Brief report

The influence of fatigue on trunk muscle responses to sudden arm movements, a pilot study

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Abstract

Objective. To examine fatigue induced changes in trunk muscle latencies following trunk muscle fatigue.
Design. A repeated measures within subject design.
Background. Trunk muscle responses to sudden movements is of interest in clinical biomechanics and motor control.
Methods. Electromyographic profiles were recorded from transversus abdominis (finewire), internal oblique, rectus abdominis and external oblique and longissimus at the level of the 3rd lumbar vertebrae bilaterally. Four asymptomatic subjects performed arm-raising task using a visual cue before and after an isometric fatiguing trunk extension task.
Results. Feed-forward responses were not detected in all muscles for every trial. In general, following fatigue trunk muscle onset latencies occur earlier (left, \( P = 0.0016 \); right, \( P = 0.0475 \)).
Conclusions. Trunk muscle fatigue alters anticipatory postural adjustments in normal subjects. It remains unclear if there is a pattern for specific muscles changes between individuals and if these are reflected in individuals with low back pain.

Relevance

Trunk muscle fatigue and altered trunk muscles latencies to movement perturbations have been associated with low back pain. These findings suggest that there may be a link between centrally mediated response to isometric muscle fatigue and anticipatory motor control strategies. © 2002 Published by Elsevier Science Ltd.

Keywords: Abdominal muscles/physiology; Electromyography; Spine/physiology; Fatigue

1. Introduction

Sudden voluntary movements of the upper limb are preceded by increased activity of muscles of the lower limb and trunk in order to minimise the postural disturbance caused by the impending limb movement [1–3]. Both feed-forward and feedback responses are integrated to develop optimal movement patterns. Recent studies in individuals with chronic low back pain have demonstrated alterations in the levels of trunk muscle activity and the timing of anticipatory postural adjustments (APAs) associated with rapid arm movements [4–8].

The mechanisms behind the motor control adaptations seen in individuals with low back pain remain unclear. They may be partly explained by modifications in both peripheral muscle and joint function (afferent and efferent) as well as adaptation in the control of the postural dynamics in concert with the focal movement [9–12].

Poor performance in back extension endurance (muscle fatigue) tasks have also been associated with low back pain [13]. Muscle fatigue induces changes in both central drive characteristics and the contractile profiles of motor units (see [14] for review). It remains unclear, however if muscle fatigue alters the feed-forward/ APAs to perturbations induced by focal movements.

The purpose of this study was to document the influence of muscle fatigue on the centrally mediated feed-forward trunk muscle activity patterns in healthy individuals during rapid arm raising.

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2. Methods

Four informed volunteers (three females, age 21–42 years) fulfilled the inclusion criteria of having: (1) good health; (2) no neurological or cardiovascular disorders; (3) no severe musculoskeletal injuries; (4) no low back pain during the past 12 months, (5) no back pain requiring medical attention or missed work.

Electromyographic (EMG) surface recordings of the trunk muscles were made using bipolar Ag/AgCl disposable electrodes, placed with an inter-electrode distance of 20 mm, impedance <10 kΩ, over the following muscles bilaterally according to Ng et al. [15] and Juker et al. [16]: internal and external oblique, rectus abdominis, and longissimus at L3.

The muscle activity profile of the transversus abdominis was recorded using fine wire (nylon coated nickel/chromium wire) electrodes (75 μm in diameter, 15 cm long, one with 2 mm receptive area and other end blunt) inserted using ultrasound guidance. The pre-amplified signals were amplified (5000–10,000 ×), band-pass filtered at 10–400 Hz, sampled at 1000 Hz, and stored to disc.

For the arm-raising task, subjects stood on two force plates and evenly (±4%) distributed their body weight. Following familiarisation subjects were instructed to “raise their arm as fast as possible” at the onset of the light in their central visual field.

For the fatiguing task subjects stood with the anterior superior iliac spines against a padded rigid support [17] and sustained a pull at 60% of their best maximal effort [18]. Real time visual and audio feedback was given and the test stopped when the subject was unable to maintain force above a threshold of 35%.

