Physiological and psychological predictors of time to task failure on a virtual reality Sørensen test in participants with and without recurrent low back pain

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Abstract

**Background:** Sørensen trunk extension endurance test performance predicts the development of low back pain (LBP) and is a strong discriminator of those with and without low back pain (LBP). Performance may depend greatly upon psychological factors, such as kinesiophobia, self-efficacy, and motivation. Virtual reality video games have been used in the LBP population to encourage physical activity that would otherwise be avoided out of fear of pain or harm. Accordingly, we developed a virtual reality video game to assess the influence of immersive gaming on Sørensen test performance.

**Objective:** To determine the physiological and psychological predictors of time to task failure (TTF) on a virtual reality Sørensen test in participants with and without a history of recurrent LBP.

**Methods:** We recruited 24 individuals with a history of recurrent LBP and 24 sex, age, and BMI matched individuals without a history of any LBP. Participants completed a series of psychological measures, including the Center for Epidemiological Studies – Depression (CES-D), Pain Resilience Scale (PRS), Pain Catastrophizing Scale (PCS), Tampa Scale for Kinesiophobia (TSK), and a self-efficacy measure. Maximal isometric strength of the trunk extensors and hip extensors and TTF on a virtual reality Sørensen test was measured. EMG of the Erector Spinae (ERS), Gluteus Maximus (GM), and Biceps Femoris (BF) was recorded during the strength and endurance trials.

**Results:** A two-way ANOVA revealed no significant difference in TTF between groups ($P = .99$), but there was a trend for longer TTF in females on the virtual reality Sørensen test ($P = .06$). Linear regression analyses were performed to determine predictors of TTF for each group. In healthy participants, normalized median power frequency slope of the ERS ($\beta = .450$, $P = .01$), and the BF ($\beta = .400$, $P = .01$), and trunk mass ($\beta = .330$, $P = .02$) predicted TTF. In participants with recurrent LBP, trunk mass ($\beta = -.67$, $P < .01$), TSK ($\beta = -.43$, $P = .01$) and self-efficacy ($\beta = .35$, $P = .03$) predicted TTF.

**Conclusions:** Trunk mass appears to be a consistent predictor of performance. Kinesiophobia appears to negatively influence TTF for those with a history of recurrent LBP, but does not influence healthy individuals. Self-efficacy is associated with better performance in individuals with a history of recurrent LBP, while a less steep median power frequency slope of the trunk and hip extensors is associated with better performance in individuals without a history of LBP.

**Keywords:** Trunk endurance, low back pain, Sørensen, fatigue, virtual reality
Introduction

Low back pain (LBP) represents a significant societal and economic burden [1]), with direct medical costs approaching $100 billion annually in the United States, alone [2]. These costs are driven primarily by the 10-15% of individuals who develop chronic pain [1,3]. Poor trunk extension endurance has been identified as a risk factor for the development of LBP [4]. Specifically, poor time to task failure (TTF) on the Sørensen back extension endurance test predicts first time episodes of LBP [5,6] as well as chronic LBP [7]. While the Sørensen test has been used for the identification of LBP risk, the underlying mechanisms driving poor performance on the test are not well understood. Research has demonstrated that in addition to physiological factors, such as median power frequency (MPF) slopes of the trunk and hip extensors and anthropometrics, psychological factors must be considered in the assessment of performance on the Sørensen test.

There is evidence that individuals terminate the Sørensen test for reasons other than subjective fatigue; these reasons have included pain, discomfort, fear, and lack of motivation [8]. Studies of rehabilitation motivation in clinical populations, such as individuals recovering from cardiac events, have demonstrated that although motivation is difficult to define and measure, it has a crucial role in rehabilitation outcomes for patients [9]. Motivation could be manipulated through the use of distracting, immersive virtual reality gaming. Virtual reality games have been implemented for pain distraction in individuals receiving chemotherapy and during burn debridement, resulting in lower pain ratings and greater tolerance of treatments [10-12], as well as encouraging greater lumbar spine flexion in individuals with kinesiophobia and LBP [13]. Thus, a virtual reality video game could enhance motivation during the Sørensen test, leading to maximal effort.

