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BACK MUSCLE FATIGUE IN HEALTHY MEN AND WOMEN STUDIED BY ELECTROMYOGRAPHY SPECTRAL PARAMETERS AND SUBJECTIVE RATINGS

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To obtain reference data for future studies of patients with low back pain, back muscle fatigue was studied by surface electromyography at L1 and L5 lumbar levels in 55 healthy subjects exerting 80% of maximal voluntary contraction of the back extensors in a sitting position. Reference data were the initial value and rate of decrease (slope) of the median frequency during the contraction. The aim was also to study the effects of contraction time, gender differences, electrode locations and correlations with torque, age and subjective ratings. Initial median frequency was 52 Hz ± 7.5, with no difference between electrode locations; steeper slopes were found at L5 level (−0.44%/s ± 0.25) than at L1 (−0.36%/s ± 0.26). No right–left differences and no gender differences were found for these parameters. A correlation was observed between slope and initial median frequency, higher for men ($r \approx -0.7$) than for women ($r \approx -0.5$). Intersubject coefficient of variation for the slope was smallest for the longest (45 seconds) recording time (60–70%), but still much higher than for the initial median frequency (14%). The torque and the subjective ratings of fatigue showed no correlation with the electromyography variables. We conclude that the same reference values can be used for men and women. Owing to the large intersubject range of the slope, the clinical use of this variable may, however, be impeded.

Key words: electromyography; erector spinae; gender; muscle fatigue; reference values; subjective ratings; torque.

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INTRODUCTION

Localized muscular fatigue is induced by sustained muscular contractions, and external manifestations include inability to maintain a desired force output, muscular tremor and localized pain (1). Muscular fatigue is a time-dependent process, and even though the externally observable mechanical performance would not be altered until the failure point (contractile fatigue), physiological changes within the muscle start from the beginning of a contraction (metabolic fatigue) (1). In studies of localized muscular fatigue, surface electromyography (EMG) has been extensively used (1). Frequency characteristics of the EMG signal, specificially the mean or the median frequency, are computed from the frequency power spectrum of the electric signal as obtained by Fourier analysis (1). The mean or the median frequency decreases when a contraction is sustained and this decrease over time is a parameter that is frequently used as an index of fatigue (1). The value is expressed as the slope (Hz/s) of a linear regression of the median frequency calculated over the duration of the contraction (2). It can be normalized (%/s) by division with the initial median frequency value (3).

Differences in EMG fatigue parameters in patients with low back pain (LBP) compared with those in healthy controls have been shown, usually as a steeper slope (2, 4). However, conversely, a less steep slope for patients with LBP have also been reported (5). A steeper slope was associated with both the existence of and the risk of developing low back pain (3). Furthermore, the slope has been shown to become less steep after training (6). The EMG median frequency has been used to discriminate between subjects with and without low back pain (2, 7). Biedermann et al. (8) were able to discriminate between physically active and passive patients with LBP, the latter having a steeper slope. Mayer et al. (4), on the contrary, are less positive about the discriminating power of the slope, because a large overlap in the ranges of the slope values for healthy subjects and patients with LBP leads to a poor discriminating ability on an individual basis.

Most previous studies of isometric back muscle fatigue where spectral parameters have been analysed have used the prone lying position, i.e. holding the torso against gravity (Sørensen's test) (3, 9–15), which is about 40–50% of maximal voluntary contraction (MVC) torque (16). Back extension in standing position (2), semi-standing (5) or sitting position (17, 18) with force feedback allows for testing on higher force levels, leading to an increased rate of decrease of the median frequency (2, 3, 19). The relationship between the initial median frequency and force is not as clear. The initial median frequency has been shown to decrease with higher contraction force when testing back muscles (2), but for limb muscles, the opposite behaviour has been reported (20). However, the correlation between initial

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Table I. *Characteristics of the subjects*

	Men ($n = 28$)		Women ($n = 27$)	
	Median (range)	Mean (SD)	Median (range)	Mean (SD)
Age (years)	35 (21–56)	35 (11)	32 (21–57)	37 (12)
Height (cm)	178 (170–192)	180 (7)	166 (154–180)	166 (7)
Weight (kg)	79 (66–103)	81 (10)	60 (49–80)	61 (8)

median frequency and force is found to be generally weak (21). Roy et al. (2) report that patients with LBP and healthy controls were better identified at 80% MVC contractile level compared to lower force levels.

