Chapter 3

The prolonged effect of lumbar extensor fatigue on postural sway: Effects of fatiguing time and fatigue level

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Abstract

The purpose of this study was to assess the prolonged effects of lumber extensor fatigue on postural sway. Of particular interest were the effects of fatiguing time and fatigue level on the lingering effect of lumbar extensor fatigue on postural sway. Twelve young male participants completed four sessions, each separated by one week. In each session, participant's lumbar extensors were fatigued to a target percentage of maximum voluntary contraction by performing intermittent static torso extensions over either 14 or 90 minutes. Measures of postural sway were collected before and after fatigue and at three-minute intervals for 30 minutes following the completion of the fatiguing protocol. Fatigue had a significant immediate effect on three of the four measures of postural sway. Though minor fatigue condition effects were apparent immediately after the fatiguing protocol, the prolonged effect of lumbar extensor fatigue was dependant upon fatigue condition. The prolonged effect of lumbar extensor fatigue was affected by both fatiguing time and fatigue level during the 30 minutes following the completion of the fatiguing protocol. In particular, a longer fatiguing time had a more prolonged effect than the shorter fatiguing time. Also, higher levels of fatigue had a more prolonged effect than lower levels of fatigue. This study has given a greater understanding of the prolonged effects of lumbar extensor fatigue on balance.

3.1 Introduction

Falls from heights are one of the three leading causes of occupational deaths in the United States, accounting for approximately 700 deaths annually (BLS 2004). In the year 2000, for example, 717 workers died of injuries caused by falls from ladders, scaffolds, buildings, or other elevations (NIOSH 2001). Approximately half of these deaths occurred in the construction industry, which is considered one of the most hazardous sectors of the workforce. Even when death is averted, falls from heights are a major source of injury. An estimated 100,000 workers in the construction industry are seriously injured each year as a result of falls from heights (OSHA 1998).

In an attempt to address the problem of falls from heights, research has been carried out to understand the cause of these falls. The most commonly mentioned cause of falls from roofs, for example, was a loss of balance (Hsiao and Simeonov 2001). It is therefore prudent to investigate factors that can contribute to a loss of balance. Localized muscle fatigue is one factor that has been shown to increase postural sway which has been interpreted as a degradation of balance. An increase in postural sway has been shown with fatigue at the ankle (Konradsen 2002; Vuillerme et al. 2002; Yaggie and McGregor 2002; Caron 2003; Vuillerme and Nougier 2003), fatigue from repetitive lifting (Sparto et al. 1997), cardiovascular and lower extremity fatigue from running and cycling (Lepers et al. 1997; Nardone et al. 1997; Gauchard et al. 2002) and with localized shoulder fatigue from prolonged overhead work (Nussbaum 2003). Similarly, a previous study in our laboratory found an increase in postural sway with lumbar extensor fatigue (Davidson et al. 2004). Lumbar extensor fatigue is common in many occupational settings, so further investigation is warranted to understand how lumbar extensor fatigue may contribute to falls from heights, and to develop interventions aimed at reducing their occurrence.

In addition to recognizing how lumbar extensor fatigue affects postural sway, it is important to understand how these effects persist and/or wane over time to fully realize any increase in risk of falling associated with lumbar extensor fatigue. The prolonged effects of other types of fatigue on postural sway have been studied, including ankle fatigue (Yaggie and McGregor 2002), neck fatigue (Schieppati et al. 2003), prolonged running and bicycling (Lepers et al. 1997), and strenuous treadmill walking (Nardone et al. 1998). The effects of these types of fatigue on postural sway were shown to last up to 5-20 minutes. Lumbar extensor fatigue has been shown to increase sway up to 30 minutes (Davidson et al. 2004).

One factor which might affect how increases in sway lumbar extensor fatigue persist is the time over which fatigue is induced (fatiguing time). This is important because outside the laboratory, fatigue is frequently induced over long periods of time, usually over the course of several hours. Inside the laboratory, however, previous studies investigating the effect of fatigue on sway induced fatigue over much shorter durations, typically over several minutes (Sparto et al. 1997; Yaggie and McGregor 2002). It is unclear if this difference in fatiguing time changes how increases in sway with fatigue persist. Davidson et al. (2004) found that fatiguing time did not have an effect on the immediate increase in postural sway associated with lumbar extensor fatigue, nor did it change how these effects persisted over time. It was noted, however, that a trend existed in which sway tended to recover more quickly after a short fatiguing time (11 minutes) protocol compared to a long fatiguing time (90 minutes) protocol. In an attempt to re-investigate this trend, the first objective of this study was to investigate the effects of two different fatiguing times (short, long) on the prolonged effect of lumbar extensor fatigue on postural sway. Based on our earlier work, it was hypothesized that a longer fatiguing time will have prolonged effects which linger for a longer period of time.

