride electrodes (recording diameter = 10 mm.) filled with conductive jelly were placed on the left and right lumbar paraspinal muscles (LPM) 3 cm away from the spinous processes at the levels of L3 and L4, with an inter-centre distance of 35 mm [13]. Ground electrodes were attached 3 cm lateral from the recording electrodes. Interelectrode impedance was reduced to less than 5 kΩ by cleaning and abrading the skin using abrasion paste. All electrodes were removed immediately after Load I and were reattached after Intervention (rest or massage) following brief skin preparations (i.e., wiping with alcohol). Precise placement between Load I and II was assured by marking the location with a permanent marker at the first EMG recording. Tests conducted prior to this project confirmed that the massage lotion we used was easily cleaned off the skin with alcohol treated cotton and does not affect the stability of electrode attachments and EMG signals.

The raw EMG signal was recorded at the sampling rate of 1,000 Hz and was band-pass filtered (10–500 Hz) and differentially amplified (gain: X2000, differential input impedance: 2 MΩ, common mode input impedance: 1000 MΩ, CMRR: >110 db). The recorded EMG signals were saved on computer and the data was transferred to Labview based software for off-line analysis.

Each 90 seconds of recorded signal (before and after treatment) was divided into 45 segments, with each segment representing 2 seconds of raw EMG data. The first segments were excluded to eliminate start transition in the subjects and of the instruments. The frequency content of each recording in each segment was analyzed by Fast Fourier Transform analysis (FFT) and the power spectrum was quantified by measuring MNF and MDF. In addition, root mean square value of EMG amplitude was calculated in each 2 second segment. MNF, MDF, and RMS of the first and the last 5 segments recorded during the 90-second contraction stage were used for later analysis.

Statistical analysis

Statistical analysis was conducted using SPSS version 10.0. The data was analyzed using a 2 × 2 × 2 × 10 repeated measures, crossover design, ANOVA. The crossover consisted of two orders of administration of treatments: (a) massage first, then rest; and, (b) rest first, then massage. For the rest of this paper, the crossover factor will be called 'Order.' The ANOVA assessed differences based on the factors of: (a) treatment (Massage / Rest); (b) muscle (left LPM / Right LPM); (c) stage (Before treatment / After treatment); and, (d) time of measurement (2 – 4 sec. / 4 – 6 sec. / 6 – 8 sec. / 8 – 10 sec. / 10 – 12 sec. / 80 – 82 sec. / 82 – 84 sec. / 84 – 86 sec. / 86 – 88 sec. / 88 – 90 sec.). Distributions of the measurements were assessed and transformed to approximate normality where applicable.

EMG signal analysis and statistical analysis of the experiment were conducted by blind assessors.

Results

Distributions of measures in the obtained sample

The distribution of the MNF – measurement was left-skewed. To obtain an acceptably normal distribution, the measurement was divided by 100 and the result was squared. A Kolmogorov – Smirnov test of normality indicated that the transformed measure was acceptably normally distributed. A Kolmogorov – Smirnov test of normality indicated that the MDF measure was acceptably normally distributed. The distribution of the RMS measurement was right-skewed. To obtain an acceptably normal distribution, the measurement was multiplied by 10,000 and the logarithm of the result was then used for the analysis. A Kolmogorov – Smirnov test of normality indicated that the transformed measure was acceptably normally distributed.

Reliability of EMG measurements

The reliability of the EMG measurements was assessed using the two-way random effects model and the coefficient for single measure reliability for absolute agreement ($ICC_{2,1}$ for absolute agreement). The intraclass correlation coefficients (ICC) for absolute agreement includes variation between "judges" (measurement sessions – in the case of this study), whereas, an ICC for only consistency, excludes such variation [14]. The ICC for absolute agreement was used in preference to an ICC for consistency only, because this study used ANOVA to assess differences between levels and so any systematic changes between measurements at different measurement sessions would have been unacceptable.

It is current practice to accept ICC values in the range of 0.8–1.0 as excellent repeatability, 0.6–0.8 as good repeatability, and values below 0.6 as poor repeatability [15]. The recorded MNF EMG measurements were found to be good reliability of $ICC_{2,1}$ = 0.69, with 95% confidence interval of (0.44, 0.84). Good reliability of $ICC_{2,1}$ = 0.74, with 95% confidence interval of (0.53, 0.87) for MDF EMG; and $ICC_{2,1}$ = 0.73, with 95% confidence interval of (0.51, 0.87) for RMS EMG.

