Electromyographic Amplitude and Frequency Changes in the Iliocostalis Lumborum and Multifidus Muscles During a Trunk Holding Test

Background and Purpose. Muscle endurance is an important variable to measure in the assessment of back muscle function. This study investigated the electromyographic (EMG) activity and fatigue patterns of iliocostalis lumborum and multifidus muscles during a trunk holding test. Subjects. Sixteen male subjects (mean age=24.2 years, SD=4.2, range=20.6–31.9) without low back pain or known pathology were recruited in the study. Methods. Surface EMG electrodes were used to record the activity of iliocostalis lumborum and multifidus muscles during a 60-second isometric contraction. To reflect the activity level and fatigue rate of the muscles, EMG amplitude (root mean square [RMS] values) and a frequency variable (median frequency [MF]) were measured. Results. The multifidus muscle displayed a higher level of activity, initial MF, and normalized MF slope than did the iliocostalis lumborum muscle. There was no difference, however, in the normalized RMS slope between the two muscles. The correlations between the normalized MF slope and the RMS slope of the two muscles were nonsignificant. Conclusion and Discussion. This study shows that monitoring frequency changes of the EMG signals may enable therapists to quantify the fatigue changes of individual muscles during the trunk holding test. The higher fatigue rate shown in the multifidus muscle compared with the iliocostalis lumborum muscle may be due to the higher activity level of the multifidus muscle during the trunk holding contraction. This greater activity of the multifidus muscle during the contraction might be explained by the functional differences between these two muscles. [Ng JK-F, Richardson CA, Jull GA. Electromyographic amplitude and frequency changes in the iliocostalis lumborum and multifidus muscles during a trunk holding test. Phys Ther. 1997;77:954–961.]

Key Words: Back, Electromyography, Fourier analysis, Isometric contraction, Muscle fatigue.

Joseph K-F Ng
Carolyn A Richardson
Gwendolen A Jull
The spinal muscle system is vital to the maintenance of spinal stability.\textsuperscript{1,2} Without muscle support, the spinal column is unable to carry normal physiological loads.\textsuperscript{3} Muscle endurance is one of the variables used to measure the functional capacity of the muscles in providing this stability. Parnianpour and colleagues\textsuperscript{4} have shown that there is an increase in the ranges of motion in other planes during fatiguing trunk flexion and extension movements, and they concluded that this apparent loss of muscle control may be one of the important causes of spinal injuries. Furthermore, there is some evidence that the endurance capacity of the back extensors is a predictor of the first onset of back pain.\textsuperscript{4}

A clinical test that is commonly used to measure the endurance capacity of the back muscles is the trunk holding test (Fig. 1).\textsuperscript{4-7} The patient is asked to hold the unsupported upper torso in a horizontal prone position. The endurance measure is the time the position can be maintained. An advantage of the test is that it requires only a submaximal effort, about 40\% to 50\% of maximum exertion.\textsuperscript{5,6,8} We believe that submaximal tests are suitable for testing the muscle function of patients with back pain. Pain inhibition, for example, is more likely to affect muscle performance if a maximal exertion is required. In addition, the test has wide applicability in clinical situations because no sophisticated or expensive equipment is required.

Holding time is a reflection of the extensor muscles as a whole and does not provide information on the fatigue rates of individual back muscles, including the longissi-
Muscle fatigue has been defined as the failure of the muscle to maintain the target force (ie, the mechanical failure point of the muscle). There is, however, considerable controversy about how fatigue is defined and measured. Some experts argue that before this failure point is reached, the muscle is already sustaining fatigue. Fatigue, from this perspective, is an ongoing process that begins from the start of a muscle contraction. According to this view of fatigue, in a sustained contraction, biochemical, physiological, and related EMG changes will begin to show in the muscles even when the force of the contraction is maintained. Some people argue that muscle fatigue may be better defined as a time-dependent process in regard to physiological and biochemical changes. There is an advantage of using EMG analysis to investigate muscle fatigue. Because fatigue changes of the muscle can be monitored by EMG from the initial part of the contraction, the subject is not required to sustain the contraction until exhaustion. This advantage of EMG analysis will lessen the influence of the motivation factor during endurance testing.

Electromyographic analysis during fatiguing contractions has been performed extensively on various muscles. During a fatiguing contraction, the EMG amplitude has been found to increase in submaximal contractions, as would occur in the trunk holding test. At the same time, changes in the frequency components of the EMG signals can also be observed. There is an increase in the lower frequency components of the EMG spectrum during sustained contractions, and this frequency shift is commonly termed the "frequency/spectral shift" or "frequency/spectral compression" toward lower frequency. This frequency shift has been used as an indicator of muscle fatigue.

