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Original Research

Recovery of Hip and Back Muscle Fatigue Following a Back Extension Endurance Test

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ABSTRACT

International Journal of Exercise Science 10(2): 213-224, 2017 Literature has not shown the minimum time required to recover from muscle fatigue after a prolonged trunk isometric contraction. The purpose of this study was to determine if the lumbar multifidus (LM) and gluteus maximus (GM) muscles would recover from fatigue after three different rest periods following performance of a back extension endurance test. Endurance time and electromyographic (EMG) activity of bilateral LM and GM muscles were collected from 12 healthy adults during a modified Biering-Sørensen test. On three separate visits, each participant performed two modified Biering-Sørensen tests, one before and one after a rest period (3, 6 or 9 min). For each endurance test, endurance time was measured and both mean and median EMG frequency fatigue rates were calculated. The results showed a significantly reduced endurance time and normalized mean frequency fatigue rates on the second modified Biering-Sørensen endurance test regardless of the rest periods (3, 6, and 9 min). This suggests that adequate rest should be considered for fatigue recovery when designing a back and hip endurance exercise program, and that future studies should investigate a rest time longer than 9 minutes for fatigue recovery following a modified Biering-Sørensen endurance test.

KEY WORDS: Electromyography, median frequency, mean frequency, fatigue rate, isometric contraction, rest intervals

INTRODUCTION

Poor muscle endurance has been associated with low back problems and has been shown to be a predictor of low back pain (LBP) development (1, 16). The Biering Sørensen test and its modified version are most frequently used by researchers and clinicians to evaluate low back muscle endurance (5, 16, 25). This endurance test is a timed test which measures how long a person can hold his/her upper body unsupported in a horizontal prone position while the lower body is stabilized with belts on a table (1). Literature has demonstrated a significantly reduced holding time for the Biering-Sørensen test in people with LBP (11, 16, 24).

The Biering-Sørensen test, in conjunction with surface electromyography (sEMG) spectral analysis, was identified as the most optimal method currently available to assess back muscle fatigue (25). In sEMG studies (3, 13, 17, 24), the median or mean frequency of the EMG power spectrum was derived using the fast Fourier transform algorithm. A linear regression analysis was then followed to determine the initial value and the slope of decline in median or mean frequency with time, and the slope of median or mean frequency was used as an index of muscle fatigability (3). In general, the reliability of the median frequency analysis for the Biering Sørensen test was shown to be good for healthy subjects (3, 7, 16), but fair-to-good for patients with LBP (8, 16, 19). In addition, a positive and close relationship has been demonstrated between the decline in EMG median frequency and a shorter endurance time of the Biering-Sørensen (4, 6). This endurance test was also found to be able to discriminate between individuals with and without non-specific LBP (11, 16).

In recent years, exercises designed for core stabilization are considered essential for low back health, in particular, for a specific subgroup of patients with LBP who have aberrant movement and positive prone instability test (20, 21). These stabilization exercises often target endurance training and require a prolonged hold, such as a full-plank or side-plank of the Pilates maneuvers. Further, because back muscle fatigue has been shown to reduce control of spinal stability in patients with LBP and postural control in healthy adults, it subsequently could cause improper exercise techniques or injuries (11, 26). To avoid fatigue and to achieve optimal training effects, it is important to give adequate resting time between repetitions or between exercises (22). Effects of different rest intervals on muscle strength and endurance performance has been studied (9, 15, 22, 23), and the rest period required to recover from fatigue (i.e. voluntary exhaustion) varies depending on the type of resistance or endurance training. An EMG study (15) demonstrated that a rest period of 10 or 15 minutes was sufficient to achieve complete recovery of back muscles in healthy men after performing a fatiguing contraction. However, the choice of times for the rest period appeared to be arbitrary, prompting us to ask the following research question: What would be the minimum amount of recovery time needed following a fatigue trial of the modified Biering-Sørensen test?