Concerning gender, differences between healthy men and women in back muscle function have been found, showing superior back extensor strength for men but better endurance for women (22, 23), except in the recent study by Dedering et al., where the endurance time was the same for men and women (12). A steeper slope of EMG median frequency for men has been shown for Sørensens test (3, 10, 11, 16), indicating greater paraspinal fatigability in men. Gender differences for higher contraction forces have not yet been reported.

When studying back muscles with EMG, it is recommended to have several recording sites for surface electrodes in order to measure the different portions of the erector spinae muscle (2). Studies on healthy subjects have shown both difference (14) and no difference (3, 10) in median frequency slope between the right and the left side of bilateral recordings of an isometric contraction, but for patients with LBP, side differences have been shown (6, 21). However, the median frequency slope at the caudal parts of the erector spinae, the multifidus muscle, seems to be greater than that for more cranial parts in isometric contractions (2, 13).

Subjective ratings may often be of great value to add to objective measurements. The Borg ratings (24) at 3 minutes of Sørensen's test have previously been shown to correlate with the total endurance time ($r = -0.68$, $p < 0.01$) and, to a lesser degree, with the EMG parameters (r between -0.41 and -0.50, $p < 0.01$) (12).

We have chosen a training and testing unit with a well-defined sitting position and, on the basis of the report by Roy et al. (2), with a contraction force of about 80% MVC. The testing unit has previously been described in a reliability study (17).

In order to investigate the usefulness of our fatigue test for assessing patients with LBP, we need reference data for this test when applied to healthy subjects in ages when LBP is most common.

The aims of this work were

1. to study the EMG spectral parameters of the fatiguing erector spinae at vertebral levels L1 and L5 on the right and the left side;
2. to investigate the possibility of shortening the contraction time of the test to make it less strenuous;
3. to investigate gender differences;
4. to evaluate the usefulness of simultaneous subjective ratings of back muscle fatigue;
5. to study correlations between initial median frequency, slope, torque, age and subjective ratings.

Table II. *Number of subjects in different age groups*

	Men ($n = 28$)	Women ($n = 27$)
21–30 years	13	13
31–40 years	7	4
41–50 years	4	5
51–60 years	4	5

METHODS

Subjects

Sixty subjects (30 males and 30 females) with no history of periodic low back pain were tested. Owing to missing values, described later under data analysis, the results were based on a sample of 28 men and 27 women (Table I). The subjects were recruited on a voluntary basis, aiming at getting an as even a distribution as possible of the ages of the men and the women (Table II). Most of the 55 subjects had never experienced any low back pain. Seven subjects had experienced one slight acute episode more than one year prior to the test. Thirteen subjects were students and 42 were employed in various professions (physical therapists, nurses, teachers, civil servants, porters). Most of the subjects were by habit physically active (about 50% of the subjects on a low level such as walking and cycling and the rest on a high level doing sports and physical training; about the same proportions for men and women). Informed consent was obtained from each subject and the study was approved by the local Ethics Committee.

Electromyography

Electrical activity was recorded from the erector spinae at L1 and L5 levels on the right and the left side. Disposable Ag/AgCl surface disc electrodes with an active diameter of 5 mm (Blue Sensor N-00-S, Medicotest A/S, Denmark) were used. The skin was cleaned with alcohol and the electrodes were applied with an interelectrode centre to centre spacing of 2 cm in the direction of the muscle fibres. The centre of the electrode arrangement was about 3 cm laterally to the centre of the spinous process. The reference electrode was placed on the iliac crest (Blue Sensor VL-00-S).

Test procedure

Each subject was tested once in an upright sitting position, in a back extension training and testing unit (David Back Extension 110, David International Ltd., Neu-Ulm, Germany) with good fixation for the lower back, the hips and the knees (17). The subject was seated according to the recommendations of David Back Clinic International (Licensee Operational Manual 1994). Reference for the movement axis is L3-L4, and the seat is adjustable to allow for individual settings, while the moment arm of the resistance pad at scapula level is fixed. The subject performed an isometric trunk extension against the resistance pad. In front of the subject a display unit (David International Ltd., Neu-Ulm, Germany) continuously showed the torque in newton metres (Nm) in digital numbers (display accuracy 1 Nm). The display unit had been calibrated by a standard method using a mechanically well-defined torque.

