Establishment of a protocol to test fatigue of the trunk muscles

G Corin, P H Strutton, A H McGregor

Background: Muscle fatigue has high relevance in human performance yet little research has evaluated how it should be assessed.

Objective: To perform a pilot study to identify suitable methods of generating and assessing fatigue of the trunk flexor and extensor muscles.

Methods: Sixteen university rugby players (mean (SEM) age 21.9 (0.2) years) were recruited and subjected to four protocols (A, B, C, D), separated by a week to allow recovery, with peak torque being recorded during each test: A, isokinetic measurements before and after fatigue, with a 10 repetition isokinetic fatigue period; B, isokinetic measurements before and after fatigue with a 45 second isometric fatigue period; C, isometric measurements before and after fatigue with a 10 repetition isokinetic fatigue period; D, isometric measurements before and after fatigue with a 45 second isometric fatigue period. All were conducted during flexion and extension of the trunk on the Cybex Norm Isokinetic Dynamometer trunk flexion-extension unit.

Results: All subjects completed all four protocols. Fatigue induction appeared more effective in flexion than extension. Significant differences in mean peak torque before and after fatigue were seen in protocols A, B, and D in flexion and only in protocol D for extension. In flexion, protocol D produced the greatest fatigue, peak torque being 16.2% less after than before fatigue, suggesting greatest sensitivity.

Conclusions: Protocol D, which incorporates isometric testing and fatigue protocols, appears to be able to produce fatigue most effectively, and therefore may provide the most valid assessment of fatigue in the trunk flexor and extensor muscles.

A n often applied definition of fatigue is an “exercise-induced reduction in maximal voluntary muscle force”. This should not be confused with the limit of endurance, which is the time period for which a constant (non-fatiguing) force output can be maintained. Further confusion can arise about whether this endurance is assessed maximally or submaximally, and as a result of test position.

Muscle fatigue is a complex and multifaceted process involving physiological, biomechanical, and psychological elements. It is an important phenomenon, as there are numerous proven relations with work related musculoskeletal injuries. Being able to identify and test muscle fatigue is particularly important because an athlete may struggle to resist gravity. It is also limited to assessment of the trunk extensor muscle group only.

The assessment of fatigue and endurance in the trunk is important because it has been widely reported that patients with low back pain develop a deconditioning syndrome that particularly influences the strength and function of the back muscles, with such patients being much weaker than healthy controls. Lack of endurance has also been highlighted as a key factor for predicting low back pain, and this suggests that the assessment of fatigue warrants further investigation. Consequently, this study focused on the flexor-extensor muscles of the spine, investigating different methods of testing and evaluating maximal fatigue of the trunk muscles.

METHODS

Study population

Ethical approval for this study was obtained from the Riverside Research Ethics Committee, at Charing Cross Hospital, London, UK. Sixteen male student rugby players (mean (SEM) age 21.9 (0.2) years, weight 91.2 (3.3) kg, height 1.8 (0.03) m) were recruited from the college’s rugby club, and written informed consent was obtained. All current members of the college club who were in full training and eligible for competition were eligible for inclusion in this study, although subjects with a current or recent low back injury (time off training or intervention four weeks before testing) were excluded from taking part. All testing fell mid-season in the rugby calendar.
Study protocol
Four trunk fatigue protocols were tested on four separate occasions, with an interval of one week between testing, all were allowed a period of familiarisation with the equipment. The volunteers received no specific training for trunk muscle exercise before or during the study.

Test protocol
Tests were carried out using the Cybex Norm Isokinetic Dynamometer (Henley Healthcare, Sugarland, Texas, USA) with an incorporated trunk flexion/extension unit (fig 1). The lower limbs were stabilised by tibial and thigh pads. A belt secured the pelvis to limit the use of the hip flexors. A shoulder harness and backrest provided anchorage to the moving upper section of the apparatus. Range of motion was recorded from 10° of hyperextension to 80° flexion as recorded through the Cybex system, which represented the limits of range of the system rather than the ranges of the subjects. All isokinetic testing was performed through this range. Subjects were tested according to the following four protocols in sequential order. These protocols were derived from previous experience obtained testing elite rowers,23 but further research is required to investigate duration and repetition number.

Protocol A
Maximum strength before fatigue was measured for both flexion and extension during an isokinetic trunk flexion-extension test. This was performed at 60°/s and incorporated one trial followed by the test. A five second rest was used to enable the subject to prepare for the fatigue section. A series of 10 maximal isokinetic flexion-extension tests performed at 60°/s was then used to fatigue the subject. Again, another five second rest was implemented to enable preparation for testing after fatigue. Strength after fatigue was recorded in the same way as before.

Protocol B
Maximum strength before fatigue was measured for both flexion and extension during an isokinetic trunk flexion-extension test. This was performed at 60°/s and incorporated one trial followed by the test. A five second rest was used to enable the subject to prepare for the fatigue section. A series of 10 maximal isokinetic flexion-extension tests performed at 60°/s was then used to fatigue the subject. Again, another five second rest was implemented to enable preparation for testing after fatigue. Strength after fatigue was recorded in the same way as before.