Another factor which might affect how increases in sway with lumbar extensor fatigue persist is the level of fatigue induced (fatigue level). This is important if higher levels of fatigue induce larger increases in sway, this would suggest higher risk of falling. Similar "dose response" relationships have been shown in muscle force as higher levels of fatigue required longer periods of time to reach unfatigued levels (Reid 1993). Although a previous study from our laboratory found no evidence of a dose-response relation when measuring sway immediately after a fatiguing protocol (Davidson et al. 2005), it is unclear if one exists later in time as the increases in sway with lumbar extensor fatigue persist. Therefore, the second objective of this study was to investigate the effects of three different lumbar extensor fatigue levels (low, moderate, high) on the prolonged effect of lumbar extensor fatigue on postural sway. It was hypothesized that higher levels of fatigue will induce greater increases in postural sway which will linger for longer periods of time than lower fatigue levels.

3.2 Methods

Twelve physically active males (20-22 years of age) participated in the experiment. Mean ± s.d. participant height and mass were 173.7 ± 6.4 cm and 70.2 ± 6.6 kg, respectively. None of the participants reported any history of low back pain or injury, and all provided informed consent in accordance with the Virginia Tech Institutional Review Board before participation.

Four experimental sessions were completed by each participant with at least one week between consecutive sessions. During each session, measures related to postural sway were collected both before and after a lumbar extensor fatiguing protocol to investigate changes in sway with fatigue. In three of the experimental sessions, each participant was fatigued to one of three fatigue levels over a fatiguing time of 14 minutes. The fatigue levels were based upon a target percentage of the unfatigued isometric maximum voluntary contraction (MVC) of the lumbar extensors and defined as low (86% MVC), moderate (73% MVC), and high (60% MVC). In the fourth session, the moderate level of fatigue was repeated, but over a fatiguing time of 90 minutes. The four fatiguing conditions were presented to the 12 participants using a balanced Latin square replicated three times to balance presentation order.

The fatiguing protocol was based on a previous investigation (Davidson et al. 2004) and thus will only be summarized here. After a brief warm-up, subjects were fitted to a construction harness and positioned on a 45 deg. Roman Chair (New York Barbell, Elmira, N.Y.). Three initial MVCs of the lumbar extensors were performed by having subjects pull against a load cell (Cooper, Warrenton, Va) that anchored the construction harness to the Roman Chair. Subjects were asked to pull evenly and consistently for several seconds for each MVC and not to “jerk” the load cell at the onset of the MVC. A one-minute rest period separated consecutive MVCs, with the highest of the three MVCs recorded as 100%. Using the load cell data and an estimation of head, arms, and trunk mass and COM position (Zatsiorsky and King 1998) to correct for gravitational force on the upper body, the corresponding torque at the 'lumbar joint' (approximately L3) was estimated for all MVCs (Davidson et al. 2004).

The fatiguing protocol involved one set of dynamic back extensions on the Roman Chair each minute for the duration of the fatiguing protocol (14 or 90 minutes). Isometric MVCs collected every two minutes were used to adjust the number of repetitions in each set in an attempt to decrease the MVC force at a roughly linear rate. Subjects were allowed to stand and stretch between sets if time permitted. An MVC was also performed at the end of the fatiguing protocol to quantify the subjects' level of fatigue. The measured fatigue levels after the experiment were 81.9 ± 4.5 % MVC (mean ± s.d.), 69.7 ± 4.5 % MVC, and 59.9 ± 3.4 % MVC during the 14 minute low, moderate, and high fatiguing protocols, respectively. These fatigue levels were significantly different from each other ($p<0.001$). Subjects were fatigued to 66.3 ± 3.4 % MVC during the 90 minute moderate fatiguing protocol. This fatigue level was not significantly different from results in the shorter moderate fatiguing protocol ($p=0.182$).