Before the test, the subject performed an isometric submaximal contraction at a low torque level, to learn to maintain a constant force aided by the visual feedback system. Maximal voluntary contraction was assessed at three 5-second trials and defined as the mean of the two highest torque values. After 2 minutes of rest, EMG was recorded during one isometric 45-second "fatigue contraction", during which the subject aimed at maintaining a constant torque of 80% of MVC by visual

Table III. *Electromyographic (EMG) spectral parameters (initial median frequency and normalized slopes for 20, 30 and 45 seconds contraction time) at four electrode locations on the erector spinae; means and standard deviations (SD)*

EMG variable	Electrode location	Men ($n = 27$)		Women ($n = 26$)	
		Mean	SD	Mean	SD
Initial MDF (Hz)	L1 right	51.9	8.0	52.7	8.0
	L1 left	51.9	11.2	54.0	11.2
	L5 right	53.0	9.2	50.6	9.2
	L5 left	50.8	9.8	51.0	9.8
Slope 20s (%/s)	L1 right	−0.247	0.63	−0.340	0.64
	L1 left	−0.333	0.53	−0.245	0.53
	L5 right	−0.538	0.57	−0.499	0.57
	L5 left	−0.491	0.55	−0.493	0.55
Slope 30s (%/s)	L1 right	−0.344	0.39	−0.372	0.40
	L1 left	−0.317	0.42	−0.357	0.41
	L5 right	−0.534	0.39	−0.435	0.39
	L5 left	−0.561	0.37	−0.415	0.37
Slope 45s (%/s)	L1 right	−0.369	0.28	−0.301	0.28
	L1 left	−0.405	0.27	−0.376	0.27
	L5 right	−0.480	0.27	−0.374	0.27
	L5 left	−0.512	0.28	−0.385	0.28

feedback from the display unit. The fluctuations in the torque were estimated to be about ± 10%. The torque was, however, not continuously recorded.

Three times during the "fatigue contraction" (at 15 seconds, 30 seconds and 45 seconds), lumbar muscle fatigue was rated by the subject using the Borg category ratio scale (CR-10) (24) placed in front of the subject.

Reliability

The reliability (reproducibility) of the present test method has been studied previously with six repeated measurements (17). Varying somewhat between different electrode locations, the within-subject coefficients of variation (CV) and intraclass correlations (ICC:1,1) were for the initial median frequency 8–10% and 0.41–0.70 (higher at L5); for the slope 35–75% and 0.04–0.46; for the MVC 11% and 0.93 and for the Borg ratings 17% and 0.84.

Data analysis

Installation of a new version of software- and computer system in the laboratory caused the loss of the EMG files of one man and three women. Prior to analysis, the raw EMG and power spectra were screened for erroneous recordings which led to the dismissal of the EMG (all 4 channels) of one man. One channel (L1 left) was omitted for one man and one woman for the same reason.The EMG signal was recorded from the four electrode sites via a telemetric system (Telemyo 16; Noraxon, USA). The sampling frequency was 1000 Hz. In retrospect, it was found that the bandwidth of the input electronics was actually too large (10–800 Hz). However, numerical analysis of the power spectra indicates that the maximum possible aliasing effect on the median frequency by the power spectrum above 200 Hz would be a shift ≈1Hz. Moreover, the shape and appearance of the power spectra above 200 Hz do not indicate the presence of any aliasing effects. EMG analysis was done using software from Noraxon (MyoResearch 97, Noraxon, USA). Hanning windowing was used prior to Fast Fourier Transformation. The median frequency of the power spectrum was calculated for consecutive 1000 ms intervals of the recorded signal. Regression analysis was made to determine the slope over 45 seconds (slope 45 s). In addition, regression analysis was made over the first 20 seconds (slope 20s) as well as the first 30 seconds (slope 30 s). The slope in Hz/s was also normalized to percent per second:

$$\text{Normalized slope } (\%/\text{s}) = (\text{slope } (\text{Hz/s}) \ / \ \text{IMDF(Hz)}) \times 100.$$

The initial median frequency was calculated in two ways: first, as the intercept of the regression line for a time period of 45 seconds (IMDF), and, secondly, as the mean value of the median frequencies of the first 5 seconds (IMDFm).

Torque normalized for body weight (Nm/kg) was defined as maximal trunk extension torque (Nm) divided by body weight (kg).