The primary purpose of this study was to examine whether or not the lumbar multifidus (LM) and gluteus maximus (GM) muscles of asymptomatic adults would recover from fatigue after 3 different rest times (3 min, 6 min, and 9 min) following performance of a modified Biering-Sørensen test. The secondary purpose of this study was to examine the association of endurance time with regard to mean and median EMG fatigue rate to determine whether mean EMG frequency or median EMG frequency would be a better indicator of fatigability of the LM and GM muscles.

METHODS

Participants

Twelve participants (5 men and 7 women, age of 27.8 ± 3.7 years) with a body mass index (BMI) of 24.4 completed the study. Eligible participants were healthy adults who had no current back or hip pain and no history of back or hip pain in the past 12 months. Participants were excluded if they had any known conditions or comorbidities that may affect back or hip muscle contraction, including but not limited to tumor, fracture or infection, systemic arthritis, current pregnancy, severe deconditioning due to cardiopulmonary disorders, and previous surgery to the back or hip. Once a participant agreed to participate in the study, the participant was informed of the risks and procedures of the study, and then signed a written informed consent form approved by the Institutional Review Board of the investigators' affiliated institution.

Protocol

A Delsys Trigno™ wireless EMG system (Delsys Inc., Natick, MA) and four wireless sEMG electrodes were used to record muscle activity. Each wireless sEMG electrode contains a built-in pre-amplifier and two sets of parallel silver contact bars with a fixed distance of 1 cm between the recording sites. One set of contact bars served as a reference electrode. The raw sEMG signals were recorded at a sampling rate of 2,000 Hz, and filtered between 20 and 450 Hz. The gain of the EMG system was 1,000 with the CMRR > 80 dB.

On each of three different visits, each participant was tested for one of three different rest periods (3, 6, and 9 min). The order of these three rest periods was randomized with six possible testing orders. To determine the testing order, each participant drew a card from an envelope that contained six cards of different testing orders. To obtain consistent sEMG activity, efforts were made to test all participants at the same time of day for their three visits, if possible. In addition, participants were asked if they had residual muscle soreness or discomfort from the previous visit's testing.

Bilateral LM and GM were selected for this study because the strength of these two muscles is often affected in people with low back problems (2, 10, 13). To prepare for sEMG recording, each participant's skin over the right and left LM and GM muscles was cleaned with alcohol and, if needed, excessive hair was shaved using a disposable razor. Disposable adhesive tape was used to affix the four wireless sEMG electrodes to the skin over the four muscles. For the LM muscle, the electrode was placed 2 cm away from the second sacral spinous process, just above the level of the posterior superior iliac spines (4). For the GM muscle, the electrode was placed at the mid-point between the posterior superior iliac spine and the ischial tuberosity (4).

The sEMG activity of the LM and GM muscles was recorded while the participants performed a modified Biering-Sørensen test (Figure 1) following the testing protocol described in previous studies (3, 4, 18). Briefly, each participant was positioned in prone on a treatment table with the superior borders of the bilateral anterior superior iliac spines at the edge of the table and the upper body hanging off of the table. The lower body of the participant was stabilized on the table by three belts placed over the hips, just below the knees, and just above the ankles. During the modified Biering-Sørensen test, each participant was instructed to extended his/her trunk and maintain the trunk in a horizontal position with the head in a neutral position, both elbows out to the side and both hands contacting the forehead. In addition, a narrow Velcro band connected by two vertical poles was placed at the level of the participant's seventh thoracic vertebrae. This Velcro band was used to provide tactile feedback to encourage the participant to maintain his/her body in a horizontal position during the testing (3, 4). An inclinometer (Fabrication Enterprises Inc. White Plains, NY) was placed over the inter-scapular area to monitor the trunk position (16). When the participant's trunk deviated more than 10° from the horizontal position, the participant was asked again to extend his/her trunk and keep it in a horizontal position. If a participant could not maintain a horizontal position, the test was ended, and muscles were considered fatigued (16).