Table 1
<table>
<thead>
<tr>
<th>Protocol</th>
<th>Before</th>
<th>Fatigue</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IK x 2 reps</td>
<td>IK x 10 reps</td>
<td>IK x 2 reps</td>
</tr>
<tr>
<td>B</td>
<td>IK x 2 reps</td>
<td>IM 45 s hold</td>
<td>IK x 2 reps</td>
</tr>
<tr>
<td>C</td>
<td>IM 5 s hold</td>
<td>IK x 10 reps</td>
<td>IM 5 s hold</td>
</tr>
<tr>
<td>D</td>
<td>IM 5 s hold</td>
<td>IM 45 s hold</td>
<td>IM 5 s hold</td>
</tr>
</tbody>
</table>

IK, Isokinetic; IM, isometric; reps, repetitions.
enable the subject to prepare for the fatigue section. A 45 second maximal isometric hold at 10° flexion was then used to fatigue the subject. Again, another five second rest was implemented to enable preparation for testing after fatigue. Strength after fatigue was recorded in the same way as before. The above was then repeated with the fatiguing isometric hold in 10° extension.

Protocol C
Maximum strength before fatigue was measured during a five second isometric hold in 10° flexion. This incorporated one trial followed by the test. A five second rest was used to enable the subject to prepare for the fatigue section. A series of 10 maximal isokinetic flexion-extension tests performed at 60°/s was then used to fatigue the subject. Again, another five second rest was implemented to enable preparation for testing after fatigue. Strength after fatigue was recorded in the same way as before. The test was then repeated with the isometric holds in 10° extension.

Protocol D
Maximum strength before fatigue was measured during a five second isometric hold in 10° flexion. This incorporated one trial followed by the test. A five second rest was used to enable the subject to prepare for the fatigue section. A 45 second maximal isometric hold, held at 10° of flexion was then used to fatigue the subject. Again, another five second rest was implemented to enable preparation for testing after fatigue. Strength after fatigue was recorded in the same way as before. This was then repeated for extension, with the spine being held in 10° extension. Table 1 gives a summary of the protocols.

Data analysis
Body weight adjusted peak torque was used in the final data analyses. This was calculated as a percentage (peak torque (N.m) divided by body weight (kg) × 100). In an attempt to provide a measure of fatigue in terms of change in force output, a fatigue index was determined to quantify the change in data after fatigue. It was calculated as a percentage (value after fatigue divided by value before fatigue × 100). Thus if 100% or more is achieved, no fatigue has occurred, whereas values lower than 100 suggest that fatigue has occurred, the lower the value the greater the fatigue.

Data obtained before and after fatigue in each protocol were examined for differences using the paired Student’s t test. In addition, to investigate if a learning effect was evident within the same type of exercise for both flexion and extension, repeated measures analysis of variance was used. All four measures of peak torque under the same conditions were compared—that is, before and after values for isokinetics in protocols A and B, and before and after values for isometrics in protocols C and D. Results were considered significant when p<0.05.

RESULTS
All 16 subjects completed all four protocols over a four week period. Figure 2 shows the body weight adjusted mean (SEM) peak torque before and after fatigue in flexion and extension. Induction of fatigue appeared to be greater in flexion than extension. The protocols that produced a significant difference in values after fatigue were A, B, and D in flexion; only protocol D produced significant fatigue in extension. The fatigue index for protocol A in extension was 103.4%, indicating that the mean peak torque after fatigue was greater than before. Indeed, a larger proportion of subjects (9 of the 16) had an increased measurement for peak torque after the fatiguing section of the protocol than those who had a decreased measurement (fatigued), suggesting a lack of compliance or understanding of the test protocol.

Figure 3 shows the mean percentage change (fatigue index) for each protocol in flexion and extension. Flexion protocols A, B, and D produced similar levels of fatigue, with protocol D producing the greatest fatigue: the mean peak torque after fatigue was 16.2% less than before, suggesting greatest sensitivity. Protocol C was the least effective at producing fatigue in flexion. Protocol D clearly produced the greatest fatigue in extension (8.8%).

With regard to a possible learning effect of the tasks over the four weeks, repeated measures analysis of variance revealed that there were differential effects depending on the type of task. The isokinetic value before fatigue for protocol B (week 3) was significantly (p<0.05) higher than that for protocol A (week 1) only in extension. For flexion, the isokinetic value before fatigue for protocol B (week 3) was significantly (p<0.05) lower than that for protocol A (week 1). For the isometric data, there were no differences between the peak values before fatigue at week 1 or 3 in either flexion or extension. These results suggest that learning was not a factor in this study.

