Back and hip extensor muscles fatigue in healthy subjects: task-dependency effect of two variants of the Sorensen test

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Abstract Paraspinal muscle fatigability during various trunk extension tests has been widely investigated by electromyography (EMG), and its task-dependency is established recently. Hip extensor muscle fatigability during the Sorensen test has been reported. The aim of the present experiments was to evaluate the task-dependency of back and hip extensor muscle fatigue during two variants of the Sorensen test. We hypothesized that the rate of muscular fatigue of the hip and back extensor muscles varies according to the test position. Twenty healthy young males with no history of low back pain volunteered to participate in this cross-sectional study. They were asked to perform two body weight-dependent isometric back extension tests (S1 = Sorensen test; S2 = modified Sorensen on a 45° Roman chair). Surface EMG activity of the paraspinal muscles (T10 and L5 levels) and hip extensor muscles (gluteus maximus; biceps femoris) was recorded, and muscular fatigue was assessed through power spectral analysis of the EMG data by calculating the rate of median power frequency change. We observed hip extensor muscle fatigue simultaneously with paraspinal muscle fatigue during both Sorensen variants. However, only L5 level EMG fatigue indices showed a task-dependency effect between S1 and S2. Hip extensor muscles appear to contribute to load sharing of the upper body mass

during both Sorensen variants, but to a different extent because L5 level fatigue differs between the Sorensen variants. Our findings suggest that task-dependency has to be considered when EMG variables are compared between two types of lumbar muscle-fatiguing tasks.

Keywords Erector spinae · Hip extensors · Sorensen test · Muscle fatigability · Task-dependency

Introduction

Low back pain (LBP) is one of the leading causes of disability, contributing to 40% of all work days lost in the United States of America [21]. Although these pain episodes generally resolve after 6 weeks or less, the LBP recurrence rate is high and amounts to 60% of the costs associated with vertebral disease in Canada [4]. One of the physical characteristics of chronic low back pain (CLBP) subjects is higher fatigability of the back extensor muscles, as demonstrated by lower back endurance test duration [14, 16, 19, 23]. Therefore, back extensor muscle endurance tests can be instrumental in assessing paraspinal muscle dysfunction.

Surface electromyography (EMG) has been used extensively to study neuromuscular mechanisms associated with muscular fatigue during endurance tests [6]. Sustained isometric muscular contraction induces changes in EMG power spectral parameters, such as a decline of median power frequency (negative MPF/time slope) [7, 22]. The reliability of this procedure for evaluating muscular fatigue has been established in both healthy [12, 17] and CLBP subjects [11, 16, 18, 25].

Various positions have been tested to assess back muscle fatigue [5, 15], raising the question: are there any

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effects of test positions on back muscle fatigue indices? Few authors have compared different test positions to evaluate paraspinal muscle fatigue based on EMG fatigue indices. Elfving and Dederig [10] observed a greater rate of paraspinal muscle fatigue during a seated test compared to a modified Sorensen test (on a 40° Roman chair). Da Silva et al. [5] tried three different fatigue protocols and noted that paraspinal muscle fatigue was lower during a lift position in comparison to Sorensen and upright tests. The results of these studies indicate a task-dependency effect. According to task specificity, different neuromechanical or neurophysiological mechanisms are involved during fatiguing muscle contraction. However, task-dependency investigations have been limited to the paraspinal muscles. In view of the fact that the hip extensor muscles participate in trunk extension movements [20] and since some experiments have disclosed their fatigability during Sorensen testing [13], we believe it is important to appraise the relative contributions of these muscles to the task-dependency effect during back muscle fatigue assessment. The aim of the present work was to evaluate the task-dependency of back and hip extensor muscle fatigue by comparing their rates of fatigue during two Sorensen test variants. We hypothesized that muscular fatigue rates of the hip and back extensor muscles would vary according to test position.

Methods

Participants

Twenty healthy young males (age: 24.7 ± 3.0 years; height: 180 ± 0.1 cm; mass: 76.4 ± 10.45 kg; body mass index: 24.3 ± 3.4 kg/m²) with no history of LBP volunteered to participate in this cross-sectional study. To control for the effect of gender and other biomechanical factors on muscle endurance, only men were tested. All participants, recruited from the university community, gave their informed consent to enact a protocol approved by the University Ethics Committee.