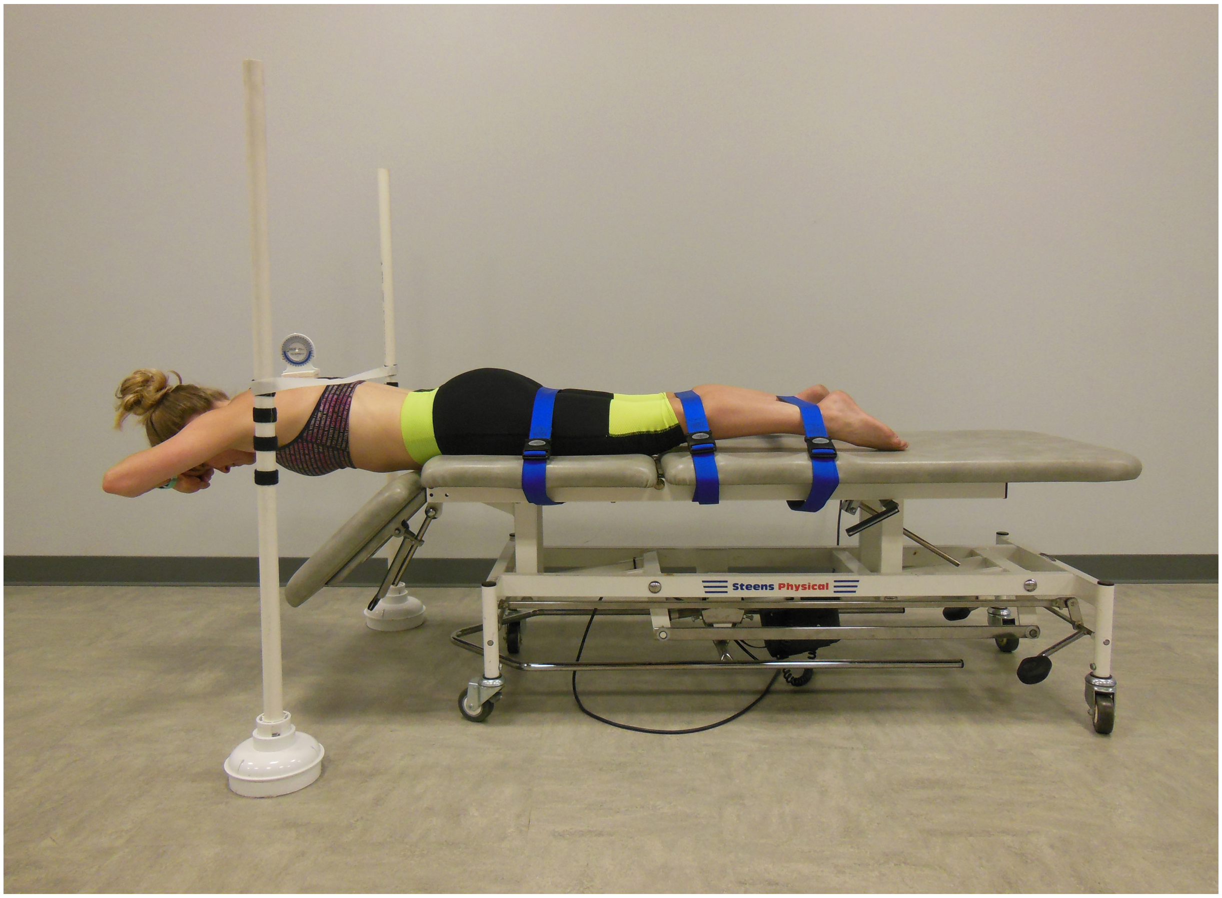

Figure 1. Modified Biering-Sørensen test.

After completing one modified Biering-Sørensen test, each participant was given a rest period. The duration of the specific rest period (3, 6, or 9 min) for each visit depended on the testing order selected at the beginning of the study. After the given rest period, each participant was asked to perform a second modified Biering-Sørensen test for endurance time and sEMG recording. All participants were asked to return for two more visits within the next seven days to perform two modified Biering-Sørensen tests with different rest periods on each visit.

