# Understanding the Biering-Sørensen test: contributors to extensor endurance in young adults with and without low back pain

Jonathan Shaw, Jesse V. Jacobs, Linda R. Van Dillen, George J. Beneck, Jo Armour Smith*

*Corresponding author

This work was supported by the Eugene Kennedy Shriver National Institute of Child Health and Human Development under grant K01HD092612

The authors report that there are no competing interests to declare

Abstract

Impaired paraspinal muscle endurance may be a contributor to persistent low back pain (LBP) and is frequently assessed using a single repetition of the Biering-Sørensen test. The aim of this study was to investigate how Sørensen test duration, and muscle fatigability, are affected by multiple repetitions of the test, and to determine predictors of Sørensen test duration in young, active adults with and without a history of LBP. Sixty-four individuals participated; 41 had a greater than one-year history of LBP symptoms. Participants performed 3 repetitions of the Sørensen test while electromyography (EMG) data were collected from the lumbar and thoracic paraspinals and the hamstrings. Muscle fatigability was quantified as the slope of the change in median frequency of the EMG signal over time. Duration of the test decreased across repetitions for both groups and was significantly less for the 2$^{nd}$ and 3$^{rd}$ repetitions in individuals with LBP. For all three muscles, fatigability increased across repetitions, but did not differ between groups. In individuals without LBP, fatigability of the lumbar paraspinals was the best predictor of test duration. In individuals with LBP, Sørensen test duration was predicted by fatigability of the thoracic paraspinals and hamstrings. Our findings demonstrate that it is necessary to amplify the difficulty of the Sørensen test to fully elucidate impairments in young adults with LBP. Training or rehabilitation programs aiming to improve lumbar paraspinal endurance in individuals with LBP should account for the endurance of other synergist muscle groups during endurance exercise.

Keywords

Biering-Sørensen test, low back pain, endurance, paraspinal

## Introduction

Most individuals with persistent low back pain (LBP) have their first episode of pain as an adolescent or young adult.[1] A history of back pain during adolescence or young adulthood significantly increases the risk of experiencing symptoms into middle age and beyond.[1,2] As episodes of LBP become increasingly disabling with time, and because LBP symptoms are difficult to eradicate once they have become chronic, it is important to establish potential contributors to LBP early in the lifespan.[3] Due to changes in lifestyle and behavior that occur around the transition to young adulthood, factors associated with back pain in young adults may be quite different from those observed in older adults.[3,4]

Many aspects of paraspinal muscle structure and function have been investigated to determine their association with risk of LBP. Impaired paraspinal muscle endurance is proposed as a contributor to persistent back pain in the general population and in athletes.[5–8] During the types of sub-maximal activities that are encountered during daily life, paraspinal fatigue results in task-specific alterations in the timing of feedforward and feedback postural responses.[9–12] Therefore, impaired paraspinal endurance may result in altered postural control and maladaptive spinal loading, and may cause new or persistent pain. Insufficient trunk and hip muscle endurance has also been suggested to contribute to LBP in athletes due to the high demands placed upon the spinal musculature and the high prevalence of back pain in sporting disciplines such as rowing and golf. [8,13,14]

The Biering-Sørensen test is commonly used in the general population and in athletes to assess endurance of the paraspinal and hip extensor musculature.[15] The test requires the participant to maintain the load of their head, arms, and trunk in a horizontal position against gravity for as long as possible.[16] Endurance during the Sørensen test is quantified using two metrics: test duration (the time that an individual can maintain the test position), and rate of muscle fatigue (the rate at which the median frequency of the muscle power spectrum declines over time, measured using electromyography). To date, results from research using the Sørensen test to investigate the relationship between endurance and current or future LBP have been mixed.[17–19] Some studies indicate that reduced test duration is a risk factor for future episodes of back pain[5,16,20] while others have found no difference in either test duration or fatigability in individuals with and without LBP.[19,21,22]