Both before and after the fatiguing protocol, participants were instructed to "stand as still and as quietly as possible" for 30 seconds with their feet together, eyes closed, and arms at their sides. Three unfatigued collections were performed before the fatiguing protocol, and fatigued collections beginning approximately ten seconds following completion of the protocol were performed every 3 minutes for the next 30 minutes. During each collection, ground reaction forces and moments were obtained using a Bertec K20102 type 9090-15 force platform (Bertec Corp., Columbus, OH). Force platform data were hardware filtered (low-pass, 500 Hz cutoff), amplified, sampled at 1000 Hz, then passed through a 10 Hz low-pass software filter (zero-phase-lag 2nd order Butterworth) and transformed into COP data (Winter 1990). Four COP-based measures of postural sway were chosen for analysis including mean velocity, peak velocity, modified ellipse area (Prieto et al. 1996), and median frequency. These measures were chosen to address two time-domain distance measures, a time domain area measure, and a frequency domain measure (Prieto et al. 1996). Differences between each fatigued collection and the mean of the three unfatigued collections were calculated for all dependent sway measures and a three point moving average (Kutner et al. 2004) was applied to the fatigued collections in an attempt to smooth the sometimes high variability in the sway data. Applying this technique, the number of fatigued collections was reduced from 11 to 9, and represented times from 3 minutes to 27 minutes, in 3-minute increments, after completing the fatiguing protocol.

To determine the immediate effect of lumbar extensor fatigue on sway, a one-sample t-test (test value = 0) was used with data from the first fatigued collection (after the moving average) pooled across fatigue conditions (four levels: 86 % MVC, 73 % MVC, 60 % MVC, and 73 % MVC/longer time). To determine the immediate effect of fatigue level and fatiguing time on sway, a one-way repeated measures ANOVA with fatigue condition as the independent variable was used. In the event of a significant effect, pairwise comparisons were performed here and throughout the analysis using a Tukey HSD. To determine the effect of fatigue level and fatiguing time on postural sway for the 27 minutes following the fatiguing protocol, a two-way repeated measures ANOVA was used with independent measures of fatigue condition and fatigued collection number. In the event of a significant collection number effect, a one-sample t-test was used to determine which fatigued collections were significantly different from zero (i.e. significantly different from UF value). In the event data deviated significantly from a normal distribution, equivalent non-parametric tests were used. A significance level of $p<0.05$ was used for all statistical tests.

3.3 Results

Immediate fatigue effect

Fatigue had an immediate effect on three of four measures of postural sway including a 11.8% increase in mean velocity ($p<0.0001$), 15.3% increase in peak velocity ($p<0.0001$), and 12.8% increase in median frequency ($p=0.0003$). Modified ellipse area was not affected by fatigue ($p=0.253$). The immediate effect of fatigue condition on sway included a significantly higher peak velocity for the high fatigue level compared to the low fatigue level. No other immediate effects of fatigue condition on sway were found (Table 3.1).

Prolonged fatigue effect

Collection number also had a significant effect on sway for mean (Figure 3.1) and peak velocity (Figure 3.2). Mean velocity was significantly different from zero until the seventh fatigued collection, and peak velocity was significantly different from zero until the third fatigued collection (although the time at which these values settled to near unfatigued values is unclear).

Fatigue condition was found to have significant effect on two measures of postural sway including mean velocity ($p=0.0031$), and peak velocity ($p<0.0001$). The prolonged effects of lumbar extensor fatigue on mean velocity and peak velocity were found to be significantly greater for the long fatiguing time than the short fatiguing time for both measures (Figure 3.3). The high fatigue level was found to have a significantly greater prolonged effect on both mean velocity and peak velocity than the moderate fatigue level following lumbar extensor fatigue (Figure 3.4). The high fatigue level was also found to have a significantly greater prolonged effect on peak velocity than the low fatigue level following lumbar extensor fatigue. No effect of fatigue condition on: modified ellipse area ($p=0.253$) and median frequency ($p=0.740$) was found.