Statistical Analysis
Muscle fatigability or fatigue rate was determined using mean and median EMG frequency slope as a function of time. First, the mean and median EMG frequency values were computed for every second using the Delsys EMGWorks software (Delsys Inc., Natick, MA) (13, 15, 18). Linear regression analysis was then performed using IBM SPSS Version 19.0 (IBM Corp.,

Armonk, NY, USA) to obtain the initial and the slope values (4, 15). In order to compare EMG frequency fatigue rates between the three rest periods, normalized mean and median EMG frequency fatigue rates (%) were calculated for each modified Biering-Sørensen test using the following formulas: normalized mean frequency fatigue rate (%) = (mean frequency slope/initial mean frequency) x 100, and normalized median frequency fatigue rate (%) = (median frequency slope/initial median frequency) x 100 (4, 12, 13). In addition, the time from the start to the end of each modified Biering-Sørensen test was recorded for statistical analysis (4, 12, 13). Lastly, three separate 2 (before- and after-rest) x 3 (rest period) repeated measure (RM) ANOVAs were performed to compare endurance time, normalized mean frequency fatigue rate, and normalized median frequency fatigue rate, respectively. The alpha level was set at 0.05 for all statistical analyses. Because the data was collected on three different visits, one-way RM ANOVAs were performed to compare before-rest endurance time and normalized EMG frequency fatigue rates.

To examine the relationship of the endurance times in regard to the normalized mean and median frequency fatigue rates, Pearson correlation coefficients were performed with $p < 0.05$. If there was no difference in three before-rest (3, 6 and 9 min) endurance times and normalized EMG fatigue rates, the average of the before-rest data was used for the correlational analyses.

RESULTS

Of 12 participants in our study, eight participants came for the three testing visits in three consecutive days, three within four days, and one within five days. None of the participants reported residual soreness on the following visits before testing. Descriptive data of endurance time (mean ± SD and median) and normalized EMG fatigue rates (mean ± SD) before and after the three rest periods are listed in Table 1 and Table 2, respectively. The baseline comparisons showed no significant differences in endurance times, normalized mean and median frequency fatigue rates for the before-rest data ($p > 0.05$), indicating that the before-rest data collected on three different visits was similar. Literature has shown that women have better endurance time than men on the Biering-Sørensen test (1, 12). In our study, five were men and seven were women, with the average endurance time before test being 83.4 sec for men and 106.6 sec for women, and the average endurance time after test being 76.6 sec for men and 102.2 sec for women.

Table 1. Mean ± SD (median) of endurance time (sec) before and after three rest periods (3, 6, and 9 min) (n = 12).

	Before	After
3-min rest	93.3 ± 33.2 (81.5)	83.9 ± 23.1 (82.0)
6-min rest	101.1 ± 45.1 (81.0)	93.7 ± 39.5 (74.0)
9-min rest	96.5 ± 33.1 (80.5)	97.0 ± 38.4 (84.5)
Average	96.9 ± 34.9	91.5 ± 32.3

Table 2. Mean and median electromyographic frequency fatigue rate (mean ± SD) before and after three rest periods (3, 6, and 9 min) for bilateral lumbar multifidus (LM) and gluteus maximus (GM) (n = 12).

Mean frequency rate (%)	Right LM	Left LM	Right GM	Left GM
3-min rest				
Before	-0.44 ± 0.27	-0.49 ± 0.29	-0.17 ± 0.14	-0.20 ± 0.17
After	-0.49 ± 0.22	-0.53 ± 0.25	-0.23 ± 0.13	-0.22 ± 0.14
6-min rest				
Before	-0.40 ± 0.24	-0.41 ± 0.26	-0.16 ± 0.12	-0.20 ± 0.17
After	-0.48 ± 0.25	-0.54 ± 0.26	-0.19 ± 0.12	-0.23 ± 0.09
9-min rest				
Before	-0.41 ± 0.21	-0.48 ± 0.22	-0.19 ± 0.16	-0.21 ± 0.23
After	-0.48 ± 0.27	-0.53 ± 0.29	-0.21 ± 0.10	-0.21 ± 0.12
Median frequency rate (%)				
3-min rest				
Before	-0.49 ± 0.30	-0.56 ± 0.33	-0.17 ± 0.20	-0.17 ± 0.13
After	-0.50 ± 0.24	-0.58 ± 0.26	-0.21 ± 0.13	-0.23 ± 0.15
6-min rest				
Before	-0.50 ± 0.23	-0.57 ± 0.30	-0.13 ± 0.26	-0.13 ± 0.25
After	-0.53 ± 0.33	-0.61 ± 0.31	-0.21 ± 0.11	-0.22 ± 0.10
9-min rest				
Before	-0.52 ± 0.28	-0.50 ± 0.32	-0.20 ± 0.20	-0.18 ± 0.05
After	-0.50 ± 0.25	-0.52 ± 0.29	-0.16 ± 0.19	-0.18 ± 0.10

