Supplementary Materials

1) Description of Vector Coding and Ellipse Area Method analyses

Vector coding is based on methods originally described by Sparrow et al.[1], and has been fully described in multiple studies[2–5].

The angular kinematic data from the pelvis and trunk segments in the axial plane across each walking turn stride cycle were first time-normalized to 100%. Relative motion between the two segments was then calculated for each successive interval in the time series of each stride cycle using the coupling angle. The coupling angle (φ) is the angle from the right horizontal of a vector connecting two consecutive data points on the angle–angle plot of the motion of two segments. The mean coupling angle (γ_i) for each time interval across the multiple trials for each participant is calculated using equations 1 and 2, where *i* is the *i*th percentile of the total stride cycle of the *j*th trial, x = pelvic segment data, y = trunk segment data.

1) $Mean\ x_i\ (\overline{x}) = \frac{1}{n}\sum(\cos\varphi_{ij})$

$Mean\ y_i\ (\overline{y}) = \frac{1}{n}\sum(\sin\varphi_{ij})$

2) $\gamma_i = tan^{-1}\left(\frac{\overline{y}}{\overline{x}}\right)$ (with correction for negative angles such that coupling angle is between 0 and 360°)

The variability of the coordination was calculated using the angular deviation of the mean coupling angle at each time interval in the time series[3,5]. The hypotenuse of the mean vectors r_i is an inverse measure of the circular dispersion of the coupling angles across repeated trials (the length of the mean vector, valued between 0 and 1) and was calculated using equation 3:

3) $r_i = \sqrt{\overline{x}_i^2 + \overline{y}_i^2}$

The angular deviation (s_i, bounded between 0 and √2 radians), was then calculated using equation 4 and then converted to degrees.

4) $s_i = \sqrt{2(1 - r_i)}$

The ellipse area method was first described by Stock et al.[6,7]. The same time-normalized angular kinematic data from the pelvis (θ_1) and trunk segments (θ_2) in the axial plane were utilized for this method. Like vector coding, measurement of inter-segmental coordination for the ellipse area method is based on vector end points on an angle-angle plot of relative motion between the two segments. Stride to stride variability is characterized as the area of an ellipse that encompasses the vector end points across the repeated trials. The ellipse is defined using standard methods[8,9]. First a covariance matrix *C* is calculated for each time interval across the multiple trials for each participant as in equation 5

5) $C_i = \mathrm{cov}((\Delta\theta_1(i), \Delta\theta_2(i))$

The length of the axes of the ellipse are calculated as the eigenvalues (*val*) of the covariance matrix. A Chi-squared scaling factor *k* is used to scale the length of the axes such that the probability (*p*) that a value will fall within the ellipse is 95% (equations 6 and 7) and the area of the ellipse (*A*) is calculated (equation 8).

6) $k = \sqrt{-2log_e(1-p)}$

7) $X_i = k\sqrt{svd(val(i))}$

8) $A_i = \Pi(prod(X_i))$

2) Muscle fatigue during the fatiguing protocol

The slope of the median frequency of electromyography (EMG) signals is often utilized to characterize muscle fatigue. As a muscle fatigues, the median frequency of the power spectrum of the EMG signal decreases. Validation work indicates that the rate of median frequency decline over time correlates with endurance hold times during the fatiguing protocol utilized in the present study[10].

Methods:

In addition to the motion capture markers, participants were instrumented with surface electromyography (EMG) electrodes bilaterally on the lumbar erector spinae at L4 using standard locations and skin preparation protocols (interelectrode distance 20mm, Myotronics Inc, WA, USA). EMG data were digitally sampled at 1500Hz (Noraxon DTS sensors, Noraxon Inc, Scottsdale, USA). EMG data were collected throughout the fatiguing protocol (Sorensen test). Data from one participant were excluded from this analysis due to signal loss during the test.

Data were transferred to MATLAB® for further processing (MathWorks, Natick, USA). For each individual, the median frequency of the power spectrum in Hz was calculated for each one second of data during the Sorensen test. The median frequency values over time were then plotted and the slope of the values calculated using regression. Exemplar data from one representative participant are shown in Figure 1.