Test of the comparison between massage and rest

As shown in table 2, the principle effect found in this experiment was a general change of measurement with time. Table 3 illustrates the nature of this effect in which the five early measurements (the beginning of 90-second contraction) are all different from the five later measurements.

Table 2: Summary of Analysis of EMG Measures (N = 29)

		F		
Source	Df	Squared MNF	MDF	Logarithm of RMS
Muscle (M)	1	2.85	0.01	4.70*
Time (T)	9	100.71***	104.65***	12.00***
Intervention (IV) × T	9	2.17*	1.16	0.72
IV × T × O	9	0.65	1.70	2.48*
M × T × O	9	1.08	1.97*	0.83
S × T	9	7.73***	7.03***	9.93***
S × T × O	9	3.17**	3.63***	1.62

Note. MNF – measure was scaled by division by 100, and squared due to a left-skewed distribution. RMS – measure was scaled by multiplying by 10,000, and transformed by taking its natural logarithm due to having a right-skewed distribution. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Table 3: Summary of Changes in EMG – Measurements (N = 29)

	Squares of MNF		MDF		Logarithm of RMS			
					Before Intervention		After Intervention	
Time of Measurement (sec.)	M	SD	M	SD	M	SD	M	SD
2 – 4	2.25	0.62	84.97	20.98	1.17	0.89	0.88	0.92
4 – 6	2.33	0.60	89.57	20.12	0.82	0.79	0.68	0.92
6 – 8	2.32	0.58	89.12	18.96	0.67	0.81	0.63	0.92
8 – 10	2.30	0.58	88.18	18.64	0.65	0.79	0.66	0.88
10 – 12	2.26	0.57	87.04	18.74	0.67	0.80	0.68	0.94
80 – 82	1.69	0.48	68.06	15.14	0.92	0.97	1.04	0.99
82 – 84	1.68	0.47	67.15	15.09	0.86	0.85	1.11	1.02
84 – 86	1.66	0.48	67.17	15.33	0.86	0.95	1.05	0.96
86 – 88	1.66	0.49	66.75	15.96	0.87	0.90	1.07	1.06
88 – 90	1.64	0.46	66.60	14.90	0.84	0.86	1.05	0.95

Note. MNF – measure was scaled by division by 100, and squared due to a left-skewed distribution. RMS – measure was scaled by multiplying by 10,000, and transformed by taking its natural logarithm due to having a right-skewed distribution.

Table 4: Summary of Differences in EMG-Measurement Changes Dependent on Intervention for Squared MNF (N = 29)

	Massage		Rest	
Time of Measurement (sec.)	M	SD	M	SD
2 – 4	2.31	0.7	2.19	0.64
4 – 6	2.39	0.64	2.28	0.59
6 – 8	2.38	0.64	2.25	0.59
8 – 10	2.35	0.64	2.25	0.54
10 – 12	2.30	0.64	2.22	0.59
80 – 82	1.69	0.54	1.69	0.48
82 – 84	1.69	0.48	1.66	0.48
84 – 86	1.69	0.54	1.63	0.48
86 – 88	1.68	0.54	1.63	0.48
88 – 90	1.65	0.54	1.62	0.48

Note. MNF – measure was scaled by division by 100, and squared due to a left-skewed distribution.

Table 4 illustrates the dependence of changes in the squared MNF measure on the treatment employed. Despite the significant treatment effect detected on ANOVA, exact areas of change were not revealed on *post hoc* analysis.

The first and last five segments of mean MNF, MDF, and RMS during the 90 second-contraction are presented in Figures 3,4,5.