3.4 Discussion

The main objective of this study was to determine the effects of fatiguing time and fatigue level on how increases in sway with lumbar extensor fatigue persist. Our main findings showed only minor effects of fatiguing time and fatigue level immediately after the fatiguing protocol. However the effects of fatiguing time and fatigue level became more apparent during the 30 minutes following the fatiguing protocol. Evidence of a fatiguing time effect was present in both mean and peak velocity measures as the long fatiguing time exhibited prolonged elevated sway values compared with the short fatiguing time. Evidence of a fatigue level effect included the high fatigue level exhibiting prolonged elevated mean velocity and peak velocity compared to the moderate fatigue level. Furthermore, the high fatigue level exhibiting prolonged elevated peak velocity compared to the low fatigue level.

It is of interest to compare the duration of the effects of lumbar extensor fatigue on postural sway with the duration of the effects of other types of muscle fatigue on postural sway. The analysis of mean velocity shows that between the 18^{th} and 21^{st} minute following fatigue, the difference between the fatigued collection and the pre-fatigued collection became insignificant (Figure 3.1). This implies, at least in statistical terms, lumbar extensor fatigue was no longer affecting postural sway. It should be noted however, that visual inspection of the end of the 30 minute rest period, reveals mean velocity and peak velocity values which are still above un-fatigued values. A similar finding was noted by Davidson et al. (2004). Other studies which investigated the prolonged effects of fatigue of different muscle groups have shown effects which persist for similar periods of time. Neck fatigue (Schieppati et al. 2003) was shown to have effects which only linger for 5 minutes, while the effects of ankle fatigue were shown to persist for up to 20 minutes (Yaggie et al. 2002). Direct comparison to other studies is difficult due to differences in fatiguing conditions, fatiguing times, fatigue level, and sway measures employed.

Our results indicate that fatiguing time affects how the increase in sway due to lumbar extensor fatigue persists after the fatiguing protocol. In particular, sway measures were higher after the longer fatiguing time. There are a few possible explanations for this increase in prolonged effects with an increase in fatiguing time. Other physiological measures have shown effects which linger proportionally to the duration of the activity. Bahr et al. (1987) found that O_2 uptake following different durations of exercise at the same intensity increased proportionally to the duration of the exercise. The prolonged increase in O_2 uptake following the activity was also dependent upon the duration of the exercise with longer exercise times producing elevated uptake levels for a longer period of time. A similar trend was observed in this experiment as longer fatiguing times resulted in elevated sway measures for a longer period of time. Another possible explanation lies in the type of fatigue induced during the fatiguing protocol. During the short fatiguing protocol, subjects performed 167 +/- 36.6 back extensions, or 12.8 back extensions per minute. During the long fatiguing protocol, subjects performed 665 +/- 169 back extensions, or 7.4 back extensions per minute. The long fatiguing protocol can be considered an endurance exercise of long duration at a moderate intensity while the short fatiguing protocol can be considered a strength exercise of short duration and high intensity. The recovery following these two classifications of exercises can help to explain the fatiguing time effects found in this study. Muscle strength exercises have shown quicker recovery than muscle endurance activities (Petrofsky et al.1981) and thus the shorter "strength" protocol resulted in effects which persisted for a shorter period of time than the longer "endurance" protocol.

Our results also indicate that fatigue level affects how the increase in sway due to lumbar extensor fatigue persists after the fatiguing protocol. In particular, higher levels of fatigue will result in prolonged significantly elevated postural sway. Higher levels of fatigue have previously been shown to exhibit higher degrees of lingering effects than lower levels of fatigue. Reid et al. (1993) found that greater losses in muscle force in the tibialis anterior exhibited reduced muscle forces levels for a prolonged period compared with lower losses in muscle force. In the present experiment, the lumbar extensors were fatigued to different levels and most likely exhibited a similar prolonged effect at higher fatigue levels. The mechanisms which are responsible for the increases in postural sway with lumbar extensor fatigue likely exhibit a similar behavior.

There are a few limitations to this study which warrant discussion. One limitation is the analysis used to study the prolonged effect of lumbar extensor fatigue on postural sway. In an attempt to quantify the effect of fatiguing time and fatigue level over the entire 30 minutes following fatigue, comparisons combined all fatigued collection numbers together in the analysis. Thus, the immediate effects of lumbar extensor fatigue on postural sway are inherently combined with the prolonged effects. Since fatigue condition (fatiguing time and fatigue level) was shown to have only minor effects on the immediate effect of fatigue, we believe this analysis is still valid. A second limitation to this study is the subject pool used. The subjects who participated in this study were only healthy young males, and caution should be taken before extrapolating these results to other populations.