There is a lack of data in the literature regarding the activity level, EMG amplitude, and frequency changes of the individual back muscles during the trunk holding test. Our study was aimed at investigating the activity level, EMG amplitude, and frequency changes of two back muscles—the iliocostalis lumborum and the multifidus—in subjects without back pain or known pathology during the trunk holding test. The correlation between the amplitude and frequency measures was also examined.

**Method**

**Subjects**

Sixteen habitually active male subjects with no history of low back pain or known pathology volunteered for this study. The subjects had a mean age of 24.2 years (SD=4.2, range=20.6-31.9), a mean height of 170.2 cm (SD=4, range=165-178), and a mean weight of 60.1 kg (SD=7.3, range=47.6-74.8). All subjects gave their informed consent to participate.

**Equipment**

The electrode position, the recording technique, and the equipment have been described in detail in a previous report and will be summarized here. Skin preparation of electrode sites involved shaving, cleaning with alcohol, and a skin abrasion technique similar to that described by Burbank and Webster. Silver-silver chloride surface electrodes with a recording diameter of 10 mm were used. After skin preparation and the placement of electrodes, the interelectrode resistance was checked by using an impedance meter, and a skin resistance of less than 5,000 Ω was considered acceptable. The EMG signals were recorded from the iliocostalis lumborum muscle at the L-2 level and from the multifidus muscle at the L-5 level on the right side (Fig. 2). The ground electrode was placed over the right acromial process.

Isolating the EMG activity of the iliocostalis lumborum and multifidus muscles was made possible by use of the following procedures. The electrodes were positioned within the borders of the muscles and were aligned with the muscles' fiber orientation (Fig. 2). For the iliocostalis lumborum muscle, the electrodes were aligned parallel to the line between the posterior superior iliac

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Graphical Controls, 215 Herbert St, Gananoque, Ontario, Canada K7G 2Y7.

Specialised Laboratory Equipment, 15 Campbell Rd, Croydon, Surrey, England CRO 2SQ.
spine (PSIS) and the lateral border of the muscle at the 12th rib. For the multifidus muscle, the electrodes were aligned parallel to the line between the PSIS and the L1–2 interspinous space. This positioning was verified in a cadaveric study and has been adopted in several EMG studies. The electrode position at these locations should probably reflect the majority of activity of the underlying muscle. The distance between the electrodes over the iliocostalis lumborum and multifidus muscles in our study was always more than 3 cm. It has been shown that the EMG signals recorded by electrodes placed more than 3 cm apart can be regarded as sufficiently specific signals. Additionally, we used a branched electrode technique to minimize cross talk. In this technique, three electrodes (inter electrode distance = 25 mm) are placed parallel to the muscle fiber orientation, with the center electrode connecting to the negative terminal and the two flanking electrodes connecting to the positive terminal of the preamplifier (Fig. 2). This arrangement can reduce the recording of cross-talk signals by removal of the voltage gradients, with constant slopes produced by tissue filtering of EMG signals from other distant muscles.

The EMG signals were passed through a preamplifier (Medelec PA63) to an amplifier/filter (Medelec A6MKHII) and then collected by a data acquisition system. Amplifier gains were adjusted for each subject. The filter bandwidth was set at 0.8 to 800 Hz, and the signals were sampled at 2,500 Hz.

**Testing Procedure**

The subjects were positioned prone lying over two electric treatment couches. The first couch supported the upper body, and the second couch supported the pelvis and the legs. The anterior superior iliac spines were positioned at the edge of the couch supporting the pelvis and the legs. The lower body was stabilized by straps over the hips, knees, and ankles. The horizontal position of the upper torso in relation to the legs was determined by a goniometer. Subjects were instructed to place their hands under their forehead with their elbows out to the side. To normalize the activity of the iliocostalis lumborum and multifidus muscles, subjects were asked to extend isometrically with a maximal effort against a fixed strap positioned over the midthoracic level. For this test, the support for the upper body was withdrawn by lowering the first couch. The isometric contraction was sustained for 5 seconds. Two trials were performed, with a 1-minute rest period between trials.

For the fatigue measurement, subjects were asked to hold their unsupported trunk for 60 seconds. A pointer on a vertical stand was placed over the midthoracic level to provide tactile feedback of the horizontal position to be maintained during the isometric hold (Fig. 1). At the commencement of the test, the couch supporting the torso was again lowered, and the subjects were asked to maintain contact with the pointer during the contraction. This horizontal position was monitored throughout the contractions. Two trials were performed, with a 5-minute rest period between trials.

**Signal Processing**

To enable comparison of the activity level between the iliocostalis lumborum and multifidus muscles during the trunk holding test, the root mean square (RMS) values of the two muscles during the first 2 seconds at the beginning of trunk holding were normalized to the maximal exertion of isometric trunk extension. For the quantification of the maximum exertion, the RMS values of the middle 3 seconds were obtained from the EMG signals of the 5-second maximal effort of trunk extension, and the average of the two trials of maximum exertion was computed.