However, psychological factors are likely still involved in performance on the Sørensen test. Self-efficacy contributes to the performance of physical activities. Self-efficacy is the magnitude of belief of one’s ability to perform a certain task to achieve a specific outcome [14]. Self-efficacy is strongly associated with sport performance [15]. While the study of self-efficacy in regard to physical activity contributes to the understanding of human behavior, application to the Sørensen test, specifically, is limited.

The influence of fear of pain may vary as a function of prior LBP experience. Chronic pain is a biopsychosocial phenomenon; an individual’s emotions and appraisal of pain contributes to chronicity [16]. Cognitive appraisal of pain varies based on the individual’s beliefs about their ability to cope with the pain. In many situations, pain can elicit negative emotional reactions that lead to the amplification of pain experiences [17]. Individuals with maladaptive emotional responses to pain who undergo traditional treatment for LBP may continue to experience pain and disability long after the symptoms are treated. A cognitive-behavioral model of chronic LBP, termed the Fear-Avoidance Model, explains the progression from acute pain to chronic pain and disability [19,20]. The model hypothesizes that an individual’s pain experience depends upon their established levels of pain-related fear. Kinesiophobic individuals, those who are prone to avoidance of movement for fear of pain or harm, respond to pain with catastrophic thoughts (i.e., “The pain will get worse if I attempt to overcome it”), leading to inactivity and further progression of disability [18,19].

Measures of kinesiophobia have been used to predict LBP [20]. Pain-related fear predicts reduced maximal force production and increased pain-related interference in daily activities, regardless of actual pain levels [21]. Kinesiophobia has also been recognized as an integral factor
in Sørensen test performance. Sørensen TTF “underperformance” in individuals with chronic LBP could be predicted in part by fear-avoidance beliefs, as well as self-efficacy [22].

Accordingly, we have developed a variation of the Sørensen test that uses a virtual reality video game to provide motivation and distraction. The aim of the current study was 1) to determine whether the use of a virtual reality video game influences performance on the Sørensen test, and 2) to determine whether predictors of TTF vary between individuals with and without recurrent LBP on the virtual reality Sørensen test.

**Methods**

**Participants**

A sample of 24 participants (50% male) with a history of recurrent LBP (LBP) and 24 individuals with no history of LBP (Healthy) matched for age, sex, and BMI were recruited for this study. Participant characteristics are presented in Table 4. Individuals with a history of hip arthroscopy or spine surgery, known neurological, visual, or orthopedic impairments, depression, ongoing drug or alcohol problems, elevated resting blood pressure (>135/>90), or BMI > 35 were excluded from the study. LBP history was defined as having experienced more than one episode of LBP with symptoms occurring in the past six months and a previous consultation regarding their LBP symptoms with a health care provider; participants reporting moderate to severe pain (Numerical Pain Rating scale > 3) within the past 6 weeks, or who did not meet the classification of category 1 (LBP that does not radiate) through category 3 (LBP that radiates beyond the knee, but without neurological signs) on the Classification System of the Quebec Task Force on Spinal Disorders were excluded from participation. The protocol was approved by the Ohio University Institutional Review Board for Human Subjects Research, and all individuals provided written consent prior to participation.

**Instruments**

*Center for Epidemiological Studies – Depression (CES-D)*

The CES-D is used in the general population to measure depressive symptomatology. Good predictive validity for the identification of depression in individuals with chronic pain has been established [22], as well as Good sensitivity (93.2%) using a cutoff score of 19 for the identification of depression in individuals with chronic pain [23].

*Pain Catastrophizing Scale (PCS)*

The PCS is a 13-item scale that measures pain catastrophizing by assessing the degree to which the respondent experiences specific thoughts and feelings during pain on a 5-point Likert-type scale with the end points "Not at all" (0) and "All the time" (4). The PCS has been identified as a reliable and valid measure of pain catastrophizing (Cronbach’s alpha = .87; test-retest ICC = .93). The PCS is consistently associated with pain sensitivity and pain-related distress in
experimental pain studies [24-26]. Pain catastrophizing is a primary vulnerability construct [27,28].