Table IV. *Electromyographic (EMG) spectral parameters for a 45-second back muscle contraction at 80% of maximal voluntary contraction (MVC) (n = 53); initial median frequency (IMDF) and rate of decrease (slope 45 s). Parameters, where there was no significant difference between gender, right–left and L1–L5, were averaged. Means, standard deviations (SD) and coefficients of variation (CV) are shown*

EMG variable	Mean	SD	CV (%)
IMDF (Hz) all levels	52	7.5	14
Slope 45s (%/s) L1 level	−0.363	0.255	70
Slope 45s (%/s) L5 level	−0.438	0.248	57
Slope 45s (Hz/s) L1 level	−0.201	0.146	72
Slope 45s (Hz/s) L5 level	−0.236	0.153	65

Statistics

Using the SPSS (Statistical Products and Service Solutions, Chicago, USA) version 8.0, a multifactorial analysis of variance (ANOVA) with repeated measures was made, where gender was set as one factor and the repeating factors were: level (L1-L5), side (right–left), slopes (20 s, 30 s, 45 s) in the different analyses. Difference in torque between men and women was tested with Student's *t*-test for independent samples. For correlation analysis, Pearson's correlation coefficient was used. As the Borg scale can be considered an ordinal scale, differences between men and women were tested with the Mann-Whitney U-test and correlations with Spearman's rank correlation. Significance level was set at $p < 0.05$.

RESULTS

The results of the study are presented in Table III. Table IV presents pooled data for parameters where differences were not significant.

Initial median frequency

The two methods for calculating the initial median frequency

Table V. *The initial median frequency (Hz) calculated as the intercept of the regression line for 45-second time period (IMDF) and as the mean of the first 5 seconds (IMDFm)* (n = 55). *Paired* t-*test was used to test for differences*

			Paired *t*-test		
Electrode location	IMDF Mean value	IMDFm Mean value	Mean difference	Standard deviation of differences	*p*-value
L1 right	52.05	51.76	0.2897	2.650	0.421
L1 left	52.97	51.90	1.0710	2.056	0.000
L5 right	51.78	51.75	0.0285	2.546	0.934
L5 left	50.90	50.00	0.9095	2.223	0.004

(the IMDF and the IMDFm) differed by 1 Hz (≈2%) or less (Table V). We have, for reasons discussed below, chosen the IMDF in our present descriptions of the results.

The IMDF did not show any significant difference between either the right and the left side of the erector spinae ($p = 0.892$) or the vertebral levels L1 and L5 ($p = 0.320$), nor was there any significant difference between men and women ($p = 0.947$) (Table III).

Slopes

Contraction time. The normalized slopes (%/s) did not differ ($p = 0.796$) between the three different contraction times (20 s, 30 s and 45 s): −0.40 %/s (SD 0.36), −0.42 %/s (SD 0.31) and −0.40 %/s (SD 0.23), respectively. Nor was any difference found for the slopes in Hz/s ($p = 0.666$). The variability between subjects, in this case the standard deviation and the range, increased with shorter contraction time (Table III, Fig. 1).

Electrode location. The normalized slopes (%/s) were significantly steeper (more negative) at L5 than at L1 level ($p = 0.004$) and the total decrease in median frequency was 16% at L1 and 20% at L5. The result was similar for slopes in Hz/s, i.e. steeper slopes at L5 level than at L1 ($p = 0.012$) (Table IV).

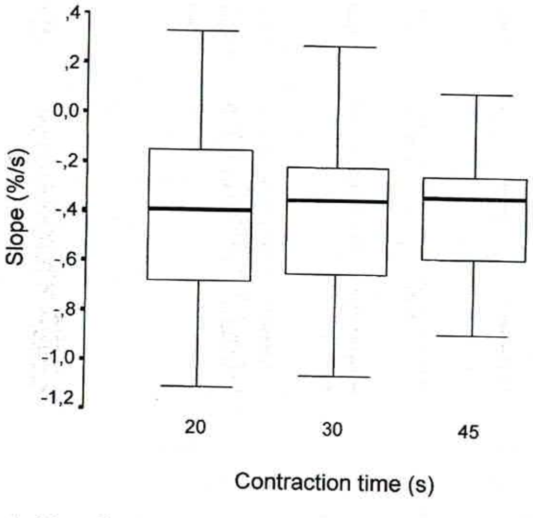

Fig. 1. Normalized slopes (%/s) for 20-, 30- and 45-second contraction; means for all four recording sites ($n = 55$);. (The boxplot shows 50% of the values within the box, the line is the median. Whiskers indicate the range).