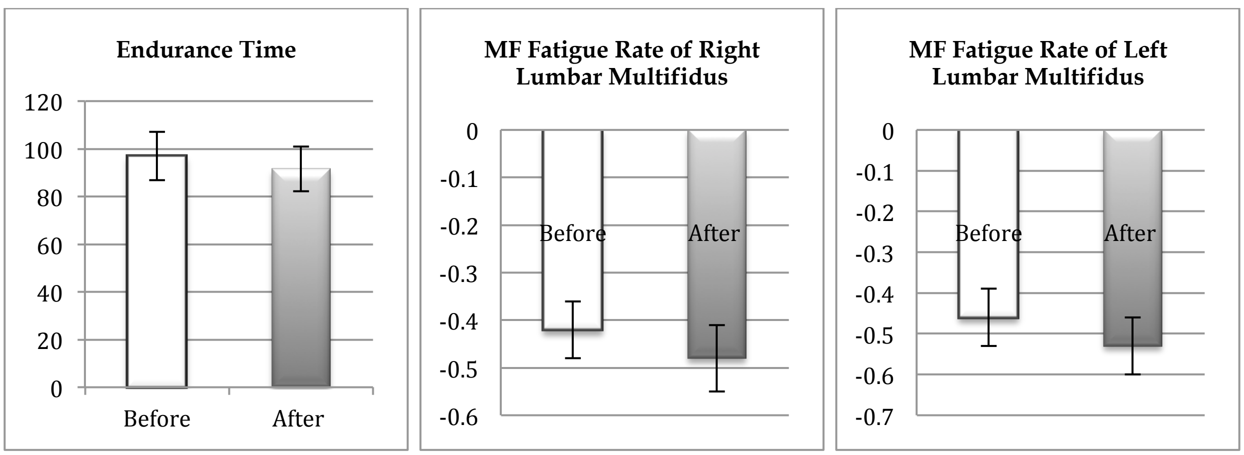

Figure 2. Average of the three before-rest and the three after-rest endurance times and normalized mean frequency (MF) fatigue rates of the right and left lumbar multifidus muscles (n = 12) ($p < 0.05$).

The 2x3 RM ANOVA results showed no significant interaction for all of the variables: endurance time ($p = 0.215$), normalized mean frequency fatigue rate ($p = 0.784$ for right LM, $p = 0.270$ for left LM, $p = 0.612$ for right GM, $p = 0.905$ for left GM), and normalized median frequency fatigue rate ($p = 0.686$ for right LM, $p = 0.948$ for left LM, $p = 0.415$ for right GM, $p = 0.512$ for left GM). However, there was a significant main effect of the before- and after-rest factor (Figure 2) for endurance time ($p = 0.035$) and for normalized mean frequency fatigue rates of the right and left LM muscles ($p = 0.034$ for right LM, $p = 0.048$ for left LM). In contrast, no significant main effect of the before- and after-rest factor was found for normalized mean frequency of the right and left GM ($p = 0.078$ for right GM, $p = 0.740$ for left

GM), and for normalized median frequency fatigue rates (p = 0.769 for right LM, p = 0.357 for left LM, p = 0.510 for right GM, p = 0.080 for left GM).