Ten arm-raising trials were performed before and after the fatigue task.

Each channel of the EMG data were demeaned, full wave rectified and secondarily filtered using 80 Hz (fourth order zero-lag Butterworth filter). The onset of the muscle burst was determined by using visual inspection combined with a detection algorithm. The algorithm identified all muscle onsets of >5 ms duration that were 3 SD above the mean of the first 1000 ms baseline. The inter-quartile range of test–retest error and the method error (standard deviation of the difference scores/√2) for the onset detection were 11.7 and 12 ms respectively.

Post-processing of the onset data included identifying muscle onsets that occurred within the APA window of 180 ms prior and 60 ms after the onset of the Deltoid. Muscle activity traces that did not have an onset detected in this window were rejected.

Median values for each muscle group for each subject were determined. Non-parametric analyses (Wilcoxon sign rank) were used to determine differences before and after the fatigue task for (a) the left and right trunk muscle onsets and (b) each muscle group.

3. Results

The reaction time before (181 ms, SD 70) and after (175, SD 84) the fatiguing task was not significantly different (P = 0.746) suggesting that trunk muscle fatigue did not affect the subject’s reaction time to initiate the focal movement.

Onsets in the APA window (before 60 ms after the onset of deltoid) were not detected in all muscles for every trial (Table 1).

Fig. 1 illustrates the boxplot for the onsets for each muscle group before and after the fatigue task. Grouped by side the muscles demonstrated a significantly earlier muscle latencies left (P = 0.0016) and right (P = 0.0475) Due to the small sample size and variance in the data sets the statistical power for differences for specific muscles was weak. However inspite of the small

Table 1

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Fatigue</th>
<th>Before</th>
<th>After</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Rectus abdominis</td>
<td>30</td>
<td>28</td>
<td>38</td>
</tr>
<tr>
<td>External oblique</td>
<td>25</td>
<td>78</td>
<td>38</td>
</tr>
<tr>
<td>Internal oblique</td>
<td>68</td>
<td>40</td>
<td>58</td>
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<tr>
<td>Longissimus</td>
<td>78</td>
<td>58</td>
<td>68</td>
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<tr>
<td>Transversus abdominis</td>
<td>65</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

Fig. 1. The boxplots (median, inter-quartile range and 10th and 90th percentiles) of the median muscle latency for all muscles before (open) and after (shaded) fatiguing extension task. Zero is onset of anterior deltoit. Negative latencies infer onset prior to deltoit onset. RA: rectus abdominis, EO and IO: external and internal obliques, LL: longissimus at lumbar 3, TrAb: transversus abdominis. Data grouped between sides.
numbers a statistically significant ($P = 0.0251$) reduction in the external oblique latency occurred.

4. Discussion

The fatigue task in this experiment is similar to others [18] and require a large degree of effort by the subject [13]. The specific details of the fatigue response of the muscles has been reported previously [17].

In determining the muscle latencies during the APAs, a specific reference window of detection was selected based on a period before the onset of the arm movement. Previous studies have stated the feed-forward window was as long as 50 ms past the onset of deltoid [19]. Therefore the last 10 ms of the window used in this study cannot be clearly delineated as feed-forward responses.

The findings of the present study suggest that onsets were clearly detected in about 60% of trials when using a window up to 60 ms after the onset of deltoid. The data also suggests that the onset detection rates were not affected by the fatiguing intervention. How this compares with similar studies is unclear due to poorly defined rejection rates and the use of a reference window that includes feedback responses. However other studies have reported trunk muscle onsets in 95% of trials with fast arm movements ($\approx 300^\circ \text{s}^{-1}$) [6].

APAs are known to be more variable at slower velocities and lower inertial loading during the focal movement [3,20]. This current study, like others in the literature encouraged the subjects to move ‘as fast as possible’ on the visual signal. Therefore, the difference between the onset detection rates may reflect individual variance and the selection of the reference window rather than testing instructions.