For the measurement of fatigue changes, 2 seconds of EMG signals were extracted at every fifth second of the 60-second contraction using a waveform editing program. Frequency and amplitude analyses were then applied to the extracted EMG signals. For the frequency analysis, the EMG signals were analyzed with fast Fourier

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2 A/D card from National Instruments, 6004 Bridge Point Pkwy, Austin, TX 78730-5039. Program was written by Department of Physiotherapy, The University of Queensland.
3 Chattanooga Australia (Pty) Ltd, 24 Pittwater Rd, Gladesville, Sydney, New South Wales, Australia 2111.

* Department of Physiotherapy, The University of Queensland.
Table 1.
Difference of Activity Between the Iliocostalis Lumborum and Multifidus Muscles in the Trunk Holding Test

<table>
<thead>
<tr>
<th></th>
<th>Iliocostalis Lumborum Muscle</th>
<th>Multifidus Muscle</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>X SD</td>
<td>X SD</td>
</tr>
<tr>
<td>Normalized* root mean square values (%)</td>
<td>64.76 18.84</td>
<td>77.53 14.30</td>
</tr>
</tbody>
</table>

* Normalized to maximal exertion.

Table 2.
Differences of Frequency (Initial Median Frequency [MF], Normalized MF Slope) and Amplitude (Normalized Root Mean Square [RMS] Slope) Changes Between the Iliocostalis Lumborum and Multifidus Muscles During the Fatigue Assessment

<table>
<thead>
<tr>
<th></th>
<th>Iliocostalis Lumborum Muscle</th>
<th>Multifidus Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X SD</td>
<td>X SD</td>
</tr>
<tr>
<td>Initial MF [Hz]</td>
<td>46.81 10.46</td>
<td>66.18 9.73</td>
</tr>
<tr>
<td>Normalized* MF slope [%/s]</td>
<td>-0.32 0.22</td>
<td>-0.56 0.25</td>
</tr>
<tr>
<td>Normalized* RMS slope [%/s]</td>
<td>0.57 0.34</td>
<td>0.44 0.27</td>
</tr>
</tbody>
</table>

* Normalized to initial values.

Data Analysis
The SAS software program was used for data analysis. The means and standard deviations of the RMS and MF data were computed. To compare the activity levels, initial MF, normalized MF, and RMS slope between the iliocostalis lumborum and multifidus muscles, Student’s t tests were applied. The correlation between the normalized MF slope and RMS slope was examined by Pearson’s correlation coefficient (r). An alpha level of .05 was used in all analyses.

Results
The normalized EMG results are presented in Table 1. These results indicate that the activity of the multifidus muscle was greater (P<.005) than that of the iliocostalis lumborum muscle during the trunk holding test. The frequency and amplitude changes of iliocostalis lumborum and multifidus muscles are illustrated in Figure 3. The differences between the MF and RMS data of the two muscles for the fatigue assessment are presented in Table 2. The multifidus muscle displayed a higher initial MF (P<.0001) and a greater normalized MF slope (P<.0005) than did the iliocostalis lumborum muscle. There was no difference (P>.05), however, between the normalized RMS slopes of the two muscles. There was no meaningful correlation between the normalized MF slope and the RMS slope of the iliocostalis lumborum muscle (r=.15) and the multifidus muscle (r=−.02).

Discussion
The results of our study showed that the activity levels of the two muscles of the back extensor group were different during the trunk holding test. The activity level of the multifidus muscle (78%) was greater than that of the iliocostalis lumborum muscle (65%). Similar activity of the multifidus muscle (79%) was also observed in our previous study, although the EMG signals in that study were normalized to a maximum back hyperextension maneuver. Vink and colleagues likewise demonstrated...
higher activity in the multifidus muscle than in the iliocostalis lumborum muscle during extension in a standing position. This finding may be due to the functional differences between the two muscles. The multifidus muscle is responsible for counteracting forces in the sagittal plane, whereas force contributions of the iliocostalis lumborum muscle are more in the frontal plane. Vink and colleagues suggested that the iliocostalis lumborum muscle is only recruited at higher force levels during trunk extension.

A consistent increase of the EMG amplitude (RMS values) was demonstrated in both the iliocostalis lumborum and multifidus muscles during the whole 60-second contraction. This finding is in agreement with findings of other investigators for the back muscles and limb muscles. This amplitude increase during a fatiguing task has been attributed to the recruitment of additional motor units in order to maintain the force output. Although the increase in EMG amplitude during exertions at submaximal levels is well established, Seidel and colleagues found that there were differences in amplitude responses at different levels of submaximal exertion. A decrease of EMG amplitude occurred below 40% of maximal voluntary contraction (MVC), but an increase occurred at a higher exertion level (65% of MVC). This finding has been explained by the different responses of motor units containing slow and fast fibers during contraction at low force levels. In our study, the load of the upper torso in the trunk holding test can be assumed to be about 40% to 50% of MVC, and a corresponding increase in EMG amplitude was evident.