In conclusion, muscle fatigue of the lumbar extensors increased postural sway as has previously been reported (Davidson et al. 2004). Though minor fatiguing time and fatigue level effects were apparent immediately after the fatiguing protocol, these effects became more apparent later during the 30 minutes following fatigue. In particular, a longer fatiguing time exhibited prolonged elevated measures of postural sway compared with the shorter fatiguing time. Similarly, higher levels of fatigue exhibited prolonged elevated measures of postural sway compared to the lower levels of fatigue. While it is important to understand the immediate effect of lumbar extensor fatigue on balance, this study has demonstrated that the prolonged effect of such fatigue should be considered when addressing falls from heights.

3.5 Acknowledgements

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3.7 Figures and Tables

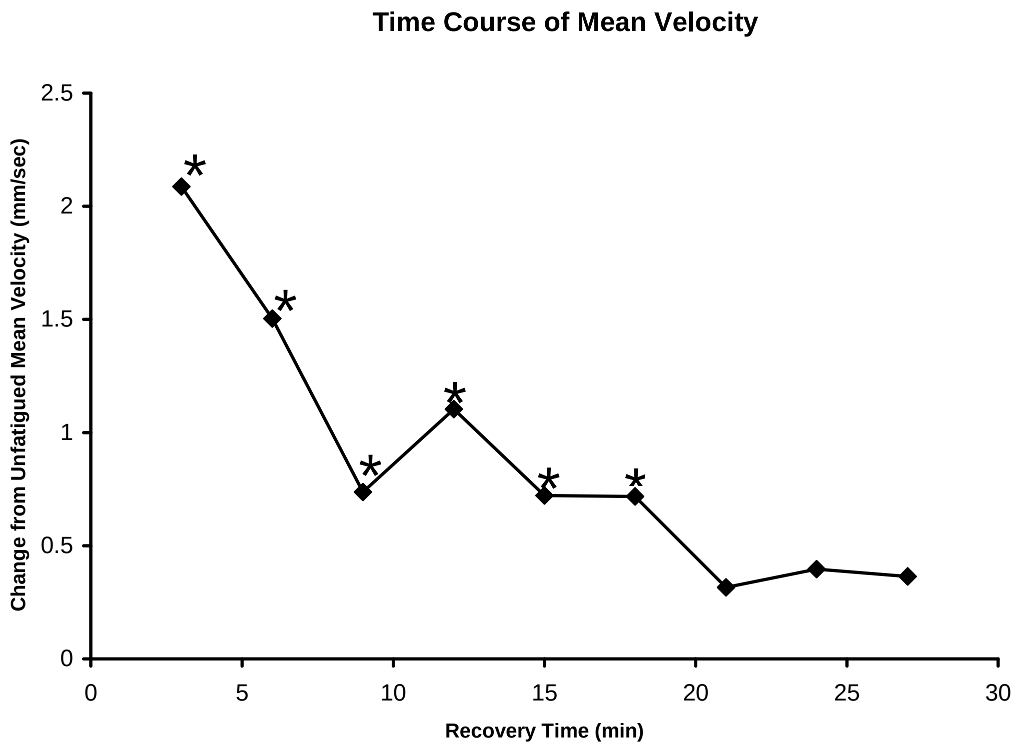

Figure 3.1: Time course of the effect of lumbar extensor fatigue on mean velocity, averaged across all four fatigue conditions. Stars indicate times at which the change in mean velocity is significantly different from zero (p<0.05). Note that recovery occurs between the 18th and 21st minute.