The conflicting findings across studies may in part be due to heterogeneity in LBP study populations. There are multiple person-specific biopsychosocial characteristics that influence Sørensen test duration and rate of fatigue.[22] One-such person-specific characteristic is level of physical activity. Typical physical activity may have an important influence on both duration of the test and muscle fatigability, due to the potential for deconditioning or disuse atrophy in individuals with low levels of physical activity.[19,22] The evidence for reduced physical activity or fitness in individuals with LBP is mixed.[23,24] However, our previous work suggests that physical activity levels are maintained in young adults with persistent LBP[3] and therefore may not influence paraspinal endurance to the extent observed in older adults. Other biopsychosocial characteristics may influence test duration but not EMG measures of fatigability. These include psychological factors such as generalized fear of movement (fear avoidance[25]), pain catastrophizing,[22] anxiety,[26] motivation and fear during the test.[19,27]

A critical factor that has not been well explored to date is the influence of synergist muscles on test duration and fatigability. The Sørensen test is typically considered to be a test of lumbar paraspinal endurance. However, the thoracic paraspinals and the hip extensors also contribute to maintenance of the test position.[28,29]As the Sørensen test involves submaximal loading, there is the potential for sharing or switching activity between paraspinal and hip extensor muscle groups during the test.[30] Few studies have examined how thoracic paraspinal or hip extensor fatigability influence the Sørensen test, and whether fatigability across thoracic paraspinal and hip extensor muscle groups differs in individuals with LBP.[7,21,28] In addition, typically only a single repetition of the Sørensen test is used. In young, active adults, a single repetition may be insufficiently fatiguing to identify muscle performance impairments related to LBP.[7] More than one repetition of the test may also be needed in some individuals with LBP, or those with lower levels of physical activity, to gain familiarity with the testing protocol and establish reliable performance.[26]

The purpose of this study was to determine how Sørensen test duration and fatigability of the lumbar and thoracic paraspinals and hip extensors are affected by three repetitions of the Sørensen test in young, active adults with and without a history of low back pain. We hypothesized that greater fatigability and shorter Sørensen test duration individuals with LBP would be evident in the third repetition of the test but not in the first two repetitions. The second purpose of the study was to determine factors that predict the duration of the Sørensen test after multiple fatiguing test repetitions have been performed in young adults with and without a history of low back pain.

## Materials and Methods

### Participants

Young adults between the ages of 18 and 35 years were recruited via flyers at college campuses and in gyms/other athletic facilities, via social media, and via word of mouth. The group with LBP included individuals who: i) reported a history of pain of at least one year's duration, primarily localized between the lower rib and the gluteal fold; ii) reported at least one episode of pain in the preceding year that limited their ability to participate in recreational activities or activities of daily living; iii) were in symptom remission/asymptomatic at the time of the data collection, defined as pain intensity less than 0.5 on a zero to ten scale. The group without LBP included individuals with no history of LBP that required modification of activity for more than three days or medical care. All participants had to be right-limb dominant. Exclusion criteria for both groups were histories of inflammatory or neuropathic disease, diagnosis of spinal stenosis, radiculopathy, spondylolisthesis or scoliosis, current injuries to the lower limbs, and history of cigarette smoking.

All participants completed the Physical Activity Scale (PAS). This measure quantifies physical activity over a typical 24-hour period, in metabolic equivalents (METS).[31] Participants report the amount of time that they spend in activities at each of nine physical activity levels, ranging from sedentary to vigorous. The PAS has been validated in comparison with exercise diaries.[31] The amount of time that participants report engaging in the most vigorous level of activity (PAS-VIG subscale) is significantly associated with cardiorespiratory fitness, assessed via maximal oxygen intake, in individuals across a range of activity levels.[32] For the current study, participants with LBP also identified the duration and frequency of their symptoms and completed measures of average pain intensity during symptomatic episodes (visual analogue scale, 0 – 10), the Fear Avoidance Beliefs Questionnaire physical activity subscale (FABQ-P[33]) and the modified Oswestry Disability Index (ODI[34]).