Experimental protocol

All these experiments were conducted in a laboratory setting. The subjects were tested during a 1-h session and were asked to undergo a body weight-dependent isometric back extension (Sorensen) test in two different positions: (a) on a horizontal table (S1), and (b) on a 45° Roman chair (S2). S1 was performed in the prone position, with the iliac crests aligned with the table edge and the lower limbs fixed by straps at the ankles and below the knees (Fig. 1a). S2 was executed in a prone position on a 45° Roman chair,

Fig. 1 Test positioning of the study subjects during Sorensen (a) and 45° Roman chair (b) back endurance testing

with the iliac crests aligned with the chair cushion edge (Fig. 1b). During each test, the subjects were instructed to keep their body (head, arms and trunk) unsupported, horizontal to the ground, as long as they could, with their arms crossed at the chest. To maintain the horizontal position throughout the test, the investigator gave them verbal feedback, and the test was ended when they could not hold the test position, even after investigator warnings. Verbalized encouragement was provided throughout the test. The subjects were also instructed to maintain the lumbar lordosis position as stable as possible. The two assessment protocols were separated by 15 min of rest to minimize inter-subject variability of EMG fatigue indices between the two tests [17]. To control for carry-over effects, the test positions were presented in random order between subjects.

Surface electrodes were fixed bilaterally on the paraspinal muscles at T10 and L5, 5 and 2 cm (respectively) laterally from the midline of the spinal process. At the L5 level, electrodes were placed at a small angle from the frontal plane [24]; gluteus maximus (GM) electrodes were positioned at the midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter; biceps femoris (BF) electrodes were placed one-third to midway along a line connecting the fibular head with the ischial tuberosity. The reference electrode was positioned over the C7 spinous process. Skin impedance was reduced by: (1) shaving excess body hair, if necessary, (2) gently abrading the skin with fine grade sandpaper and wiping the skin with alcohol swabs. EMG activity was recorded with a Bortec Biomedical acquisition system (Model AMT-8, common mode rejection ratio of 115 dB at 60 Hz, input impedance of 10 MΩ, preamplification gain of 500) and was sampled at 1,000 Hz by the Labview custom program.

The surface EMG electrodes remained in place on the back and hip extensor muscle sites for the second test.

Data analysis

The EMG data were filtered digitally with 10- to 450-Hz bandpass, zero-lag, fourth-order Butterworth filters, and muscular fatigue was assessed through power spectral analysis. MPF was calculated from successive windows of 500 ms equally spaced by Fast-Fourier transformation (Hanning window). Least square linear regression analysis was applied to the MPF time series (MPF as a function of time) to calculate the rate of decline (MPF/time slope) and the coefficient of determination (R^2).

Statistical analysis

The Kolmogorov–Smirnov test was used to assess the homogeneity of variance of the fatigue indices. Two-way analysis of variance (ANOVA) with a repeated measures design was then performed to investigate the effects of the test variants (protocols S1 and S2), muscles (T10, L5, GM and BF) and test by muscle interaction effects on the EMG indices (MPF slope and coefficients of determination). Because no differences between the left and right EMG sides were found, as reported previously by other authors [8, 18], all statistical analyses were undertaken with mean EMG values of the left and right sides. Tukey HSD post hoc comparisons were made for each factor whenever ANOVA yielded a significant difference ($P < 0.05$). We applied the dependent samples t test to compare endurance times between the Sorensen test variants. To study correlations between two Sorensen test variants, Pearson's correlation coefficient (r) was analyzed for holding time and all EMG variables. The correlation coefficients were interpreted according to the characterization proposed by Donner and Eliasziw [9] as: slight (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80) or almost perfect (0.81–1.00). All statistical analyses were performed with the Statistica computer package (Statsoft, Tulsa, OK, USA). The level of statistical significance was set at $P < 0.05$.

Results

The test subjects achieved significantly higher endurance times during S2 compared to S1 (262 ± 81 s vs. 163 ± 70 s). Moderate and significant correlation between S1 and S2 was observed for endurance time ($r = 0.59$, $P < 0.05$) (Fig. 2).