Effect of massage and rest on fatigue VAS

The paired t-test indicated that there was a significant increase in fatigue VAS at the end of the second load compared to the end of the first load under rest. There was a

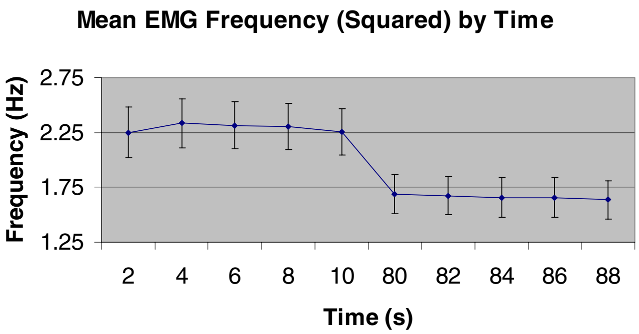

Figure 3
Mean EMG Frequency (Squared) by Time

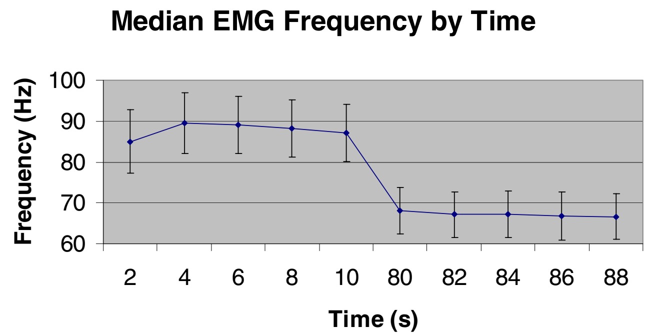

Figure 4
Median EMG Frequency by Time

significant difference in fatigue VAS change between massage and rest condition (Table 5).

Discussion

Massage has been utilized widely in the conditioning of athletes [16]. Decrease of fatigue and improvement of muscle function are the main expectations of benefits [17,18]. This investigation was carried out to evaluate the possible effect of massage against localized muscle fatigue using EMG analysis and subjective fatigue evaluation.

On VAS, there was a significant increase in the degree of lumbar muscle fatigue following the second load under rest condition. The degree of VAS change was significantly different between massage and rest condition. However, mean difference in VAS changes between massage and rest condition was relatively small (-0.32 VS +0.86). It should be noted that while the vast majority of subjects reported less fatigue after massage, four subjects indicated a notable increase in fatigue ranging from +2 to +6 on VAS after the massage. This substantially contributed to the deviation of the mean second VAS score towards the positive side in the massage condition. The increase observed in some subjects after massage might be associated with the elicitation of a relaxation response. Several subjects commented that they felt "too relaxed" after the massage and that they had experienced difficulty lifting their trunk and sustaining the contraction. The relaxation response should be favourable in most clinical situations and after athletic events. However, this reaction may have caused autonomic alterations in some cases, and may have resulted in unfavourable physiological or psychological status (e.g., inhibition of blood flow to muscles, reduced muscle tone, and/or altered mental activity such as decreased alertness) for immediate strenuous activity.

As indicated, massage application showed positive influence on subjective feeling of fatigue evaluated on VAS, however this study failed to demonstrate significant changes in any of the EMG parameters. The non-significant effect on physiological parameters and significant changes in subjective parameters are consistent with previous studies evaluating the effect of massage on fatigue and endurance [19]. Since the present study used Rest (no-treatment) as a form of control condition, any possible emotional or psychological influence such as expectation of better performance (i.e., placebo effect) could not have been eliminated. However before concluding that the positive effects of massage are solely psychological in nature, several issues need to be addressed:

In this study, massage was applied for a duration of only five minutes. We considered five minutes of manual massage to be sufficient to cause a physiological reaction (if any) in local surrounding tissues based on the results of a previous Japanese study [20]. That study showed a significant increase of intramuscular blood flow after five minutes of massage stimulation using a commercial mechanical massage device. We realize that the length of massage treatment in this study is shorter and the areas of massage application are more limited than those in a clinical setting. Therefore, it should be noted that the conclusions from our study are not applicable to massage treatments of longer duration, wider areas of application (i.e., full body massage), or where different techniques are employed. Furthermore, since localized fatigue was induced after 90 seconds of sustained contraction, the conclusions cannot be extrapolated to situations where fatigue was caused by activity of a different duration or intensity. Nevertheless, despite the effects commonly de-

Table 5: Summary of Visual Analogue Scale (N = 29)

Comparison	Comparison Measure		Compared Measure		
	M	SD	M	SD	t
After Massage to Before Massage	5.97	2.45	5.64	2.73	0.75
After Rest to Before Rest	6.01	2.23	6.87	1.88	3.03**
Change in VAS with Massage to Change in VAS with Rest	0.86	1.53	-0.32	2.34	2.69*

Note. All paired t – tests have 28 degrees of freedom. * $p < 0.05$. ** $p < 0.01$.