DISCUSSION
Muscle fatigue is an important area of research and performance assessment, and consequently it has been the focus of many studies. It is a basic element of muscular performance that potentially has great relevance to activities of daily living, particularly in the trunk, where it is of importance for activities such as bending and lifting. Fatigue may also have an important role in athletic performance. However, the optimal method for assessing fatigue has not been clearly established. In fact, Mayer et al have suggested that in the back “the measurement of trunk muscle
endurance remains a more elusive goal than strength measurement”.

One of the few validated measures of trunk fatigue is the Biering-Sorensen test, which is an isometric test of back extensor strength. However, its principle limitation in fatigue assessment is the fact that it is not a true measure of maximum voluntary contraction, with some suggesting that it records less than 50% of true maximum contraction and many questioning the reliability of the measures. There has also been criticism of this test, as it does not eliminate hip extensor activity. Also it is limited to the trunk extensors, and attempts to measure flexors with a view to recording fatigue ratios between the two muscle groups have been confounded by the use of submaximal tests performed either against or with the assistance of gravity. Other studies of trunk fatigue have examined the electromyographic activity of the back muscles using a protocol whereby an exercise, either the holding of an unsupported position such as in the Biering-Sorensen test or a series of timed flexion-extension movements, is performed until failure. However, there is little consensus on how many or what types of muscle tests are appropriate for inducing this failure. Arguments, however, exist as to what the electromyographic shifts observed are measuring and inconsistencies have been noted between subjects with back pain and controls, the relevance of which is unclear as yet.

The ability to study dynamic strength has existed for several years, with protocols primarily consisting of repeated contractions at 50% of maximal contraction until the point of failure. However, owing to the size and role of the trunk muscles, such methods were considered inappropriate by Mayer et al because they generated an unacceptably high anaerobic load. Thus, in that study, the subjects performed tests at maximal ability for fewer repetitions, and this was noted to be as reliable as isometric testing in a Roman Chair device. However, most studies have focused on isometric contractions.

Isometric tests of trunk fatigue and endurance have included chest raises, pulling tasks, and tests performed on sitting or standing dynamometers. During such tests, test position—that is, sitting or standing—has also been noted to affect the results, with Koumantakis et al suggesting that fatigue testing was more reliable in the upright position. Assessment of the impact of test position, however, was beyond the scope of this study.

Unfortunately, few studies have examined fatigue or endurance of the abdominal muscles, and few have compared isokinetic tasks with isometric tasks, although literature reviews tend to favour the use of isometric testing because of its low cost and equipment demands. Udermann et al examined the repeatability of endurance testing on a Roman Chair device and on a lumbar extension dynamometer, with endurance measured as time to maintain a set level of contraction or to hold a set position. Tests on the dynamometer included both static and dynamic tests, but the results of these different types of test were not compared, as in this study. However, their findings did suggest that all three methods had similar levels of repeatability.

What is already known on this topic

- Fatigue has been highlighted to be of importance in the development of low back pain
- In many studies on fatigue a clear definition has not been provided, and often tools used to measure fatigue have not been assessed or validated

What this study adds

- This initial study attempts to follow a published definition of fatigue, namely an “exercise induced reduction in maximal voluntary muscle force”.
- On the basis of this definition we have investigated different methods for generating and quantifying fatigue, in an attempt to provide a valid fatigue testing protocol.
Test ing trunk muscle fatigue

fatigue than isokinetic methods. However, further work is needed to examine the repeatability of this test protocol.

During the study, on questioning, subjects perceived higher levels of exertion during protocols involving an isometric fatigue (B and D). It is therefore not surprising that these induced greater levels of fatigue. However, greater levels of perceived exertion do not necessarily correlate with greater levels of fatigue, although in this study there is support for this concept. A further important implicating factor is motivation, as all forms of endurance of fatigue testing depend on the motivation of the subject to complete the test to his or her own perceived limits of fatigue.

We were unable to quantify or control for this factor, but we did attempt to minimise it by recruiting highly motivated and competitive athletes from the college rugby team.

Overall, the most effective method of inducing and measuring fatigue in the muscles of the trunk was protocol D—that is, isometric testing and fatigue. With mounting evidence that lack of trunk muscle endurance rather than actual strength is a predictor of low back pain, and that fatigue is potentially a key factor that may alter the loads on the spine and impose injury, it is important that a valid and repeatable method of testing fatigue is used in future research studies.

ACKNOWLEDGEMENTS

We thank the members of Imperial Medics RFC for their participation in this study and the ARC who funded the equipment for this study.

Authors’ affiliations
G Corin, P H Strutton, A H McGregor, Imperial College London, UK

Competing interests: none declared

Written consent from the subject has been obtained for publication of figure 1 in print and online.

REFERENCES


Establishment of a protocol to test fatigue of the trunk muscles

G Corin, P H Strutton and A H McGregor

doi: 10.1136/bjsm.2004.015537

Updated information and services can be found at:
http://bjsm.bmj.com/content/39/10/731

These include:

References
This article cites 36 articles, 2 of which you can access for free at:
http://bjsm.bmj.com/content/39/10/731#BIBL

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Topic Collections
Articles on similar topics can be found in the following collections
Rugby (171)

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/