**Pain Resilience Scale (PRS)**

The PRS asks participants how they respond when faced with intense or prolonged pain by rating items on a 14-item Likert scale using a "Not at all" (0) to "All the time" (4) scale that. Strong internal consistency and acceptable levels of stability have been established ($\alpha = .93$, ICC = .80) [29].

**Tampa Scale for Kinesiophobia (TSK) & Tampa Scale for Kinesiophobia - General Population (TSK-G)**

Two versions of the TSK were used in this study, each using 17 items on a 4-point Likert scale ranging from “Strongly disagree” (1) to “Strongly agree” (4). The LBP group completed the standard TSK, which assessed fear of movement at the risk of injury or (re)injury. The healthy group completed the TSK-G, which used items modified to ask how much the respondent would fear movement at the risk of injury or (re)injury if they had LBP. Construct validity and predictive ability has been established in LBP populations [30]. In the general population, the TSK-G is also reliable and valid as a self-report measure of fear of movement and (re)injury [31].

**Self-efficacy measure**

The self-efficacy measure was developed for this study based on [32,33]. After practicing the task position for a brief period, the participant was asked to indicate their confidence in their ability to maintain the Sørensen test position for one, two, three, and four minutes on a scale ranging from "Not at all confident" (0) to "Highly confident" (100).

**Data Collection**

Participants completed two separate testing sessions. Participants in this study were first included in an assessment of performance on the classic Sørensen test [34] and were invited to participate in the virtual reality Sørensen test 3-14 days later. During the first testing session, participants completed the psychological surveys, maximal strength assessments, and the classic Sørensen test. During the second testing session, participants completed the virtual reality Sørensen test.

**EMG data**

Electromyography was collected as previously described test [34]. In brief, EMG was collected using a 16 channel Delsys Bagnoli system (Delsys Inc., Boston; bandwidth 20-450 Hz); the bar leads were modified with clip leads to allow attachment to Ag-Ag Cl surface electrodes over the Erector Spinae (ERS) at the L2 and L4 level aligned between the posterior superior iliac spine (PSIS) and the lateral border of the muscle at the 12th rib, Gluteus Maximus (GM) midway between the greater trochanter and the posterior superior iliac spine, and long head of the Biceps Femoris (BF) midway between the fibular head and the ischial tuberosity. The raw surface EMG data was amplified (1k) and A/D converted with 16-bit resolution, sampled at 1000 Hz, and averaged across sides for each muscle.
Median Power Frequency

The MPF was calculated as previously described [35]. Using a fast Fourier transformation with a 512-point Hamming window, the EMG power spectrum for each muscle was calculated. MPF was determined using a 2-s moving window with 50% overlap. The normalized slope of the MPF was determined as follows: (MPF slope/initial MPF) * 100 [35]. All processing of EMG data was performed with custom software written in MATLAB (Version 2016b, The MathWorks, Natick, MA).

Force output and torque moment data

MVC data were measured as previously described [34]. In brief, our custom articulated fatigue table integrated a 6 degree of freedom (DOF) load cell (MC5-1250, AMTI, Watertown, MA) into the trunk platform connected to a signal conditioner (GEN 5, AMTI, Watertown, MA), and single DOF load cell (XTS4-500, Load Cell Central) into the leg brace connected to an analog signal conditioner (OM19, Load Cell Central, Milan, PA). Force and torque data were A/D converted at 16-bit resolution and sampled at 1000 Hz.

Position data

Trunk position during the Sørensen test was measured as previously described [34]. In brief, custom-made potentiometers were anchored over the participant’s sacrum at the level of L5-S1 and trunk at the level of T12-L1. An algorithm converted the potentiometers’ voltages into position (degrees of rotation), with an excellent linearity of fit ($R^2 = .9988$). Our custom LABVIEW (Version 13, National Instruments, Austin, TX) program used the algorithm to track position during the Sørensen tests. The horizontal position was individually calibrated prior to each test.