The inability to detect muscle onsets for all trials also has implications as to the clinical significance of altered latency responses. Since this study only examined the reference window for anticipatory responses, it is expected that some trials would not have onsets detected for some muscles. This would be most evident in muscles where previous research has indicated that the mean and variance infer some trials had muscle latencies >60 ms. For example, the mean and standard error of the muscle latencies of the rectus abdominis and external oblique during arm flexion have been reported as 60 (SEM 14) and 57 (SEM 14) ms respectively [5]. If the anticipatory response window were to be set at 60 ms, as it was in this study, then approximately half of the trials in the Hodges and Richardson [5] study would have been rejected. This would co-incidentally reflect the rate of onset detection reported in this present study of about 50%. Using this same argument and study [5] a greater rate of muscle activity onsets for transversus abdominis should have been detected in this experiment.

The clinical significance of absence anticipatory responses in isolated trunk muscles may also reflect the nature of the motor control system. Unlike this experimental setting, activities of daily living evoke postural adjustments over and above an underlying movement perturbations. In real life situations the dynamic stability is controlled in synergies in which the output of one element is dependent upon the output of other elements [21]. Therefore, if a marker exists for a central motor control deficit in pre-emptive protective responses in individuals with low back pain, then it may be seen within a synergy of muscles all acting within the anticipatory response window. Previous studies [6] have reported lower detection rates and delays in both internal oblique and transversus abdominis in the back pain population compared to matched controls. This synergy among muscles maybe masked by incorporating feedback responses in the muscle onset profiles and may account for the identification of transversus abdominis being singled out as a marker for control dysfunction. This hypothesis however, needs further investigation.

If subtle anticipatory responses are a major determinant of episodic low back pain then the trials when specific muscles onsets are not detected open a question as to the sensitivity of this parameter in isolation as a marker of a central deficit. It may be that the other muscles, also contribute to the system of stability and the pattern of muscle onset latencies is modulated under various dynamic patterns.

4.1. Reaction time following fatigue

The reaction times for the pre- and post-fatigue conditions did not significantly change. The mean and spread of reaction times were similar to that reported by De Wolf et al. [10]. Unlike De Wolf et al. [10], anticipatory responses in this study were not investigated in respect to reaction time. It would be of interest to see if fatigue provided a stimulus to integrate the focal rapid arm movement with that of the APAs. Luoto et al. [22] demonstrated slower psychomotor speed/reaction time in individuals with chronic low back pain and that these reaction time increased with recovery of the systems. Although this reflects factors associated with the focal movement control system there is evidence that there are parallel adaptation in the anticipatory responses in chronic low back pain following rehabilitation and recovery of symptoms.

4.2. Muscle onsets following back extension fatigue

The main finding of this study was that there was a general decrease in muscle latencies post fatigue. This may be an adaptation to facilitate an earlier activation in the muscles since it would be expected that the rate of force production would be decreased due to the fatigue
response. Therefore a decrease in latency may increase the capacity to meet a specific force threshold. The fatiguing task however, was unlikely to fatigue all the trunk muscles equally [17] so the adaptation seen in this pilot study may suggest a generalised adaptation to the fatigue response.

The changes of the APA control strategy induced by the fatigue activity also suggest an independence of the control system underlying the reaction time of the focal movement. Conversely, the results may be explained by a change in the integration of both elements by one control system. Previous authors have presented the arguments that there maybe an integration of the two parallel control systems for both focal and postural adjustments [10,11,23]. This may impact on the interpretation of the role of each system in the protection of the spine during fatigue related work injuries. Low back injuries during activities of daily living and work manifest in many different ways. Determining the impact of fatigue on anticipatory protective strategies may provide an avenue for the development of rehabilitation strategies that adapt both the capacity of peripheral muscle as well as modifying the central protective muscle activation patterns. Such rehabilitation protocols are likely to incorporate both muscle capacity training as well as motor learning principles of skill acquisition and development.

5. Conclusion

The findings of this study suggest that in normal subjects, fatiguing back extension task induced adaptations of the automatic APAs without altering the reaction time of the focal task. Further study is necessary to elucidate specific muscle adaptations and document if similar patterns exist in individuals with a history of low back pain.

References