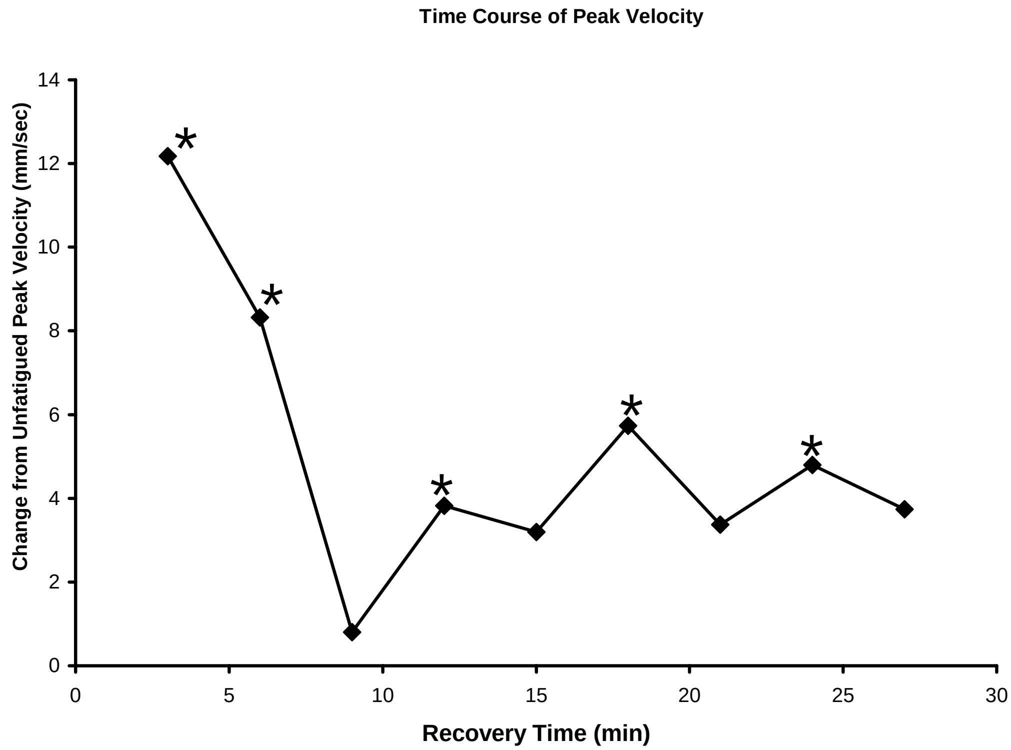

Figure 3.2: Time course of the effect of lumbar extensor fatigue on peak velocity, averaged across all four fatigue conditions. Stars indicate collection numbers at which the change in peak velocity is significantly different from zero ($p<0.05$). Note that there is no clear indication of recovery has occurred.