MVC procedure

The MVC procedure was completed as previously described [34]. As illustrated in Figure 1, subjects were situated on the custom fatigue table with the anterior superior iliac spine (ASIS) aligned with the edge of the table and the torso supported by platform positioned such that the trunk center of mass was centered over the 6 DOF load cell. The torso was secured to the platform, the pelvis was secured to the table, and the lower legs were secured at 33% of hip height by a padded bar connected to the single DOF load cell. Bracing of the feet was inhibited with a foam roll placed below the ankles. Trunk mass was measured in this position. EMG was measured as previously described and the custom LABVIEW (Version 13, National Instruments, Austin, TX) program collected the EMG and load cell measurements.
For the trunk extension trials, participants were instructed to pull their torso up into the back restraint. Three submaximal trunk extension attempts of increasing intensity were followed by three maximal trunk extension attempts. Participants were then instructed to extend their legs up against the stationary leg restraint. Three submaximal hip extension attempts of increasing intensity were followed by three maximal attempts. Two minutes of rest was provided between each attempt. Verbal encouragement and visual and audio feedback via the custom LABVIEW (Version 13, National Instruments, Austin, TX) program were provided.

**Virtual Reality Sørensen procedure**

The participants performed the virtual reality Sørensen test on a standard table, with belts across the pelvis and calves at 33% of hip height, the ASIS aligned with the edge of the table and the upper body unsupported (Figure 2). Subjects wore an Oculus Rift Head Mounted Display (Oculus Rift Developers Kit 2), as shown in Figure 2. During the test, the Oculus Rift displayed a sky environment in which the participant attempted to ‘fly’ through hoops (Figure 7). Extending and flexing the trunk appeared to make the subject fly higher and lower, respectively. The hoops were positioned such that the participant was encouraged to maintain a horizontal position for as long as possible. Immediately following a brief practice attempt of less than 5 seconds, participants completed the self-efficacy questionnaire. Participants then attempted to maintain the task position until failure while receiving audio and visual feedback via the virtual reality video game; a tone played when the participant’s position was >2° beyond the target position in either direction, which was visually represented by flying above or below the hoops. The trial was terminated when the participant fell out of the range (± 2°) for more than three consecutive seconds.

**Statistical analysis**

Independent samples t-tests were used to evaluate differences in participant demographics. A two-way ANOVA was used to determine group and sex differences in TTF on the virtual reality Sørensen test. Stepwise linear regression analyses were performed to determine
which physiological factors were related to TTF on the virtual reality Sørensen test in each group. A second set of linear regression analyses was performed with the significant physiological factors entered into the first block and psychological factors entered stepwise in the second block to determine which psychological factors were related to TTF on the virtual reality Sørensen test in each group. All analyses were performed in SPSS (IBM Corp., Armonk, N.Y., USA) and results are reported as mean ± SE unless otherwise stated.

Results

Demographics

Independent samples t-test revealed no significant differences between Healthy and LBP groups with one exception; the depression scores were significantly higher in the LBP group compared to the healthy group (Table 2).

Table 2. Anthropometric, strength, and psychological survey measures (mean ± standard error)