Instrumentation

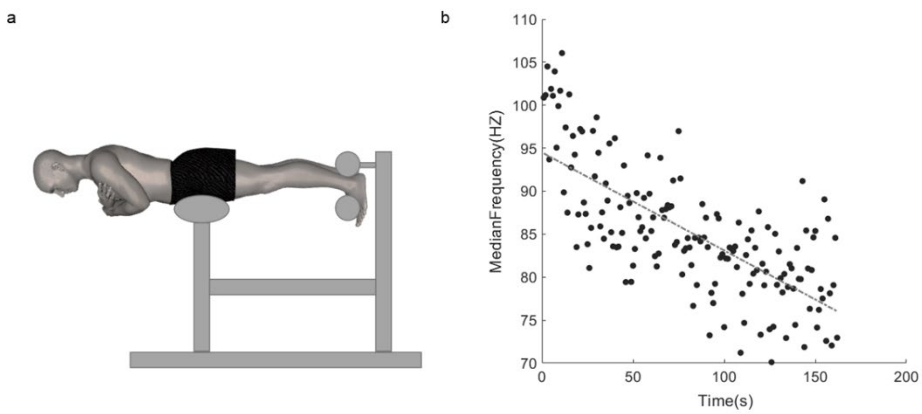
Participants were instrumented with self-adhesive silver chloride bipolar surface electromyography electrodes (interelectrode distance 20mm, Myotronics Inc, WA, USA). Following standard skin-preparation procedures,[35] electrodes were placed bilaterally on the following musculature: lumbar erector spinae/multifidus (LES, 2cm lateral to the L4/L5 interspace, thoracic erector spinae (longissimus thoracis pars thoracis, TES, lateral to the spinous process of T10 on the muscle belly), and hamstrings (biceps femoris, HS, midway between the ischial tuberosity and the lateral tibial epicondyle),[35–37] and attached to wireless sensors digitally sampling at 1500Hz (Noraxon DTS sensors, Noraxon Inc, Scottsdale, USA).

Fatiguing exercise (Biering-Sørensen Test)

Participants performed three Biering-Sørensen tests. Between each test, participants performed other tasks for a period of approximately ten minutes, during which they repeated sub-maximal movements involving either raising a leg in supine, raising an arm in standing, or walking. These tasks, which were components of a larger research study, have been described in detail elsewhere, and the order in which they were completed was randomized.[38–40] Because these tasks required different postural orientations and did not involve the low back as the primary mover, for this study we termed these times of activity between Biering-Sørensen tests as active-rest periods.

For the Biering-Sørensen tests, participants lay prone on a Roman chair with their lower limbs stabilized and their head, arms, and trunk unsupported (Figure 1). Participant position was standardized so that the anterior superior iliac spines were aligned with the edge of the pelvic padding. Participants crossed their arms across their chest and were instructed to maintain a horizontal body position for as long as possible. The correct test position of the participants was monitored visually by observing the change in position of a plumb bob hung from the participants' necks.[19] Participants were given standardized verbal encouragement every 30 seconds during the test. If the observer noticed the plumb bob deviating more than two inches lower than its starting height, they reminded the participant to return to their initial position. The end of the test occurred when the participant could not maintain the horizontal test position after verbal prompting or when the participant felt unable to continue the test The duration of the test was noted. After each repetition of the Sørensen test, any back pain/discomfort that persisted during the ten-minute active-rest period was quantified using a visual analogue scale.

Figure 1. a) Testing position for the Biering-Sørensen test. b) Representative data from the lumbar paraspinal muscle from a single participant showing the decline in the median frequency of the electromyography signal over the duration of a test. Fatigability is quantified as the slope of the decline in median frequency, normalized to the initial median frequency.




Data processing

EMG data processing was conducted using custom written code (MATLAB® version R2018B, The MathWorks, Natick, MA). EMG data were band-passed filtered (30-450 Hz) and then notch-filtered at 249 – 251 and 499 - 501 Hz to remove environmental noise.[41] Rate of fatigability was quantified as the change in median frequency of the EMG signal from each muscle over time. The downward slope of the EMG median frequency during fatiguing exercise is a valid and reliable measure of muscle fatigue during isometric contraction.[15,19,42] For each participant, the median frequency of the power spectrum, in Hz, was calculated for every second of the entire Sørensen test using a Fast Fourier transform. The slope of the median frequency values over time was calculated using least squares linear regression. Median frequency slopes were normalized to the initial median frequency to account for individual differences in subcutaneous tissue depth.[43]

Data Analysis

Data analyses were conducted in SPSS® Statistics (Version 26, IBM®, Armonk, USA). Data were checked for assumptions of normality and homoscedasticity. Where necessary, data were log transformed to meet these assumptions. Demographics and the Sorensen test characteristics were compared between groups with independent t-tests or $chi^2$ tests as appropriate. The normalized median frequency slope data were analyzed with separate mixed-model ANOVA tests for each muscle, testing for main effects of repetition (Sørensen repetition 1, 2, and 3), group (Control and LBP), and repetition*group interactions. Post hoc comparisons were made where significant main effects or interactions occurred, with Bonferroni correction for multiple comparisons within each set of tests.

