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The effects of work experience, lift frequency and exposure duration on low back muscle oxygenation

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Abstract

Background. Previous studies have shown changes in low back muscle oxygenation after static muscle contractions or short-term dynamic lifting exertions. The aim of this study was to document the changes in low back muscle oxygenation during prolonged lifting activity over an entire workday as of function of work experience and lift frequency.

Methods. Four novice and six experienced subjects participated in a lifting study in which they lifted load with a given weight at one of five different frequencies (2, 4, 8, 10, 12 lifts/min) for an 8-h period. Oxygen saturation of the left and right erector spinae was measured continuously and non-invasively using near-infrared spectroscopy during each lifting session.

Findings. Exposure duration had a statistically significant effect on muscle oxygenation level ($P < 0.0001$). Oxygen saturation in the erector spinae increased during the 8-h lifting period. As lift frequency increased, back muscle oxygenation in experienced subjects also increased. In general, the increase in muscle oxygenation for experienced subjects was less than that for novice subjects.

Interpretation. This study suggested that the requirement of oxygen for the low back muscle in a typical industrial lifting job increased over time and experienced workers responded differently from the novice subjects. These findings may provide more insight into the physiological changes of the working muscle and the potential risks of developing muscle injury.

Keywords: Low back pain; Near-infrared spectroscopy; Muscle oxygenation; Work experience; Exposure duration; Lift frequency

1. Introduction

Occupational low back pain is the most common and most costly musculoskeletal disorder in the workplace in the US. Although the etiology of non-specific low back pain remains elusive, one of the possible sources of pain is the back musculature. Localized muscle fatigue during manual materials handling (MMH) activities has been associated with discomfort and increased risk of injury (National Research Council and the Institute of Medicine, 2001). Marras and Granata (1997) suggested that back muscle fatigue after repetitive lifting might result in alternative trunk muscle recruitment strategies and different spinal loading patterns. However, the mechanism of muscle fatigue and pain is still unclear. Previous studies have shown that decreased muscle oxygenation could be one of the causes of muscle fatigue (Hogan et al., 1996; Murthy et al., 2001). Significant differences in back muscle oxygen level were also found between healthy subjects and patients with muscular back pain (Kovacs et al., 2001). These studies indicate that monitoring back muscle oxygenation level could provide more insight into the physiological changes of the working muscle.

Near-infrared spectroscopy (NIRS) is a non-invasive technique that can be used to measure local muscle oxygenation. It is based on the differential absorption of light by hemoglobin (Hb) in small blood vessels, such as arterioles, capillaries and venules and myoglobin (Mb) within the muscle. Two different wavelengths of light are usually used, because at lower wavelength (e.g. 760 nm) deoxygenated

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Hb/Mb absorbs more light, while at higher wavelength (e.g. 850 nm) oxygenated Hb/Mb has a higher absorbency (Rolfe, 2000). The signals from Hb and Mb are indistinguishable with NIRS, but study has shown that the majority of the NIRS signal comes from Hb, while Mb contributes less than 10% (Seiyama et al., 1988). The difference of reflected light signals indicates the change in oxygen saturation of the muscle measured, providing information on the balance between local oxygen delivery and oxygen utilization (McCully and Hamaoka, 2000). Oxygen saturation will decrease if oxygen delivery is less than tissue oxygen consumption, whereas it will increase if oxygen supply exceeds oxygen utilization. NIRS has been successfully used to study the trends in oxygenation of different muscles during various exercise activities, such as cycling, weight-lifting, skating and gripping (Belardinelli et al., 1995; Hamaoka et al., 1996; Rundell et al., 1997; Tamaki et al., 1994).

In recent years NIRS has also been used to study the changes in low back muscle oxygenation. Most studies have evaluated the oxygenation of erector spinae during isometric muscle contractions (Jensen et al., 1999; Kell et al., 2004; McGill et al., 2000; Yoshitake et al., 2001). They have shown that low back muscle oxygenation decreased during static contractions with intensity ranging from 2% to 80% of maximum voluntary contraction (MVC). Decreased muscle oxygenation may be attributable to increased oxygen demand and metabolic rate of the contracting muscle and increased intramuscular pressure, which may restrict oxygen supply via blood flow. However, blood volume measurements showed either increasing or decreasing responses in different studies (Kell et al., 2004; Yoshitake et al., 2001). Few studies have used NIRS technique to monitor back muscle oxygenation changes during dynamic lifting activities. Kell and Bhambhani (2003) found that erector spinae oxygenation decreased during repetitive incremental lifting and lowering at 10 lifts/min until voluntary fatigue. Maronitis et al. (2000) reported increased trend of back muscle NIRS oxygenation while the subjects lifted a 13.6 kg box at a frequency of 12 lifts/min for 60 min. There has been no report of changes in back muscle oxygenation during prolonged period of lifting, for example, in a typical 8-h workday. These studies also chose a relatively higher frequency of lifting. Whether the back muscle oxygenation responds the same at lower lifting frequency is not known. Previous research showed that experienced lifters use their back muscle in a different way from inexperienced workers and they experience different spinal loading (Granata et al., 1999; Keir and MacDonell, 2004). But no study has compared the difference of back muscle oxygenation between these two groups of subjects.

The purposes of the current study were to: (1) investigate the relative changes in low back muscle oxygenation during prolonged lifting activity over an entire workday; (2) examine the effects of lifting frequency and work experience of lifters on muscle oxygen saturation. We hypothesized that at the end of the workday back muscle oxygenation would increase as compared with that in the beginning of the day due to the effect of increased oxygen demand. We also hypothesized that as lifting frequency changes muscle oxygenation may also change and novices and experienced subjects would response differently to the same physical load.

2. Methods

2.1. Subjects

Four inexperienced and six experienced subjects participated in a lifting study. Except for one female subject in the inexperienced group, all other nine subjects were male. Inexperienced lifters were recruited from the university student population. Experienced lifters were recruited from local shipping and distribution centres or grocery stores. They were also required to have at least 1 year of full-time employment in a lifting job. All subjects were screened for health conditions, such as previous low back pain and/or surgeries prior to participation. Presence of any of these conditions made a subject ineligible. All subjects were to be in good health and capable of performing the study. The demographic data of the 10 subjects are presented in Table 1. There was no statistically significant difference between the inexperienced and experienced groups for the demographic data ($P > 0.05$).

2.2. Experimental design

The experiment was a repeated measures design with two between-subjects factors (load at three levels and experience) and one within-subjects factor (lift frequency at five levels). This design resulted in 15 different experimental conditions. Because it would not be possible for one subject to attend all the 15 test sessions, the desired fully randomized block factorial experimental design could not be achieved. Rather, the subjects were randomly assigned to one of the three load levels (either 1.1, 4.9, or 11.7 kg) and all five frequency levels. By doing so, all subjects were tested five times on five separate days for one load level but different lift frequencies. There was a 1-week resting period between each testing session.

The independent variables and their levels were chosen to be representative of those observed in industry. The

Table 1
The demographic data of subjects

Variable	Inexperienced group ($n = 4$)	Experienced group ($n = 6$)
Age (years)	24.8 (4.2)	22.8 (3.4)
Height (cm)	176.3 (7.4)	174.8 (3.5)
Weight (kg)	75.7 (9.9)	76.0 (9.5)
BMI (kg/m^2)[a]	24.3 (1.6)	24.9 (3.4)

[a] BMI: body mass index.