No right–left difference was found either for the normalized slope ($p = 0.890$), or for the slope in Hz/s ($p = 0.965$).

Gender. No significant gender difference was found for any of the above slope parameters.

Torque

Maximal extension torque was significantly higher for men, 281 Nm (SD 72) than for women, 150 Nm (SD 39) ($p = 0.000$) as was the normalized torque; men 3.5 Nm/kg (SD 0.9) and women 2.5 Nm/kg (SD 0.7) ($p = 0.000$).

Subjective ratings of back muscle fatigue

The ratings for back muscle fatigue reported at 15, 30 and 45 seconds during the contraction were somewhat higher for men than for women but the difference was not significant ($p > 0.05$). Median ratings for men were 3.5 (range 0–6), 5 (range 0–9) and 6 (range 0–10), and for women 3 (range 0–5.5), 3.5 (range 0–7) and 4.5 (range 0–9). The range in ratings between subjects increased during the contraction (Fig. 2).

Correlation between slope and IMDF

Significant correlations between the slope (Hz/s) and the IMDF were found (r = between −0.46 and −0.76 for the four electrode locations); a steeper slope correlated with a higher IMDF (Fig. 3). There was a gender difference showing a stronger correlation for men ($r^2 \approx 0.5$) than for women ($r^2 \approx 0.2$).

Correlation between slope and normalized torque

A weak correlation between the slope 45 seconds (but not for shorter times) and the MVC torque normalized for weight (Nm/kg) was found for women ($r = -0.47$; $p < 0.05$); a steeper slope correlated with a higher normalized torque (Fig. 4). However, no correlation was found between slope and MVC torque (Nm).

Missing correlations

No correlations were found for normalized slope versus Borg ratings of back muscle fatigue. Moreover, no correlation was found for IMDF versus age, for slope versus age or for IMDF versus normalized MVC torque.

DISCUSSION

In the present results, the intersubject coefficients of variation

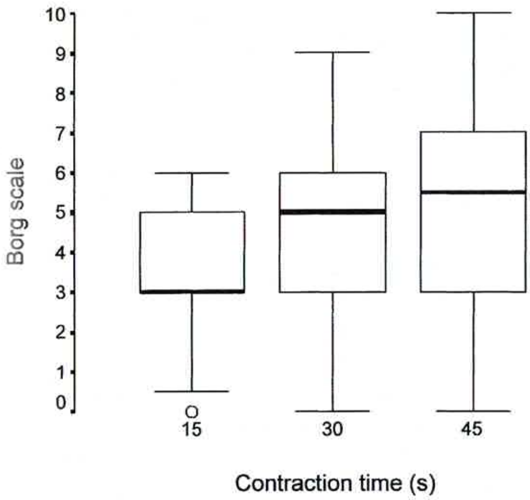

Fig. 2. Ratings of back muscle fatigue (CR 0–10 scale) by the subjects ($n = 50$) at 15, 30 and 45 seconds of the contraction. (The boxplot shows 50% of the values within the box, the line is the median. Whiskers indicate the range and O is an outlier, more than 1.5 box-length from the end of the box).