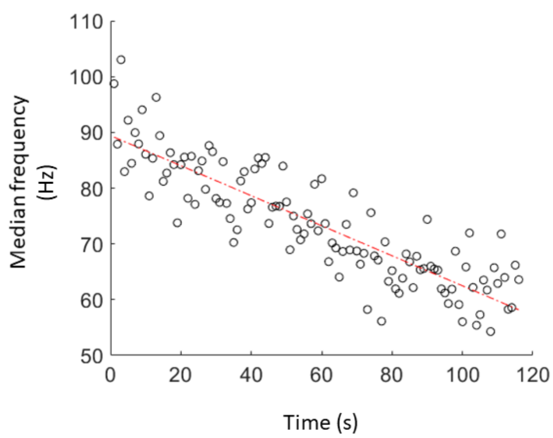

Figure 1. Median frequency slope during the fatiguing protocol. Representative data from one participant (right lumbar erector spinae) showing decline in median frequency over time. Each data point is the median frequency for 1 second of data, and the red line indicates the linear regression slope.

The average slope of the median frequency in the right and left lumbar erector spinae during the fatiguing protocol is shown in Figure 2. The slope was significantly different from zero in both cases (one-sample t-test, $p < 0.001$ for both right and left). Group data for median frequency slope are shown in Figure 2.

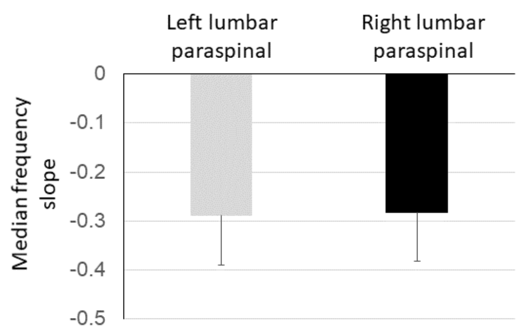

Figure 2. Average median frequency slope during the fatiguing protocol across the group. Error bars represent standard deviations.

3) Duration of muscle fatigue after the fatiguing protocol

A pilot study (n = 5) was conducted to determine the duration of paraspinal muscle fatigue following the fatiguing protocol. Participants were instrumented with surface EMG as previously described. EMG data were collected during a task requiring submaximal, isometric activation of the trunk extensors (maintaining straight trunk alignment for 60 seconds while positioned on a roman chair at 30 degrees of inclination). Participants then completed the fatiguing protocol (Sorensen test) as previously described. Participants repeated the submaximal task at 1 minute, 5 minutes, 10 minutes, and 20 minutes after the fatiguing protocol. Between the submaximal task repetitions, participants rested in a supine position. Median frequency during each 60 second iteration of the submaximal task was calculated as previously described. Change in median frequency (intercept of the slope) from baseline to each post-fatigue time-

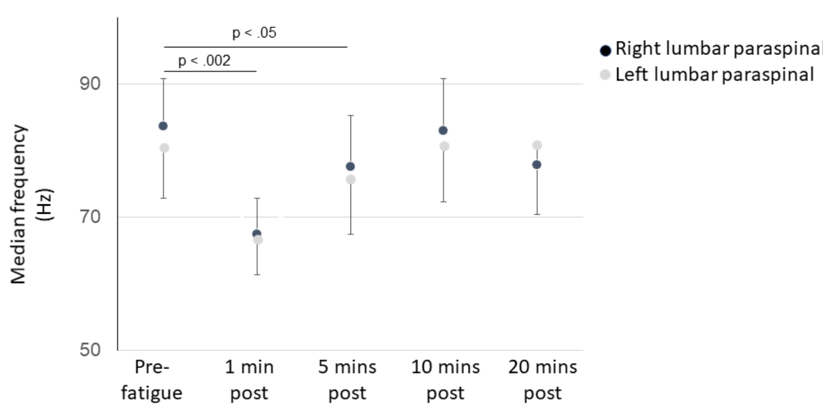

Figure 3. Duration of change in median frequency (intercept of the slope) following the fatiguing protocol.

point was assessed using paired t-tests. Group data are shown in Figure 3. The median frequency remained significantly reduced at 1 minute and 5 minutes after the fatiguing protocol was completed but was not significantly different by 10 minutes post-fatigue. As a result, during the main study we ensured that all of the post-fatigue walking trials were completed within 5 – 7 minutes after the end of the Sorensen test.

References for supplementary material

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