There was no difference in endurance time and in normalized EMG frequency fatigue rate for the three before-rest (3, 6 and 9 min) measurements. Therefore, the average of the before-rest data was used for the correlational analyses. Table 3 displays Pearson correlations coefficients (r) of endurance time versus normalized mean frequency fatigue rate, and of endurance time versus normalized median frequency fatigue rate for the before rest, after 3-min rest, after 6-min rest and after 9-min rest measurements of all four muscles. The correlation analyses showed fair-to-moderate correlations between the endurance time versus both normalized mean and median frequency fatigue rates for the bilateral LM muscles, but poor-to- moderate correlations for the bilateral GM muscles. The correlation coefficients between endurance times and normalized mean frequency fatigue rates were slightly stronger than those between endurance times and normalized median frequency fatigue rates.

Table 3. Correlation coefficients (r) of endurance time versus mean electromyographic (EMG) frequency fatigue rate and endurance time versus median EMG frequency fatigue rate for bilateral lumbar multifidus (LM) and gluteus maximus (GM) (n = 12).

	Endurance Time (sec) vs. Mean Fatigue Rate (%)			
	Right LM	Left LM	Right GM	Left GM
Pre-rest	0.362	0.683*	0.281	0.530
Post-3 min rest	0.531	0.619*	-0.152	-0.211
Post-6 min rest	0.548	0.675*	0.280	0.574
Post-9 min rest	0.482	0.770*	0.191	0.617*
	Endurance Time (sec) vs. Median Fatigue Rate (%)			
	Right LM	Left LM	Right GM	Left GM
Pre-rest	0.560	0.629*	0.261	0.410
Post-3 min rest	0.475	0.496	0.047	-0.181
Post-6 min rest	0.463	0.817*	0.462	0.443
Post-9 min rest	0.638*	0.671*	0.351	0.340

* Significance at $p < 0.05$.

DISCUSSION

The results showed no significant changes in endurance times or in normalized EMG frequency fatigue rates (both mean and median frequencies) between the 3 rest periods before and after rest. Although the endurance time appeared to be improved after a 9-min rest, the non-significant finding could be due to the high variance of the endurance time data, with SD ranging from 23.1 to 45.1 sec. The differences between the mean and median values, as shown in Table 1, also demonstrate variability of the endurance times for all conditions except after 3-min rest. Further, the SD values found in our study are similar to those reported in the previous studies (8, 12). In addition, our results showed that women had better performance than men on the modified Biering-Sørensen test, which is in agreement with previous studies (1, 12). However, we do not believe that the gender difference would have impacted our results because the number of women and men are almost equally distributed (seven women, five men).

The results of the study showed a significant main effect of the before- (96.9 sec) and after-rest (91.5 sec) endurance time, indicating that there was a significantly reduced endurance time on the second modified Biering-Sørensen test (Figure 2). Further, we speculate that although the participants were given up to 9 minutes of rest, this still may have been inadequate for recovery from performing a fatigue trial of the modified Biering-Sørensen test, and that even longer rest periods should be considered for fatigue recovery when designing a back and hip endurance exercise program. However, Larivière et al. (15) demonstrated complete back muscle recovery after a 10-minute rest, but we have doubt that complete recovery in our testing protocol would occur between 9 and 10 minutes. The 10-minute recovery time possibly could be underestimated in Larivière et al.'s study (15). Their fatigue trial consisted of a 30-sec isometric contraction performed at 75% of maximal voluntary contraction, whereas the fatigue in our study was defined as the participant no longer being able to maintain his/her trunk in a horizontal position for the modified Biering-Sørensen test. In addition, the participants in our study had an average of 96.9 sec performance before they fatigued, which was almost one minute longer than the fatigue trial selected in Larivière et al.'s study (15). Furthermore, Larivière et al. (15) tested their participants in a standing position whereas we used an anti-gravity horizontal position, which could fatigue the participants further. Comparisons could not be made with other rest interval studies (9, 22, 23) which only included repeated isotonic contractions.