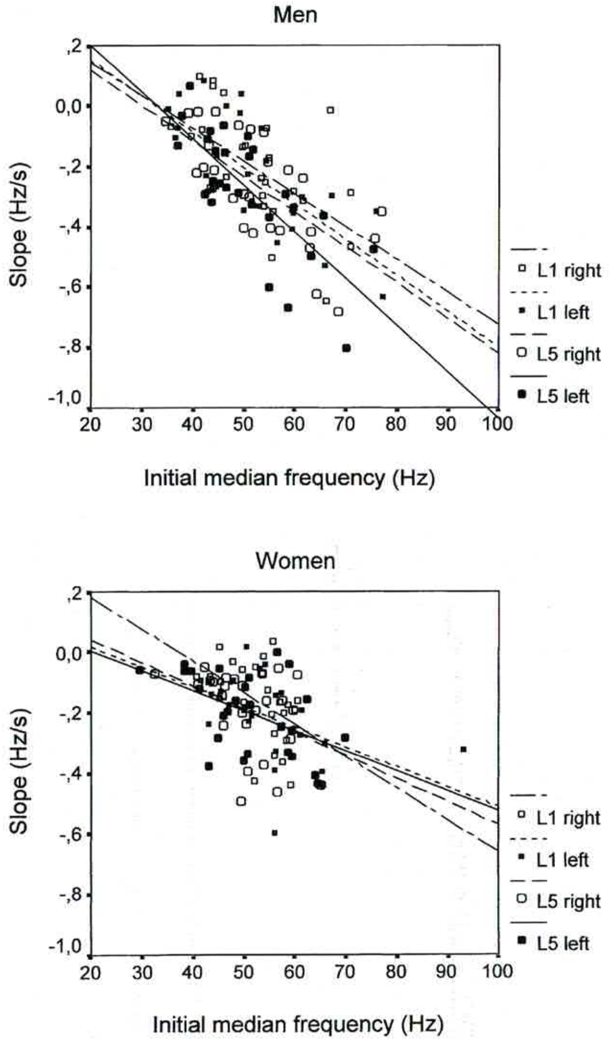

Fig. 3. Correlation between the slope for 45 seconds contraction and the initial median frequency for men ($n = 28$) and women ($n = 27$). Regression lines for the different recording sites are indicated. Pearson correlation coefficient (r) was for the men: −0.57** (L1 right), −0.73** (L1 left), −0.70** (L5 right), −0.76** (L5 left) and for the women: −0.47 *(L1 right), −0.51** (L1 left), −0.46* (L5 right), −0.50** (L5 left). ** = significant $p < 0.01$ * = significant $p < 0.05$.

(CV) for the slopes were large (Table IV), which has also been found in other studies (CV 40–70%) (3, 11–13, 15). Large intersubject variability between healthy subjects combined with poor reliability for the slope (17) should increase the difficulty in detecting systematic differences between healthy subjects and patients with LBP. Low reliability for the slope (ICC < 0.6) has also been reported by Peach et al. (25), but, despite this finding, some of their tested EMG fatigue parameters (including slope) could be used to distinguish patients with LBP from healthy subjects (5). The IMDF, on the other hand, had in our study a smaller intersubject CV (14%), and the reliability has previously been shown to be rather good (17). Nargol et al. (26) also note that the IMDF had better reproducibility over time and at different loads than the slope. The IMDF might possibly be of clinical use, as differences in the IMDF between patients and healthy subjects have been shown, albeit with varying and sometimes opposing results (2, 5, 8, 14).

For Sørensen's test, no gender difference in IMDF has been found (10, 12). This agrees with our present results, though, with a higher contraction force and, for this reason, a different fibre-type recruitment, a gender difference could have been expected; the diameter of the type II fibres is smaller for women than for men, resulting in a twofold higher type I/type II area ratio for women (27). This gender difference in fibre types could also be the reason for the steeper slopes shown for men than for women in Sørensen's test (3, 28). However, Dedering et al. (12) found this gender difference only at one electrode location (L5 right). Our results indicate a trend for men to have a steeper slope (−0.52 %/s) than women (−0.43 %/s), but only at L5 level, and the difference was not significant.

The result of our test was a significantly steeper slope at lower vertebral level (L5) compared with higher level (L1). This is in accordance with Roy et al. (2), who tested male subjects performing back extension at 40%, 60% and 80% of MVC and found this difference level between for all contraction forces. Biomechanical reasons leading to greater forces generated by the lower lumbar muscles might explain this difference (2). Sparto et al. (15), however, report that the significantly greater slope of median frequency (Hz/s) at the lower lumbar level was no longer significant when the slope was normalized to the IMDF (%/s). Conversely, in our data there was a significant difference level between for the slope (Hz/s) as well as for the normalized slope (%/s). The reason for this might be the reported significant difference in IMDF in the study by Sparto et al., which was not found in our results. Patients with LBP might show different slope patterns. For this reason we intend to continue to measure at both levels.