Predictors of test performance were calculated using the duration of the final, third Sørensen test, as we hypothesized that participants would be most fatigued during this repetition, and that therefore this repetition would be most sensitive to highlighting differences between groups. Bivariate relationships between the dependent variable (duration of the third Sørensen test repetition, Duration 3) and potential explanatory variables were tested with Pearson correlation coefficients for each group separately. Variables that were correlated with Duration 3 ($p < 0.05$) were checked for multicollinearity and distribution of residuals prior to being entered into separate ordinary least squares regression models using a backward stepwise approach ($\alpha$ enter $p = 0.05$ and $\alpha$ exit $p = 0.10$). Models were checked for influential outliers using Cook's Distance.

Results

Sixty-four individuals participated: 41 with a history of LBP and 23 without LBP. Participant demographics, duration of hold for each repetition of the Sorensen test, and discomfort reported after each Sørensen test are shown in Table 1.

In the group with LBP, 57% of participants reported that they had been experiencing symptoms for between two to five years, with 40% reporting symptoms for greater than five years. Average pain intensity in the group with LBP during symptomatic episodes was reported as 4.8 (± 2.2)/10. Average pain intensity at the beginning of the data collection was 0.3 (± 0.3)/10 (Table 1). Average FABQ-P score in the group with LBP was 9.2 (± 4.8), and the average ODI score was 16.0 (± 13.3), suggesting minimal disability.

There was no difference between the groups with and without LBP in age, distribution of sex, or total and vigorous physical activity. Individuals with LBP had significantly higher BMI ($p = 0.004$), although both groups exhibited an average BMI within the normal range.

All experimental data from one participant without LBP were excluded because the participant reported that the duration of their Sørensen test for all three repetitions was limited by anterior thigh discomfort rather than paraspinal or hip extensor fatigue. Two participants with LBP did not complete the third repetition; one because of anxiety about exacerbating their symptoms, and one because of time constraints. All other participants with LBP completed the full testing protocol without difficulty and reported that Sørensen test duration was limited by fatigue rather than reproduction of their symptoms. EMG sensor failure prevented collection of the third repetition from one participant without LBP. Visual inspection of EMG signals by the first and senior authors revealed that two or three individuals had EMG signal with periods of signal drop-out for each muscle due to loss of sensor connectivity on one or more test repetitions and these signals were excluded after a consensus decision was reached.

Table 1. Group demographics and Sørensen Test duration (means and standard deviations)

| | **With LBP (n = 41)** | **Without LBP (n = 23)** |
|---|---|---|
| Age (years) | 21.9 (3.1) | 23.5 (3.6) |
| Sex | | |
| Male | 16 | 9 |
| Female | 24 | 14 |
| Not specified | 1 | |
| BMI (kg/m$^2$) | **24.3 (4.5)** | **21.8 (2.2)** |
| PAS (METS) | 46.9 (11.4) | 45.1 (12.8) |
| PAS-VIG (METS) | 10.1 (13.4) | 7.8 (8.0) |
| Duration 1 (s) | 99.2 (37.6) | 112.5 (44.8) |
| Duration 2 (s) | **89.3 (29.0)** | **109.8 (37.8)** |
| Duration 3 (s) | **80.2 (25.0)** | **101.2 (36.8)** |
| Post-test pain 1 (VAS) | **0.6 (0.7)** | **0.2 (0.4)** |
| Post-test pain 2 (VAS) | **0.7 (0.7)** | **0.3 (0.6)** |
| Post-test pain 3 (VAS) | 0.8 (0.8) | 0.4 (0.8) |
| Typical pain | 4.8 (2.2) | n/a |
| FABQ-P | 9.2 (4.8) | n/a |
| ODI | 16.0 (13.3) | n/a |

BMI – Body Mass Index. PAS – Physical Activity Scale. PAS-VIG – Physical Activity Scale, vigorous sub-scale, measured in metabolic equivalents (METS). VAS – Visual Analogue Scale for Pain, 0 – 10. FABQ-P – Fear Avoidance Beliefs Questionnaire, physical sub-scale. ODI – Modified Oswestry Disability Index. Characteristics with significant differences between groups are shown in bold.