As mentioned earlier, our results showed a significantly reduced endurance time on the second modified Biering-Sørensen test. The average of the before-rest endurance time was 96.9 sec and the after-rest endurance time was 91.5. A similar result was found in the normalized mean frequency fatigue rates of the bilateral LM muscles with the fatigue rate of the right LM being -0.42 for before-rest and -0.48 for after-rest, and that of the left LM being -0.46 for before-rest and -0.53 for after-rest. These findings indicate that the LM, not the GM, may be the primary muscle contributing to fatigue recovery, thus affecting the performance of the second modified Biering-Sørensen test. However, no significant change of the median frequency fatigue rates was found before and after rest.

The statistical analyses of the endurance times and normalized mean frequency fatigue rates generated a similar finding, but the analyses of normalized median frequency fatigue rates yielded a different one. This discrepancy could indicate that the mean frequency fatigue rate may be a better indicator for muscle fatigue of LM following a prolonged isometric trunk contraction. Further, the correlations of normalized mean frequency fatigue rates and endurance times are slightly stronger than the correlation of normalized median frequency fatigue rates to endurance times, thus supporting this hypothesis. However, neither normalized mean nor median frequency fatigue rates were strongly correlated to the endurance times as shown in Table 3. Our findings are in agreement with a previous study in which Coorevits et al. (4) reported a moderate correlation coefficient of 0.612 for LM at L5 and a fair correlation of 0.467 for GM. Interestingly, there was a noticeable difference in the correlations of normalized frequency fatigue rates and endurance time between the right and left LM. All of our participants were self-reported right-side dominant, which could have contributed to the difference between the right and left LM. The effect of side-dominance on median frequency fatigue rate of lumbar muscles was also found in a previous study by Mannion et al. (17).

The participants in this study had an average endurance time of 96.9 sec for the modified Biering-Sørensen test. This fatigue time was approximately 10-15 seconds shorter than the times reported in the previous studies (4, 12, 18). Both Biering-Sørensen (1) and Kankaanpää et al. (12) suggested that age and BMI could affect the endurance time slightly, with a decrease with a high BMI, but an increase with age. Although the participants in our and previous studies had similar BMI, our participants were on average 10 years younger than those in previous studies. The age difference could explain in part the lower endurance time found in this study. In addition, motivation could have contributed to the lower endurance time found in our study. No encouragement was given during the modified Biering-Sørensen test in our study, whereas encouragement was given throughout the test in other studies (4, 18). Interestingly, the normalized median frequency fatigue rates of LM (-0.49% to -0.61%) and GM (-0.16% to -0.23%) were similar to those reported in previous studies (2, 3, 4, 6). This may imply that normalized EMG frequency fatigue rate may not be affected by age or motivation. However, further research is needed to validate this speculation. Furthermore, the normalized median frequency fatigue rate of the LM was twice that of the GM muscle, indicating the LM muscle fatigued more quickly than the GM. However, this result was in disagreement with that reported by Kankaanpää et al. (13) who found similar fatigue rate in GM and lumbar paraspinals.

One notable limitation of the study was that the EMG data was collected on three separate visits rather than on the same day, and this could have affected our results. Nevertheless, we chose not to test the three rest intervals on the same day because the fatigue and motivation factors from the modified Biering-Sørensen endurance test might have severely impacted the results (12, 14). In addition, we made every effort to ask the participants to return at the same time of the day for testing and to ensure no residual muscle soreness from the previous visit's endurance testing. Statistical analysis also showed no difference in before-rest data for all variables. However, most of our participants came for the three testing visits in three consecutive days. Although the participants did not report residual muscle soreness, it is difficult to know for certain that every participant had a complete recovery from the prior day's testing, especially on their third day of testing.

In conclusion, a significantly reduced endurance time and normalized mean frequency fatigue rates were found on the second modified Biering-Sørensen endurance test. The results suggest that adequate rest should be considered for fatigue recovery when designing a back and hip endurance exercise program. Future studies should investigate a rest time longer than 9 minutes for fatigue recovery following a modified Biering-Sørensen endurance test.

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