The MPF/time slope values are presented in Fig. 3. No significant difference in MPF/time slope values was

Fig. 2 Correlations between Sorensen (S1) and 45° Roman chair (S2) back endurance testing for hold time (s): $r = 0.59$, $P < 0.05$

apparent between test variants (mean $\pm$ SEM: -0.20 ± 0.03 vs. -0.14 ± 0.02). A significant between-muscle effect was obtained, with post hoc comparisons showing a higher rate of decline of the MPF/time slope at the L5 paraspinal level compared to all other muscle groups. Interaction of the test variants by muscles gave a significant p value, with L5 paraspinal muscles presenting a greater MPF/time slope value during S1 than S2 (Fig. 3). Low and non-significant correlations were found for the MPF/time slope between S1 and S2 (T10: $r = 0.38$; L5: $r = 0.29$; GM: $r = 0.29$; BF: $r = 0.10$, $P > 0.05$) (Fig. 4). Figure 5 reports the correlation coefficients between endurance time and the MPF/time slope. The GM was the only muscle group that manifested a moderate and significant correlation for the two tests (S1: $r = 0.63$; S2: $r = 0.46$, $P < 0.05$). Moderate and significant correlation coefficients were obtained between endurance time and the MPF/time slope for T10 and L5 in S1 (T10: $r = 0.42$; L5: $r = 0.46$, $P < 0.05$), with non-significant correlation coefficients in S2 (T10: $r = 0.15$; L5: $r = 0.22$, $P > 0.05$). The correlation coefficients were low and non-significant for the BF muscle in the two tests (S1: $r = 0.26$; S2: $r = 0.14$, $P > 0.05$).

Fig. 3 Average rates of median frequency change for each muscle. The data are mean $\pm$ SEM

Fig. 4 Correlations between Sorensen (S1) and 45° Roman chair (S2) back endurance testing for the median frequency slope of T10 ($r = 0.38$); L5 ($r = 0.29$); GM ($r = 0.29$) and BF ($r = 0.10$)

Fig. 5 Correlations between hold time (s) and the median frequency slope (MPF/T; Hz/s) in Sorensen S1 (T10: $r = 0.42$; L5: $r = 0.46$; GM: $r = 0.63$; BF: $r = 0.26$) and S2 (T10: $r = 0.15$; L5: $r = 0.22$; GM: $r = 0.46$; BF: $r = 0.14$) testing. S1 filled triangle (line); S2 filled square (dotted line)

A significantly lower R^2 value was noted during S2 compared to S1 (mean $\pm$ SEM: 0.31 ± 0.02 vs. 0.40 ± 0.02). In addition, a significant between-muscle difference was observed, and post hoc comparisons disclosed that L5 had a higher R^2 value than all other muscles (mean $\pm$ SEM: 0.58 ± 0.05 vs. 0.33 ± 0.03 , 0.25 ± 0.03 and 0.25 ± 0.04 for T10, GM and BF, respectively). Of all the interaction effects, none had a significant P value.

Discussion

This study investigated the task dependency effect of two Sorensen test variants on paraspinal and hip extensor muscle fatigue. An important finding was that EMG variables had low between-test correlations. A modification of approximately 45° of hip sagittal orientation influenced the

EMG indices during a similar isometric testing procedure with the trunk placed in a weight-dependent horizontal position. These results support the hypothesis of a task-dependency effect on lumbo-pelvic muscle fatigue. We initially hypothesized that the difference in hip sagittal orientation between Sorensen variants would induce a task-dependency effect on the hip extensor muscle EMG fatigue indices. We observed that the hip extensor muscles tended to fatigue simultaneously with the paraspinal muscles during both Sorensen variants. However, only L5 level EMG fatigue indices showed a task-dependency effect between S1 and S2. It appears that the hip extensor muscles contribute to load sharing of the upper body mass during the two Sorensen variants, but to a different extent because L5 level fatigue differs between Sorensen variants. The hip extensor muscles have biomechanical and anatomical links to the thoracolumbar fascia, and their relative elongation

(contraction or stretching) can influence tension of the posterior thoracolumbar fascia layer [27]. Because the thoracolumbar fascia can commit to the lumbar extension moment, an increase of hip extensor muscle stretch may result in a higher contribution of the thoracolumbar fascia to the lumbar extensor moment. Consequently, a lower paraspinal muscle effort at L5 could be necessary during S2 to maintain the unsupported load of the upper body. Other authors have documented hip extensor muscle involvement in load bearing of the trunk during a Sorensen test like S1 [13]. Arendt-Nielsen et al. [1] hypothesized that the contribution of passive tissues as well as the energy required creating and maintaining a cross-bridge is lower for the stretched muscle. During S2, the hip extensors were stretched to a greater extent than during S1 because the hips were flexed at a 45° angle. This could explain the significantly lower rate of paraspinal muscle fatigue during S2.