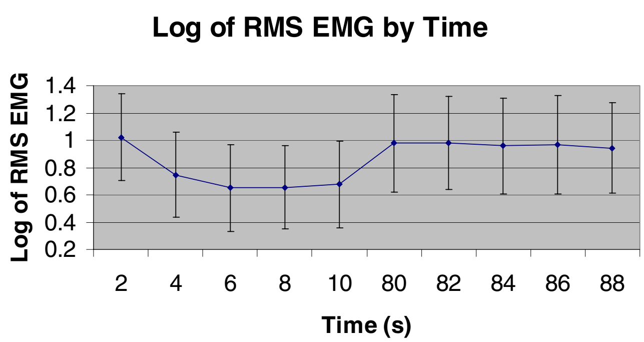

Figure 5
Logarithm of RMS EMG by Time

scribed in various massage texts, there is a paucity of comparative study data available which have demonstrated unique therapeutic benefits induced by different massage techniques. Thus, the length and the types of massage application are often based solely on the athletes' and therapists' preferences and not on any scientific data [18,21].

The frequency analysis of the EMG signals in particular has been recognized as a useful tool for the measurement of local muscle fatigue [9,10]. The lower EMG power spectrum shift during fatigue is considered to be related to biochemical by-product accumulation (H+ and lactic acid) in the muscle, which changes the action potential conduction velocity [22]. Other factors, such as firing rate of motor units, motor unit synchronization, additional recruitment of motor units, and muscle temperature influence the frequency changes [22]. If massage application helps increase local circulation and decrease metabolic waste products, it is reasonable to expect changes in EMG power spectrum (i.e., decreased MNF and MDF slope decline during the 90 second-contraction). In this study, significant change in EMG parameters (MNF, MDF, RMS) was attributed to a time effect. ANOVA detected some evidence that the Intervention (massage or rest) may have influenced the change in MNF. However, the *post hoc* analysis could not reveal further details, possibly due to the minute difference in MNF changes.

Lower MNF shift related to fatigue is believed to be more reflected in type II fibre fatigue. Komi and Tesch [23] showed in their experiment that MNF declined significantly during fatigue in subjects with a high proportion of fast-twitch fibres, but showed only a slight decrease in those with a high proportion of slow-twitch fibres. *Erector spinae* muscles are composed of about 40% type II and 60% type I fibres [24]. Postural muscles contain less type II fibres than many other muscles [25], although the proportion of type II fibres tend to be larger in LBP subjects [26]. Our study involved subjects who had no history of back problems. The undetectable MNF change in our study may have resulted from the fact that the MNF analysis did not reflect sensitively the small changes that may have occurred among healthy subjects. More investigation is necessary using other muscle groups and chronic low back pain subjects to further elucidate the possible influence of massage on localized muscle fatigue

Conclusions
Massage application on the lumbar region provides significant difference in the fatigue scale as compared to rest suggesting that massage application helped the subjects overcome the subjective feeling of the fatigue. On EMG analysis, although some effect was indicated based on MNF change, there was not enough evidence to conclude that there is an effect of massage on myoelectrical muscle fatigue.

Competing interests

This study was supported by a research grant from the College of Massage Therapists of Ontario (the provincial regulatory body for the practice of massage therapy in Ontario).

Authors' contributions

THT carried out the study, wrote the paper, and provided overall coordination of the project.

GL participated in data analysis

HM participated in study design

KN participated in study design

Acknowledgements

The authors wish to thank James Gilchriest, at the Clinical Engineering department of Touro College School of Health Sciences for the help in EMG signal analysis and Leon Samadi, RMT, Joanna Rogowska, RMT, and Agata Mielcarek, RMT for providing massage therapy for the study.