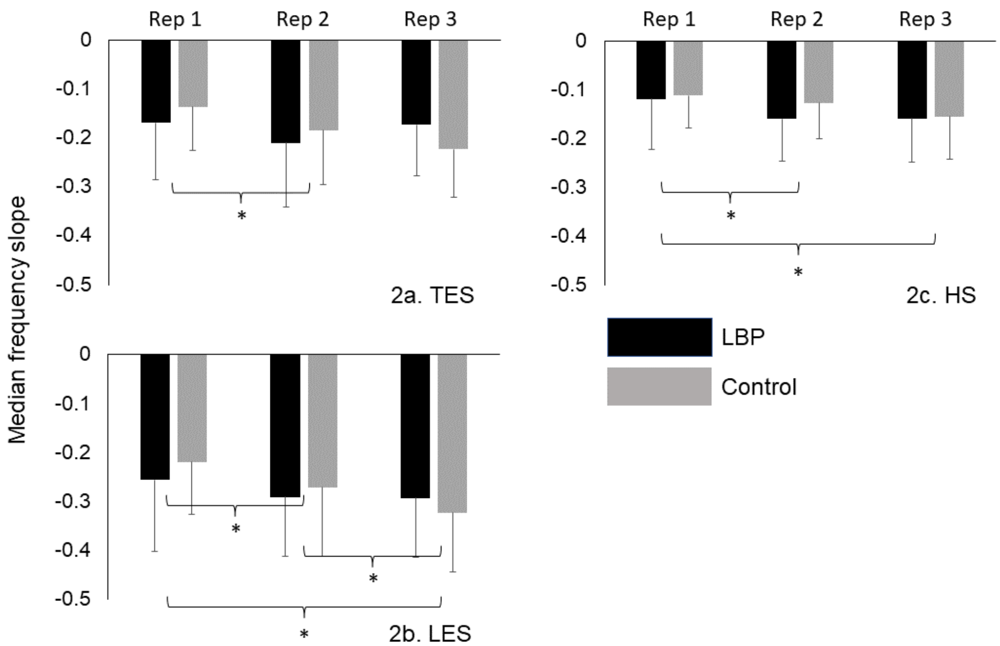



Figure 2. Normalized median frequency slope for a) Thoracic Erector Spinae (TES), b) Lumbar Erector Spinae (LES), c) Hamstring (HS), with significant post-hoc comparisons for the main effect of repetition (Rep 1, 2, 3) indicated by asterisks. N = 37 in the group with LBP and 21 in the group without LBP. Error bars indicate standard deviations.

## Group comparisons

Normalized median frequency slopes for the right and left sides of all three muscles were significantly correlated in each repetition of the test ($p < 0.05$ for all muscles and all repetitions). Therefore, the average of the median frequency slope from both sides was calculated for each repetition for each participant and these average slope variables were used in all further analyses to reduce the number of comparisons (thoracic erector spinae TES1, TES2, TES3; lumbar erector spinae LES1, LES2, LES3; hamstrings HS1, HS2, HS3).

For TES, the normalized median frequency slope declined significantly across the three test repetitions (main effect of repetition $F = 5.161$, $p = 0.007$), indicating increasing rate of fatigue. Post-hoc pairwise comparisons showed that the rate of fatigue was significantly greater for repetition two than repetition one ($p = 0.003$, Figure 2a). There was no main effect of group, or repetition*group interaction. Similarly, for LES the median frequency slope declined across repetitions (main effect of repetition $F = 29.623$, $p < 0.001$) but with no group or interaction effect. All post-hoc comparisons were significant ($p < 0.001$ in all cases), with the rate of fatigue increasing at each repetition (Figure 2b). The same findings were evident for the HS, with a main effect of repetition ($F = 12.523$, $p < 0.001$), but no main effect of group or interaction. Rate of fatigue in the hamstrings was significantly greater in the second repetition compared with the first, and in the third repetition compared with the first (p = 0.012 and p < 0.001 respectively, Figure 2c).