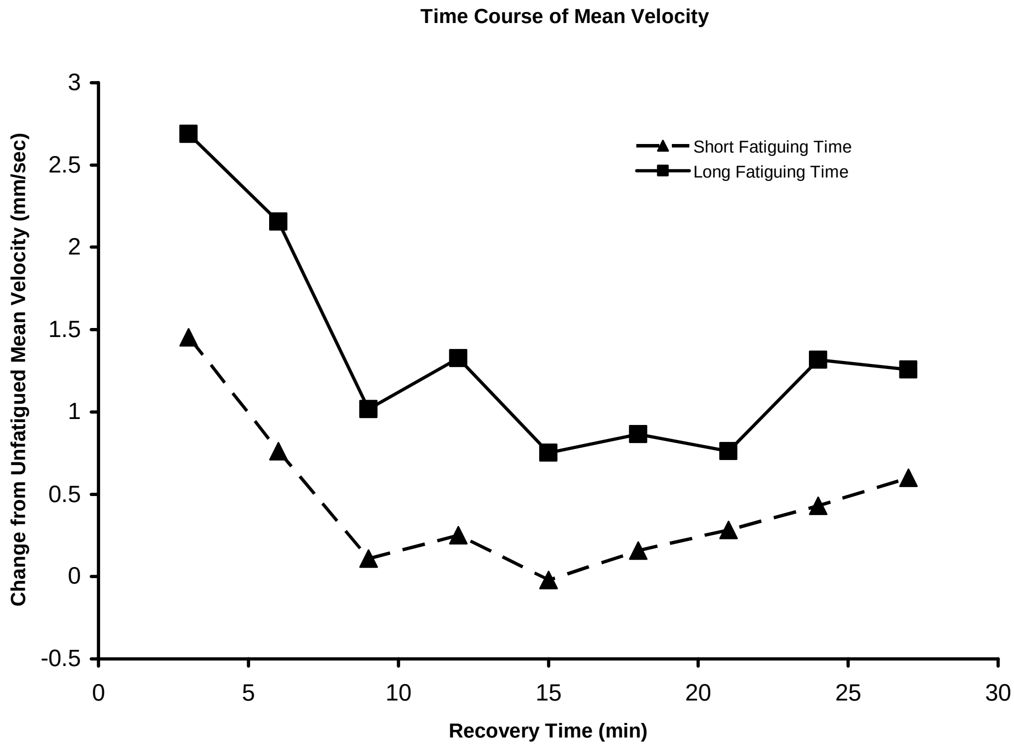

Figure 3.3: Fatiguing time effect on the prolonged effect of lumbar extensor fatigue on mean velocity following fatigue. The long fatiguing time is significantly greater than the short fatiguing time.

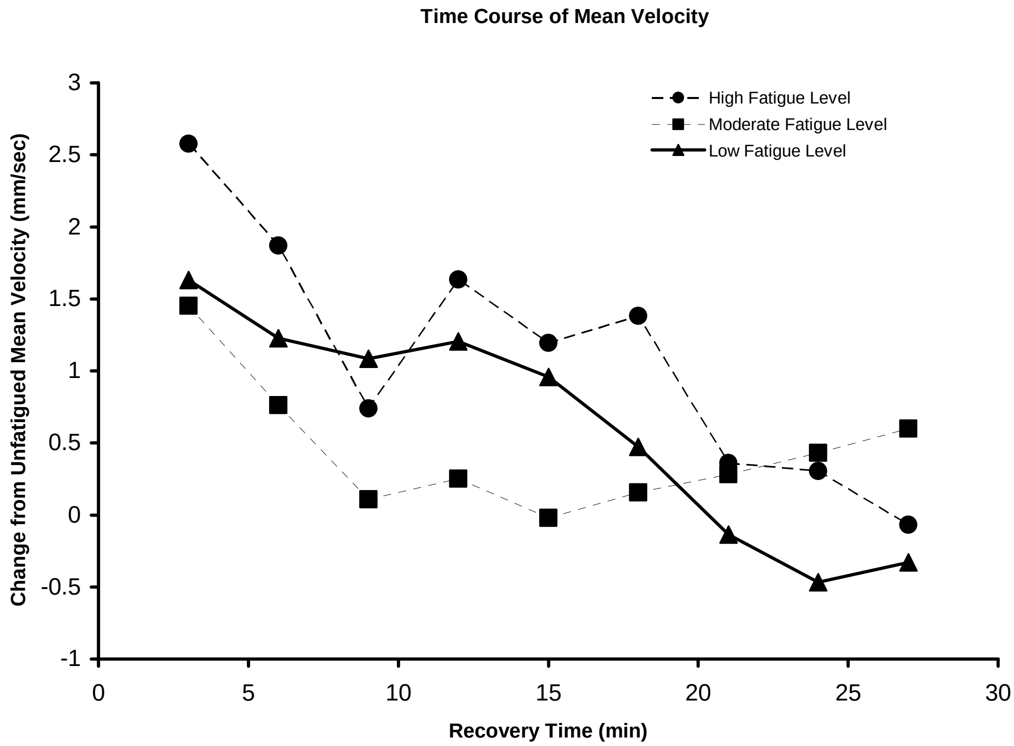

Figure 3.4: Significant fatigue level effect on the prolonged effect of lumbar extensor fatigue on mean velocity following fatigue. The high fatigue level is significantly greater than the moderate fatigue level.

Table 3.1: Results of statistical analysis. Conditions: 1=Low Fatigue Level, 2=Moderate Fatigue Level, Short Fatiguing Time, 3=High Fatigue Level, 4=Moderate Fatigue Level, Long Fatiguing Time

Fatigue Analysis	mean velocity (mm/sec)	peak velocity (mm/sec)	Median Frequency (Hz)
Immediate Fatigue Effect	<0.0001	<0.0001	0.0003
Fatigue Condition Effect	0.325	0.009	0.826
Fatigue Condition Comparisons	-	3>1	-
Recovery Analysis			
Main Time Effect	<0.0001	0.010	0.798
Fatigue Condition Effect	0.003	<0.0001	0.740
Interaction	0.736	0.093	0.999
Fatigue Condition Comparisons	3>2, 4>2	3>1, 3>2, 4>1, 4>2, 4>3	-