<table>
<thead>
<tr>
<th></th>
<th>Healthy (n = 24)</th>
<th>LBP (n = 24)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk Mass (kg)</td>
<td>36.7 ± 1.5</td>
<td>35.4 ± 1.6</td>
<td>.54</td>
</tr>
<tr>
<td>Trunk Length (m)</td>
<td>0.5 ± 0.0</td>
<td>0.4 ± 0.0</td>
<td>.15</td>
</tr>
<tr>
<td>Vertical Trunk Force (N)</td>
<td>476.7 ± 52.8</td>
<td>511.7 ± 35.4</td>
<td>.65</td>
</tr>
<tr>
<td>Trunk Moment (Nm)</td>
<td>42.3 ± 4.1</td>
<td>45.4 ± 5.4</td>
<td>.66</td>
</tr>
<tr>
<td>Hip Force (N)</td>
<td>131.0 ± 8.2</td>
<td>138.4 ± 8.6</td>
<td>.50</td>
</tr>
<tr>
<td>Mass-to-Strength Ratio</td>
<td>-0.4 ± 0.0</td>
<td>-0.4 ± 0.0</td>
<td>.13</td>
</tr>
<tr>
<td>ERS MPF slope (%/sec)</td>
<td>-0.1 ± 0.0</td>
<td>-0.1 ± 0.0</td>
<td>.32</td>
</tr>
<tr>
<td>GM MPF slope (%/sec)</td>
<td>-0.3 ± 0.0</td>
<td>-0.2 ± 0.0</td>
<td>.16</td>
</tr>
<tr>
<td>BF MPF slope (%/sec)</td>
<td>3.8 ± 0.8</td>
<td>7.6 ± 1.2</td>
<td>.38</td>
</tr>
<tr>
<td>Depression (0-60)</td>
<td>39.3 ± 2.1</td>
<td>37.7 ± 2.1</td>
<td>.01*</td>
</tr>
<tr>
<td>Pain Resilience (0-56)</td>
<td>7.6 ± 1.3</td>
<td>6.8 ± 0.9</td>
<td>.61</td>
</tr>
<tr>
<td>Pain Catastrophizing (0.52)</td>
<td>30.9 ± 1.3</td>
<td>32.0 ± 1.3</td>
<td>.59</td>
</tr>
<tr>
<td>GM Tension (N/m)</td>
<td>38.7 ± 3.4</td>
<td>48.7 ± 3.6</td>
<td>.54</td>
</tr>
</tbody>
</table>

All values reported as mean ± standard error. ERS: Erector Spinae; MPF: Median Power Frequency; GM: Gluteus Maximus; BF: Biceps Femoris; *significant difference

TTF

A 2 Group (Healthy, LBP) x 2 Sex (Male, Female) two-way ANOVA revealed no significant differences in group (F = 0.00, P = .99) or group by sex (F = 0.33, P = .57; see Table 6); however, there was a marginal effect of sex (F = 3.89, P = .06), which reflected a tendency toward longer TTF in female versus male participants.

Table 3. Time to task failure on the virtual reality Sørensen test

<table>
<thead>
<tr>
<th></th>
<th>Healthy</th>
<th>LBP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>107.2 ± 9.6</td>
<td>98.1 ± 9.7</td>
<td>102.7 ± 6.7</td>
</tr>
<tr>
<td>Female</td>
<td>128.7 ± 21.1</td>
<td>137.3 ± 17.8</td>
<td>133.0 ± 13.5</td>
</tr>
<tr>
<td>Total</td>
<td>118.0 ± 11.6</td>
<td>117.7 ± 10.7</td>
<td>117.8 ± 7.8</td>
</tr>
</tbody>
</table>

Predictors of VR Sorensen TTF
Simple correlations were run between TTF and each of the physiological and psychological factors that were entered into the linear regression analyses. The Pearson correlations are displayed in Table 4.

Table 4. Simple correlations between TTF and factors entered into the linear regression analyses

**Healthy**

A stepwise linear regression analysis identified the normalized MPF slope of the ERS (β = .45, P = .01), normalized MPF slope of the BF (β = .40, P = .01), and trunk mass (β = -.32, P = .03) as significant predictors of TTF. A separate linear regression analysis was then run with the MPF slopes of the ERS and BF and trunk mass entered into the first block and all psychological measures (i.e., CES-D, TSK, self-efficacy, PCS, PRS) offered stepwise into the second block. Only trunk mass and the normalized MPF slopes of the ERS and BF were retained as significant predictors of TTF on the virtual reality Sørensen test in the healthy group.