Table 2. Linear relationship between duration of the third Sørensen test, in seconds, and potential predictor variables. Note that, for median-frequency slopes, positive correlation indicates that a more negative slope (faster rate of fatigue) was associated with shorter duration of the third Sørensen repetition.

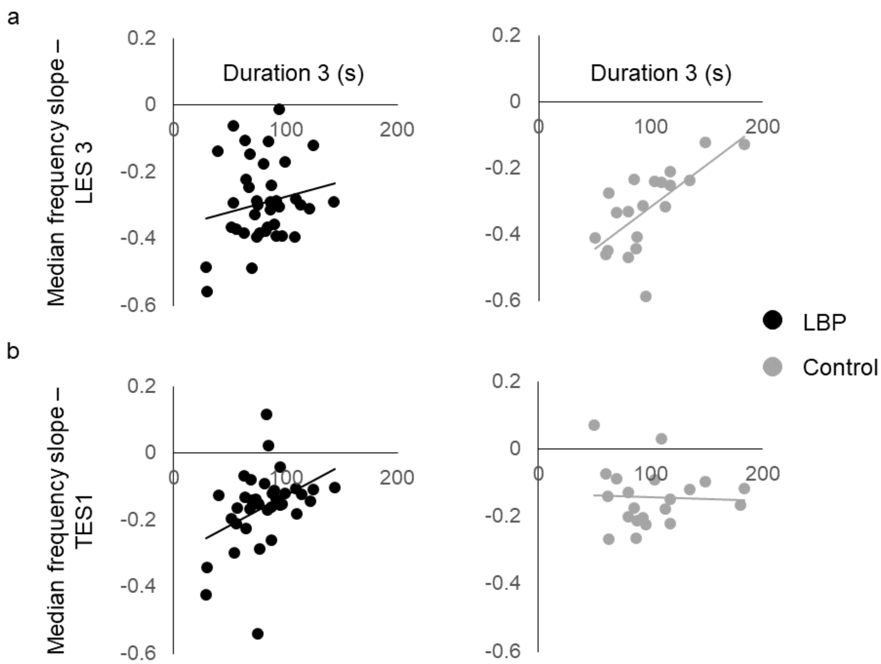
| | LBP | Control |
|---|---|---|
| Age (years) | **-0.318** | **-0.541** |
| BMI (($kg/m^2$) | -0.125 | -0.269 |
| PAS (METS) | 0.154 | -0.160 |
| PAS-VIG (METS) | 0.015 | -0.260 |
| TES1 (normalized slope) | **0.453** | -0.117 |
| LES1(normalized slope) | **0.412** | **0.471** |
| HS1 (normalized slope) | **0.422** | 0.306 |
| TES2 (normalized slope) | 0.263 | 0.134 |
| LES2 (normalized slope) | 0.197 | **0.512** |
| HS2 (normalized slope) | **0.327** | 0.319 |
| TES3 (normalized slope) | 0.104 | 0.436 |
| LES3 (normalized slope) | 0.246 | **0.649** |
| HS3 (normalized slope) | 0.207 | 0.413 |
| Post-test pain 1 (VAS) | 0.177 | 0.086 |
| Post-test pain 2 (VAS) | -0.052 | 0.143 |
| Post-test pain 3 (VAS) | 0.065 | 0.154 |
| Typical pain (VAS) | 0.126 | n/a |
| FABQ-P | 0.127 | n/a |
| ODI | -0.095 | n/a |

BMI – Body Mass Index. PAS – Physical Activity Scale. PAS-VIG – Physical Activity Scale, vigorous sub-scale. VAS – visual analogue scale for pain. FABQ-P – Fear Avoidance Beliefs Questionnaire, physical sub-scale. ODI – Modified Oswestry Disability Index. TES – Thoracic Erector Spinae. LES – Lumbar Erector Spinae. HS – Hamstring. Significant correlations (p <, 0.05) are shown in bold.

## Predictors of third test duration

Bivariate relationships between candidate explanatory variables and the duration of the third Sørensen test are shown in Table 2 and Figure 2. In the group with LBP, greater age was associated with shorter Sorensen test duration. The TES1, LES1, HS1 and HS2 normalized slopes were also significantly associated with duration, with faster rate of fatigue (steeper slope) correlating with shorter duration of the third repetition. In the group without LBP, greater age, and greater rate of fatigue in the LES1, LES2, and LES3 were significantly correlated with shorter durations of the third Sørensen repetition.