References

1. Chaffin DB: **Localized muscle fatigue – definition and measurement.** *J Occup Med* 1973, **15:**346-54
2. Basmijan JV, De Luca CJ: **Muscle fatigue and time-dependant parameters of the surface EMG signal.** *In: Muscles Alive: Their function revealed by electromyography Baltimore: Williams & Wilkins* 1985, 203
3. Johnson J: **The Root of Sports Massage.** *In: The Healing Arts of Sports Massage Emmaus: Rodale Press, Inc* 1995, 1-2
4. Tappan F, Benjamin PJ: **Sports and Fitness.** *In: Healing Massage Techniques Appleton & Lange* 1998, 311-315
5. Rinder AN, Sutherland CJ: **An investigation of the effects of massage on quadriceps performance after exercise fatigue.** *Complement Ther Nurs Midwifery* 1995, **1:**99-102
6. Cafarelli E, Sim J, Carolan B, Liebesman J: **Vibratory massage and short-term recovery from muscular fatigue.** *Int J Sports Med* 1990, **11:**474-8
7. Perrin RN, Edwards J, Hartley P: **An evaluation of the effectiveness of osteopathic treatment on symptoms associated with myalgic encephalomyelitis. A preliminary report.** *J Med Eng Technol* 1998, **22:**1-13
8. Kankaanpaa M, Taimela S, Airaksinen O, Hanninen O: **The efficacy of active rehabilitation in chronic low back pain. Effect on pain intensity, self-experienced disability, and lumbar fatigability.** *Spine* 1999, **24:**1034-42
9. Jurell KC: **Surface EMG and fatigue.** *Phys Med Rehabil Clin N Am* 1998, **9:**933-47
10. De Luca CJ: **Myoelectric manifestations of localized muscular fatigue in humans.** *Crit Rev Biomed Eng* 1984, **11:**251-279
11. Cohen J: **Statistical power analysis and research results.** *American Educational Research Journal* 1973, **10:**225-230
12. Lee KA, Hicks G, Nino-Murcia G: **Validity and reliability of a scale to assess fatigue.** *Psychiatry Res* 1991, **36:**291-8
13. Zipp P: **Recommendations for the standardization of lead positions in surface electromyography.** *Eur J Appl Physiol Occup Physiol* 1982, **50:**41-54
14. McGraw KO, Wong SP: **Forming Inferences About Some Intraclass Correlation Coefficients.** *Psychological Methods* 1996, **1:**30-46
15. Kollmitzer J, Ebenbichler GR, Kopf A: **Reliability of surface electromyographic measurements.** *Clin Neurophysiol* 1999, **110:**725-34
16. Schlossberg B: **Gold medal massage: Touch helps Olympic and Paralympic athletes reach the podium.** *Massage* 2002, **98:**44-48
17. Goats GC: **Massage – the scientific basis of an ancient art: Part 2. Physiological and therapeutic effects.** *Br J Sports Med* 1994, **28:**153-6
18. Callaghan MJ: **The role of massage in the management of the athlete: a review.** *Br J Sports Med* 1993, **27:**28-33
19. Hemmings B, Smith M, Graydon J, Dyson R: **Effects of massage on physiological restoration, perceived recovery, and repeated sports performance.** *Br J Sports Med* 2000, **34:**109-14
20. Otsuka T, Hirai K, Mori H, Nishijo K: **Change of intramuscular circulation by commercial massage device.** *Nihon Shugi Ryouho Zasshi* 1999, **10:**
21. Cafarelli E, Flint F: **The role of massage in preparation for and recovery from exercise. An overview.** *Sports Med* 1992, **14:**1-9
22. Bigland-Ritchie B, Donovan EF, Roussos CS: **Conduction velocity and EMG power spectrum changes in fatigue of sustained maximal efforts.** *J Appl Physiol* 1981, **51:**1300-5
23. Komi PV, Tesch P: **EMG frequency spectrum, muscle structure, and fatigue during dynamic contractions in man.** *Eur J Appl Physiol Occup Physiol* 1979, **42:**41-50
24. Thorstensson A, Carlson H: **Fiber types in human lumbar back muscles.** *Acta physiologica Scandinavica* 1987, **131:**195-202
25. MacCance KL, Huether SE: **Pathophysiology, The Biologic basis for disease in adults and children.** *In St. Louis: Mosby* 1998, 1425-1426
26. Roy SH, De Luca CJ, Casavant DA: **Lumbar muscle fatigue and chronic lower back pain.** *Spine* 1989, **14:**992-1001

Pre-publication history

The pre-publication history for this paper can be accessed here:

http://www.biomedcentral.com/1472-6882/2/9/prepub