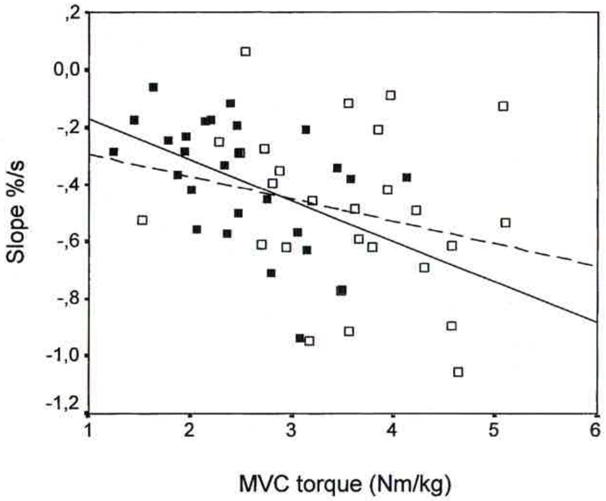

Fig. 4. Correlation between the slope for 45 seconds (%/s) and the normalized maximal voluntary contraction (MVC) torque at L5 (mean of the right and the left side) for men □ – – – ($n = 28$) and women ■ —— ($n = 27$). The correlation coefficient was higher for women ($r = -0.47$; $p < 0.05$) than for men ($r = -0.25$; $p > 0.05$). This correlation was about the same at L1 level.

The correlation that we found between the IMDF and the slope indicates a physiological connection between the IMDF and the slope, which was more noticeable for men than for women. Moritani et al. (29) found a similar correlation for men (women were not investigated) between mean power frequency obtained during MVC and the decrease in mean frequency during a fatigue contraction of the biceps brachii. Moritani suggests that motor units with a higher mean frequency would fatigue to a greater extent than those with relatively lower mean frequency at MVC. The mean frequency is furthermore dependent on the muscle fibre composition, as the decline of the mean frequency has been shown to be more rapid in muscles with a high proportion of fast twitch fibres than in muscles with a high proportion of slow twitch fibres (30). The relevance of this argument for the presently observed correlation is however not quite clear.

As the slopes for the different times (20 s, 30 s and 45 s) did not differ significantly, the assumption of a linear decrease is confirmed in retrospect. However, the variability between subjects (SD and range) increased substantially with shorter regression time (30 s and 20 s), which, in accordance with our discussion above, will make us choose the longer (45 s) contraction time in future work.

The definition and calculation of the initial median frequency can be made in at least two different ways, e.g., IMDF and IMDFm as defined above. The intercept of the regression line (IMDF) has been widely used, for example by Roy et al. (2), by Mannion & Dolan (16) and by Ng et al. (13). Mannion & Dolan used the intercept explicitly because it was expected to yield more reliable results than using the first data points (16). Our results and conclusions, for example those concerning the correlation coefficients between the initial median frequency and the slope, are not substantially different when using the IMDFm instead of the IMDF (Table V). We have chosen to use the IMDF following the more usual method and also, for continuity, since we used this variable in a previous reliability study (17).

The maximal torque (Nm) was 47% higher for men than for women, and the normalized maximal torque was 30% higher, which is similar to the results of Smidt et al. (23). However, strong back muscles did not largely affect the values of the IMDF and the slope in this study. Kondraske et al. (19), though, found a correlation ($r = 0.58$, $p < 0.01$) between slope and force/body weight (only male subjects studied). However, lack of correlation between EMG slope and back extensor isometric (3) or isokinetic (4) strength has also been shown. According to Roy et al. (6), lower MVC values for patients with LBP compared with those for control subjects did not influence the discriminatory power of the EMG parameters. Patients may vary in MVC measurements because of pain. An interesting question is whether the lack of correlation between the MVC torque and the IMDF and slope extends to patients with LBP and what the effect would be in a clinical context.

With the present type of test position and with a test contraction as high as 80% MVC, fatigue is felt in the whole body, but especially in the legs. Therefore, many subjects expressed difficulties in rating the localized back muscle fatigue, which might be the reason for the wide range in ratings and the lack of correlation with the EMG variables. We therefore think that the use of subjective ratings of back muscle fatigue for healthy subjects in this test is very doubtful. Instead, we could suggest that the Borg ratings could be useful when testing patients with LBP, and back pain instead of muscle fatigue may be more important to rate. Taimela et al. (31) have used subjective ratings during dynamic back extensions and show that the Borg ratings for fatigue increased faster and the score at the end of the test was higher for a group of patients with LBP when compared with a control group. However, Borg ratings for pain are not mentioned in their article.

CONCLUSIONS

For the presently reported EMG parameters as reference values, one may critically consider the large intersubject variability of the slope. The IMDF showed a considerably smaller variability. There was a gender difference in the correlation between the IMDF and the slope, but otherwise it seemed that the EMG parameters were not gender dependent. There was no correlation between the exerted MVC torque and the EMG parameters, and the clinical relevance of this finding remains to be seen. Subjective ratings in the present test (sitting position, isometric contraction) had low validity in estimating fatigue in the lower back muscles, judging from the lack of correlation with EMG data.

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