Figure 3. Scatterplots showing relationship between duration of the third Sørensen test in seconds and a) normalized median frequency slope of the lumbar paraspinals during the third test (LES3); b) normalized median frequency slope of the thoracic paraspinals during the first test (TES1).




The explanatory variables with significant bivariate relationships in each group were then entered into the multivariate linear regression models. For the group with LBP, duration of the third Sørensen repetition was predicted in the final model by a combination of TES1, and HS1 slopes ($R^2 = 0.284$, $F = 6.739$, $p = 0.003$, β TES1 0.353, β HS1 0.293). To ensure that the results were not excessively influenced by outlier values, the model was rerun with data from two individuals with high leverage removed and the same results were obtained ($R^2 = 0.385$, $F = 10.018$, $p < 0.001$, β TES1 0.317, β HS1 0.391). For the group without LBP, duration of the third Sørensen repetition was predicted in the final model by LES3 ($R^2 = 0.652$, $F = 13.317$, $p = 0.002$, β LES3 = 0.652). The final model was robust to the removal of data from one individual with high leverage (with one individual removed $R^2 = 0.602$, $F = 25.711$, $p < 0.001$, β LES3 = 0.776).

## Discussion

This study shows for the first time that, in active young adults, more than one repetition of the Sørensen test is needed to identify impairment in paraspinal/hip extensor endurance in individuals with history of LBP. Despite being minimally disabled by their symptoms, active young adults with LBP had significantly poorer test endurance for the second and third test repetitions than individuals with no history of LBP. Physical activity and other person-specific characteristics did not significantly influence the duration of the third repetition of the Sørensen test. However, in individuals with LBP, fatigability of the thoracic paraspinals and hamstrings, rather than lumbar paraspinals, predicted the duration of the final test.

Like other studies that have investigated young, minimally symptomatic adults[7,28] we did not observe reduced test duration in the group with LBP for the first repetition of the Sørensen test. This suggests that the first repetition of the test did not fatigue individuals sufficiently to demonstrate group differences. During any fatiguing exercise test, muscle performance is influenced by multiple task-dependent mechanisms. These include peripheral muscle structure and function, neural activation strategy, and sense of effort.[30] Although the Sørensen test requires maintenance of the test position until failure, the submaximal nature of the test may result in the participant's perception of fatigue (sense of effort) being the limiting factor rather than decreased ability to generate force.[7,30] As a result, the addition of multiple test repetitions or increased load may be necessary to ensure paraspinal and hip extensor fatigue during the Sørensen test. A previous small study in healthy adults showed that the Sørensen test duration was shorter, and lumbar paraspinal rate of fatigue was significantly faster, for a second repetition of the test following nine minutes of rest.[44] Therefore, the short rest period (ten minutes) that we employed between test repetitions likely resulted in cumulative and progressive muscle fatigue across test repetitions. [44]

Our findings of similar rate of lumbar paraspinal fatigue in the two groups supports earlier studies investigating young, or minimally disabled individuals with LBP.[19,21,45] Unlike in older individuals with greater disability due to LBP, physical deconditioning and disuse atrophy are less likely to have occurred in the young adults in the present study. In our participants, total and vigorous physical activity, characterized by the Physical Activity Scale, was not significantly different between the individuals with LBP and the back-healthy controls. This finding is consistent with our previous work investigating several different cohorts of young adults.[3,46] Therefore, deconditioning is unlikely to be the cause of impaired test duration in the individuals with LBP that we observed. Total MET scores were very similar to those reported in several large cohorts of healthy adults using the same PAS scale, and reflect moderate levels of physical activity.[32,47] Interestingly, in this cohort, individuals who reported higher levels of physical activity did not demonstrate greater endurance during the final test. Additional research is needed to determine if type of physical activity in the more active individuals would influence these findings Similarly, in the individuals with LBP, shorter Sørensen test duration was not a result of elevated fear avoidance beliefs. The fear avoidance model encompasses fear of movement, pain catastrophizing, and avoidance behaviors and has been related to persistence of LBP and poorer prognosis in response to treatment.[3,48] The lack of significant association between fear avoidance and test duration in the present study may be due to the small range of FABQ scores observed in this study. The average score in the physical domain (9.2) was below the threshold of 15 points for clinically relevant elevated fear avoidance,[48] and only four of the 41 participants had scores that exceeded this threshold. In addition, neither pain experienced following the Sørensen test repetitions in either group, nor average pain reported during symptomatic episodes in the group with LBP influenced performance on the final repetition of the test. Although post-test pain differed between the groups following the first and second Sørensen repetitions, this group difference was smaller than the minimal detectable difference for visual analogue scales for back pain.[49] Additionally there was no difference in discomfort between groups after the third test and discomfort after the first and second tests were not significantly associated with the duration of the third test.