Our results reveal that endurance-holding times between the Sorensen variants are moderately correlated. We also found a significant difference between Sorensen variants for endurance time, indicating that the subjects systematically achieved greater holding time during S2. In the present experiments, greater than previously reported endurance times were observed in S1 [3, 23] with slightly lower endurance times in S2 [8, 10]. An important factor that could explain these results is selection of the test cessation criteria. In our study, the test was ended when the subjects could no longer reposition their upper body in the horizontal position after verbal feedbacks provided by the investigator. McKeon et al. [23] gave only one chance to their test subjects to reposition their upper body during the test and obtained a time duration of 124.4 s, whereas Dederig et al. [8] (385 s) used a light-induced sensor and discontinued the test when relative displacement of the torso was over 2 cm. To reduce day-to-day variability and to standardize the isometric horizontal position procedure, proprioceptive or tactile feedback appears to be important.

Variability of the lumbar curvature is another factor to consider during the assessment of back extensor fatigue. Coorevits et al. [3] evaluated lumbar curvature during the Sorensen protocol, and the fatigue indices were calculated with a fixed threshold value of variance of the lordosis angle. Tveit et al. [26] reported a significant effect of lumbar lordosis curvature on lever arm length of the back extensor muscles. A longer lever arm of the paraspinal muscles could lead to a mechanical advantage in creating back extensor moments. During our experiments, we carefully instructed the subjects to maintain a normal lumbar curvature during the tests. Further studies should be conducted with kinematic analysis to ascertain the relationship between lordosis curvature and muscle fatigue during different Sorensen protocols and CLBP subjects.

Some authors, comparing EMG fatigue indices of the back muscles between CLBP and healthy participants, observed that CLBP had a lower rate of back muscle fatigue [11, 16, 23], but others did not find significant differences [5, 14]. A hypothesis that could explain these conflicting results is that CLBP subjects adopt alternative neuromuscular strategies that could modulate EMG fatigue indices of the back extensor muscles. One of them could be a reweighed contribution of the lumbo-pelvic extensor muscles in bearing the upper body load [14, 23]. CLBP subjects showed a greater rate of hip extensor muscle fatigue when compared to healthy subjects. These results indicate that LBP participants might increase the contribution of their hip extensor muscles during back endurance tests. Our study highlights the task-dependency effect on the lumbo-pelvic muscles that could contribute to discrepancies in the results of these previous investigations.

The test subjects' motivation to sustain isometric contraction as long as possible could have influenced the endurance time variable. Some authors have proposed a high correlation between hold time and EMG fatigue indices as a sign of subject motivation [2, 5, 14]. We detected a task-dependency effect on this relationship. Only the GM showed a significant correlation in both S1 and S2 testing positions, explaining around 40% of the variance, whereas the T10 and L5 paraspinal levels presented a significant relationship only between hold time and EMG fatigue indices during S1 ($R^2 \approx 0.20$). During both test variants, we provided the subjects with verbal encouragement. Thus, it appears that factors other than motivation could also contribute to the endurance time difference between tests.

We applied a linear regression model to calculate the MPF/time slope. Interestingly, higher R^2 values were found for L5 level paraspinal muscles, showing that MPF data better fit the simple linear regression model than hip extensor muscles. However, a recent study has demonstrated that more complex statistical models are not valuable on fatigue-related EMG indices [3].

Conclusion

Our data suggest that task-dependency has to be considered when EMG variables are compared between two types of lumbo-pelvic extensor muscle-fatiguing tasks. Different study results obtained with different protocols have to be interpreted with care, particularly in CLBP subjects or other populations with neuromuscular affections of the lumbo-pelvic muscles. The next step is to assess the effect of CLBP on task-dependency of the lumbo-pelvic extensor muscles.

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