**LBP**

A stepwise linear regression analysis identified trunk mass (β = -.53, P = .01) as a significant predictor of TTF. A separate linear regression analysis was then run with trunk mass entered into the first block and all psychological measures (i.e., CES-D, TSK, self-efficacy, PCS, PRS) offered stepwise into the second block. In the final model, trunk mass (β = -.67, P < .01), ERS: Erector Spinae; MPF: Median Power Frequency; GM: Gluteus Maximus; BF: Biceps Femoris; *P < .05; **P < .01.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unstandardized β</th>
<th>SE</th>
<th>Standardized β</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy (Constant)</td>
<td>301.32</td>
<td>10.20</td>
<td></td>
<td>7.50</td>
<td>.00</td>
</tr>
<tr>
<td>ERS MPF</td>
<td>140.21</td>
<td>45.17</td>
<td>.45</td>
<td>3.10</td>
<td>.01</td>
</tr>
<tr>
<td>BF MPF</td>
<td>130.24</td>
<td>44.74</td>
<td>.40</td>
<td>2.91</td>
<td>.01</td>
</tr>
<tr>
<td>Trunk Mass</td>
<td>-1.12</td>
<td>0.49</td>
<td>-.32</td>
<td>-2.30</td>
<td>.03</td>
</tr>
<tr>
<td>LBP (Constant)</td>
<td>342.21</td>
<td>61.68</td>
<td></td>
<td>5.55</td>
<td>.00</td>
</tr>
<tr>
<td>Trunk Mass</td>
<td>-2.08</td>
<td>0.48</td>
<td>-.67</td>
<td>-4.34</td>
<td>.00</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>-3.56</td>
<td>1.27</td>
<td>-.43</td>
<td>-2.81</td>
<td>.01</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>1.15</td>
<td>0.49</td>
<td>.35</td>
<td>2.34</td>
<td>.03</td>
</tr>
</tbody>
</table>
Discussion

This study aimed to examine performance on a variation of the Sørensen test using a virtual reality video game in individuals with and without a history of recurrent LBP. To the best of our knowledge, this is the first study to use a virtual reality video game in conjunction with the Sørensen test. Contrary to much of the published literature, we did not find a significant difference in TTF between the groups. In the first longitudinal study, males with a short TTF on the Sørensen test were most likely to experience LBP in the following year, identifying the test as a predictor of first-time LBP [36]. The test was later recognized as a discriminator of those with and without LBP; individuals who had no prior LBP experience had a significantly longer TTF than those with any LBP experience [37]. Many studies have reported consistent findings; however, others have failed to find a difference in performance between those with and without LBP. There are many physiological factors that have been found to influence performance on the task, including BMI, trunk mass, MPF slopes of the trunk and hip extensors, and maximal trunk and hip strength, which we have discussed previously [34].

Although our sample of individuals with recurrent LBP performed just as well on the virtual reality Sørensen test as those without LBP, several interesting findings emerged regarding the factors associated with TTF. In our healthy group, it appears that TTF was driven primarily by trunk mass and the MPF slopes of the trunk and hip extensors, which is consistent with our previous work [34]. Trunk mass was also a predictor of TTF in the LBP group. Other studies have demonstrated significant effects of anthropometrics on performance, as well. The workload of the task is governed by the weight of the body above the hips. It is obvious that an individual with a heavier trunk mass will not be able to maintain the test position for as long as another individual with the same strength capacity but lighter trunk mass. The effects of anthropometrics tend to be consistent in both individuals with and without LBP. Significant associations have been identified between body mass, BMI, and the MPF slope of the ERS in males and females with and without LBP [38]. A significant association between TTF and torso mass in females with and without LBP has also been demonstrated [39]. Trunk mass is an important factor in Sørensen test TTF, especially in those with a history of LBP, and should be considered when assessing performance. A variation of the Sørensen test that normalizes the workload to a consistent percentage of maximal strength would account for differences in trunk mass and strength to allow for a more objective assessment of endurance.