We did discover differences between groups for the factors that predicted performance in the third Sorensen test. In individuals without LBP, lumbar fatigability during all three test repetitions was significantly correlated with duration of the third Sørensen test, and lumbar paraspinal fatigability during the third test predicted duration in the regression model. This is consistent with other previous work in healthy individuals demonstrating a significant linear relationship between the median frequency slope of the lumbar paraspinals and the duration of the Sørensen test.[6,21,50] However, this relationship between lumbar paraspinal fatigability and test duration was not evident in the young adults with LBP. In the individuals with LBP, fatigability of the thoracic paraspinals, and biceps femoris to a lesser extent, during the first repetition of the test predicted duration of the final test. We are not aware of previous research reporting the contribution of the thoracic paraspinal musculature to group differences in test duration. In support of our results for the hamstrings, in a sample of individuals with chronic and disabling LBP, Moffroid et al.,[26] demonstrated a significant correlation between the median frequency slope of the biceps femoris and Sørensen test duration, but no relationship between the fatigability of lumbar paraspinals and test duration. Our study extends these previous findings to young adults who were minimally disabled and asymptomatic at the time of testing**.** We speculate that in the individuals with LBP, the fatigability of biceps femoris is more predictive of Sørensen test duration than the lumbar paraspinals because these individuals avoid maximally fatiguing the lumbar paraspinals in order to limit sense of effort in the symptomatic area. As a result, their test duration is impaired. Pitcher et al.,[7] have also reported that the median frequency slope of the biceps femoris during the Sørensen test differed significantly between individuals with and without LBP. Importantly, they found that this difference was only evident when additional loading was added to the upper trunk. This confirms that it is necessary to amplify the difficulty of the Sørensen test, via the addition of extra trunk loading or test repetitions, to fully elucidate impairments in young adults with LBP. In addition, our findings highlight that training or rehabilitation programs aiming to improve lumbar paraspinal endurance in individuals with LBP should account for the endurance of other synergist muscle groups during endurance exercise.

We acknowledge some limitations to this study. The PAS is validated against other measures of activity and cardiovascular fitness. However, like all subjective measures it may represent an over-estimation of activity.[51] In addition, the use of surface electromyography did not enable this study to differentiate between components of the paraspinal muscle group.[19,52] Previous work indicates that the lumbar multifidus may fatigue more rapidly than the erector spinae during

Sørensen testing.[7] Further, the structure and function of multifidus may be affected by a history of low back pain to a greater extent than the erector spinae.[53,54] However, the signal from the lumbar paraspinal electrode in this study likely represents activation of both the lumbar fibers of multifidus and longissimus thoracis pars lumborum. The amount of mass contained in the head, arms and trunk, and the length of the lever arm for that mass relative to the lumbo-pelvic axis of rotation, vary across individuals. Therefore, the torque that individuals must exert to maintain a horizontal position will be greater in individuals with larger mass in the trunk[28], which was not quantified or controlled for in this study. However, we did not observe a significant relationship between duration of the third test and BMI. Finally, paraspinal endurance is typically greater in women than in men.[6,55] Given this known sex difference, we recruited the same proportion of males and females to each group.

## Conclusion

In young, active adults, more than one repetition of the Sørensen test is needed to adequately assess paraspinal and hip extensor muscle endurance. Whereas in young adults without symptoms, fatigability of the lumbar paraspinals contributes most to test duration after multiple repetitions, fatigability of the thoracic paraspinals and hip extensors is more influential than the lumbar paraspinals in individuals with LBP.

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