The frequency shift or compression of the EMG signals to lower-frequency values during fatiguing contractions has been demonstrated in many different muscles. This gradual increase of lower-frequency content is attributable first to a decrease in muscle fiber conduction velocity, which in turn is due to a decrease in intramuscular pH and possibly an increase in potassium ions in the extracellular fluids and second to changes in the synchronization and firing rate of motor units. The rate of the frequency shift or compression, which is commonly expressed as the rate of decline in MF, is regarded as the fatigue rate of the muscle. In addition, it has been shown that there is a relationship between the normalized MF slope of the back muscles (erector spinae) and the endurance time of the trunk holding test.

There was a difference in the fatigue rate (normalized MF slope) between the iliocostalis lumborum and multifidus muscles, with a greater fatigue rate in the multifidus muscle. Similar findings have been demonstrated in a recent study on a similar trunk holding position, as well as during isometric trunk extension in the standing position and in the semi-sitting position. This difference in fatigue rate may be attributed to the higher level of activity of the multifidus muscle than of the iliocostalis lumborum muscle in trunk extension, as shown in

![Graph A](https://academic.oup.com/ptj/article-fig/77/9/954/2633210/1)

![Graph B](https://academic.oup.com/ptj/article-fig/77/9/954/2633210/2)
our study. The relatively higher fatigue rate in the multifidus muscle may therefore be inevitable.

The initial MF of the multifidus muscle was greater than that of the iliocostalis lumborum muscle in our study. This observation is consistent with findings of other studies.\textsuperscript{11,12,28} The absolute values of the initial MF of the two muscles, however, were different from those of other studies, and this difference may be attributed to different experimental setups. The greater initial MF determined here could be an indication of the histochemical composition of the muscle.\textsuperscript{11,12,28} Muscles containing a greater percentage of fast fibers demonstrate higher initial MFs.\textsuperscript{38} This finding may be due to a higher proportion of fast fiber action potentials, resulting in numbers of higher-frequency components in the spectrum.\textsuperscript{38}

In our study, there were consistent and similar increases in amplitude of both the iliocostalis lumborum and multifidus muscles, but a greater MF slope was found for the multifidus muscle than for the iliocostalis lumborum muscle. Additionally, no correlation was demonstrated between EMG amplitude and the slope of the MF. This finding may be explained by the differential behavior of the two measurements used to quantify the fatigue changes. The change of EMG amplitude is more pronounced near the mechanical failure point, whereas the MF decrease is more evident at the beginning of the sustained contraction.\textsuperscript{16,29} Recordings of MF changes may be more relevant than the amplitude changes in our study, because the trunk holding test was sustained only for 60 seconds. This 60-second contraction time is shorter than the endurance times recorded for male subjects without known pathology, which have ranged from 116 seconds\textsuperscript{6} to 171 seconds\textsuperscript{4} to 198 seconds\textsuperscript{3} before fatigue. Moreover, it has been suggested that the change of EMG amplitude over time may not be a reliable indicator of muscle fatigue.\textsuperscript{11,16,28} The amplitude of the EMG signals is easily affected by other factors such as electrode type and placement.\textsuperscript{16,29} In this regard, the poor correlation between amplitude and frequency changes in our study may be partly explained by the problems associated with using amplitude changes to monitor fatigue.

Although there are advantages in applying EMG frequency analysis in quantification of muscle fatigue, there are limitations in the application of this technique in clinical practice at the present time.\textsuperscript{21} There is still a lack of a normal database of the behavior of the individual back muscles in trunk holding test. Variables such as gender, age, and training history may affect the behavior of the back muscles. It is difficult to determine whether a normalized MF slope of $-0.32\,\% / s$ is within the normal range. Further research to establish a normal database is necessary. Electromyographic frequency analysis, however, may still be applied to assess the changes within individuals during rehabilitation because their status can be compared before and after exercise training. Roy and colleagues\textsuperscript{57} have shown that the EMG frequency changes are in accordance with improvement in the endurance of the back muscles in patients with back pain after a rehabilitation program.

**Conclusion**

Electromyographic frequency analysis may be able to quantify the different fatigue rates of the individual muscles in the back extensor group during the trunk holding test. The results of our study confirm that the components of the back muscles behave differently during endurance contractions. Future research is needed to determine whether the measures of fatigue used in our study provide clinically useful information. Interesting information will also be gained from comparing the fatigue changes of back muscles between subjects with and without back pain.

**Acknowledgments**

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**References**