In the current study, self-efficacy emerged as an important factor in Sørensen test performance. Motivation has long been recognized as a consequential factor in Sørensen test performance [22,36,40-43], but, to the best of our knowledge, we are the first to attempt to manipulate it through the use of a virtual reality video game. The self-efficacy measure was
created specifically for the Sørensen test task, which likely explains its strong association with TTF in the LBP group. Interestingly, self-efficacy was not predictive of performance in the healthy group. Thus, in this sample of individuals without a history of LBP, it appears self-efficacy did not drive performance. Alternatively, our sample of individuals with a history of recurrent LBP performed better on the virtual reality Sørensen test if they reported higher ratings of confidence in their capacity to perform the task. This is in agreement with our previous findings on the standard Sørensen test [34], as well others who found that performance was predicted in part by self-efficacy [22]. This would suggest that self-efficacy may be a worthwhile target for cognitive-behavioral interventions for LBP.

There was also a significant effect of kinesiophobia in our LBP group; those who had lower TSK scores maintained a longer TTF on the virtual reality Sørensen test. This would suggest that TSK is predictive of performance in individuals with recurrent LBP when provided with a distraction element. On the classic version of the Sørensen test [34], TSK was not predictive of performance in this same group of individuals with recurrent LBP. The virtual reality video game may have actually exacerbated fear cognitions by blocking the participant’s view of the real-world, reducing their sense of control and instead redirecting focus toward their pain-related fear. Future research could benefit from investigating the response to different types of games to determine whether certain games are more effective, or if games are not effective in any form to counteract pain-related fear.

Previous research has demonstrated an effect of sex on performance on the Sørensen test. Females tend to maintain the test position for longer than males [43,44]; however, several studies have found no sex differences [45,46], and others have found that males maintain the test position for longer than females [47-49]. We did identify a trend toward a sex difference on TTF, with females maintaining the position slightly longer than males ($P = .06$). Others have reported that healthy females maintained an isometric trunk extension task significantly longer than healthy males [50]. The authors attributed their results to the muscle mass and strength hypothesis, which describes the relationship between total muscle mass, vascular compression, and the demand for oxygen. Because females typically have lower muscle mass, the vasculature is less compressed during isometric exercise, and the demand for oxygen to the active muscles is [51,52]. There is also some evidence that females have a greater ratio of Type I oxidative muscle fibers in the trunk extensors [53], which would have a greater concentration of Beta-2 adrenergic receptors, enhancing vasodilation [54]; there is also evidence that females have a greater degree of capillarization in some muscles [55], enhancing perfusion. However, others have demonstrated that intramuscular pressure may not be associated with a shift in the MPF during isometric trunk extension exercises [56,57]. Although muscle mass was not measured in the current sample, it is possible that TTF was influenced by perfusion.

As with any study of human subjects, this study is not without its limitations. Our LBP group consisted of individuals with mild, recurrent LBP, which may have also restricted the sample to individuals with low levels of disability and pain-related fear. Individuals with higher disability and pain-related fear have poorer rehabilitation outcomes and typically perform more poorly on the Sørensen test. Thus, significant pain-related fear associations may have emerged in a sample of individuals with more severe kinesiophobia and disability symptoms. This group was also primarily young, fit, college-aged students; future studies will benefit from measuring physical activity levels, as cardiorespiratory fitness is likely associated with performance on any endurance task, such as the Sørensen test.
Conclusions

We have demonstrated that individuals with and without mild, recurrent LBP perform similarly on a variation of the Sørensen test using a virtual reality video game, but the underlying mechanisms driving performance vary between the groups. Performance on this variation of the Sørensen test in healthy individuals is driven primarily by physiological factors, including trunk mass and MPF slopes of the ERS and BF. Trunk mass is also an important factor of performance in individuals with a history of recurrent LBP; however, levels of self-efficacy and kinesiophobia also appear to be important predictors of TTF on this virtual reality Sørensen test.

Abbreviations

ASIS: Anterior Superior Iliac Spine
BMI: Body Mass Index
BF: Biceps Femoris
CES-D: Center for Epidemiological Studies - Depression
DOF: Degree of freedom
ERS: Erector Spinae
GM: Gluteus Maximus
LBP: Low Back Pain
MPF: Median Power Frequency
MVC: Maximal Voluntary Contraction
PCS: Pain Catastrophizing Scale
PRS: Pain Resilience Scale
SE: Standard Error
TSK: Tampa Scale for Kinesiophobia
TTF: Time to Task Failure

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