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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.

workplace factors consisted of three load-moment levels and five lift frequency levels. The worker factor was work experience level. The levels of these variables and their relationship to that observed in industry are:

1. Three load-moments, 8, 36, and 85 N m, were chosen to represent the 25th, 50th, and 75th percentiles respectively of load-moments observed in industry (Marras et al., 1993). Subjects were randomly assigned to only one of the three load-moment levels.
2. Five lift frequencies (2, 4, 8, 10, and 12 lifts/min) were chosen to represent the central 90th percentile range of lift frequencies observed in industry (Marras et al., 1993). The order of presentation of the frequency levels was randomized.
3. Two work experience levels, novice (no lifting experience) and experienced (at least 1 year of full-time lifting experience), were chosen to represent the range of novice and experienced manual materials handlers so that the results could be applicable to a wide range of MMH workers.

The duration of the lifting period for the five frequency levels lasted up to 8 h. The end of an experimental session was determined by completion of the 8 h duration or the subject's endurance time, whichever occurred first.

The dependent variable was the oxygen saturation of the left and right erector spinae measured continuously during each lifting session.

2.3. Apparatus

The INVOS® 4100 Cerebral Oximeter (Somanetics Corporation, Troy, MI, USA) was used to measure muscle oxygen saturation. It utilizes two wavelengths of light (730 and 805 nm) generated by LEDs on the sensors to measure the difference of light absorption by the underlying tissue. The INVOS sensor incorporates a light emitter and two detectors, one 30 mm and another 40 mm from the emitter. The system provides non-invasive and continuous information of changes in regional oxygen saturation, indicating the balance of tissue oxygen delivery and consumption. A regional oxygen saturation index (rSO_2) is calculated as the percentage of oxygenated hemoglobin relative to total hemoglobin.

2.4. Experimental procedure

Upon arrival, the experimental procedure was explained and the consent form approved by the university's Institutional Review Board was signed by each subject. The experimental lifting task required one subject to lift a box from a stand in front of him/her and place it on a conveyor located to the right side of the subject. The box was then delivered to another person by the conveyor. The other person performed the same operation with another box and conveyor. In this manner a continuous lifting cycle is created where both persons performed 90° asymmetric lifts simultaneously, paced by a computer-generated tone for each of the five lift frequencies. The lift origin and destination vertical heights were 88 cm and 121 cm, respectively, which represented the 25th and 75th percentile of the database created from the surveillance study of MMH industries (Marras et al., 1993). Load-moment arm distance was 74 cm, which represented the 50th percentile of the database.

A typical workday was simulated in each session, consisting of an 8-h lifting period and typical industrial breaks. The 8 h of lifting were also divided into four time blocks. After the first 1 h and 45 min of lifting (block 1), a 15-min break was given. After another 2 h lifting period (block 2), a 30-min lunch break was taken, followed by another 1 h and 45 min of lifting (block 3), another 15-min break, and another 2-h lifting period (block 4).

Before the lifting task started, the skin over the low back muscle was shaved if necessary to remove hair and degreased with a prep pad containing acetone alcohol. Two self-adhesive NIRS sensors were applied to the subject's skin over the left and right erector spinae at the L3 level. Muscle oxygenation was recorded every 30 s over the lifting period and the sensors were disconnected to the monitor during breaks to allow the subjects to walk around and rest. A resting baseline data point was also collected before the lift started when the subject stood still and relaxed. All data were stored in a computer for further analysis.

2.5. Data analysis

The baseline muscle oxygenation data were used as reference to normalize the data taken for the rest of the day, thus all data were represented as changes relative to the resting level. Statistically significant differences in the left and right erector spinae were evaluated with analysis of variance (ANOVA) implementing the mixed model procedures using SAS software (SAS Institute, Cary, NC, USA). The mixed procedure allowed for fixed effects in addition to random effects. The fixed effects were the effects of frequency, weight, time block, and work experience level. The random effect was the subject effect. Both main effects and the two-way interaction effects of frequency, weight, time block and work experience level were examined for significance. Post hoc estimates were used to identify significant differences of complex interactions at the 0.05 level of significance.

3. Results

For the right erector spinae (RES), the main effects of work experience, frequency, and time block were statistically significant. The only significant interaction effect was experience × frequency. For the left erector spinae (LES), only the main effects of experience and time block were statistically significant. The main and interaction

Table 2
Main and interaction effects and *P*-values for the right and left erector spinae

Main and interaction effects	*P*-values for RES	*P*-values for LES
Weight	0.9369	0.8159
Experience	0.0468[a]	0.0474[a]
Frequency	0.0064[a]	0.1284
Time block	<0.0001[a]	<0.0001[a]
Weight × experience	0.1315	0.2013
Weight × frequency	0.1452	0.5724
Weight × time block	0.1971	0.1435
Experience × frequency	0.0216[a]	0.0813
Experience × time block	0.4981	0.3907
Frequency × time block	0.3614	0.3059

[a] Significant effect at $\alpha = 0.05$.

effects and *P*-values of the statistical results for the left and right erector spinae are listed in Table 2.

For both sides of the erector spinae, work experience had a significant effect on normalized oxygen saturation ($P = 0.0474$ for LES, $P = 0.0468$ for RES) (Fig. 1). In novice subjects, local LES and RES oxygen saturation was 16.7% and 15.1% higher than resting level, respectively. Contrastingly, for experienced subjects, the oxygen saturation only increased 8.8% for the LES and 10.3% for the RES from the baseline.

Lift frequency only had a significant effect on oxygen saturation level of the RES ($P = 0.0064$) (Fig. 2). At the

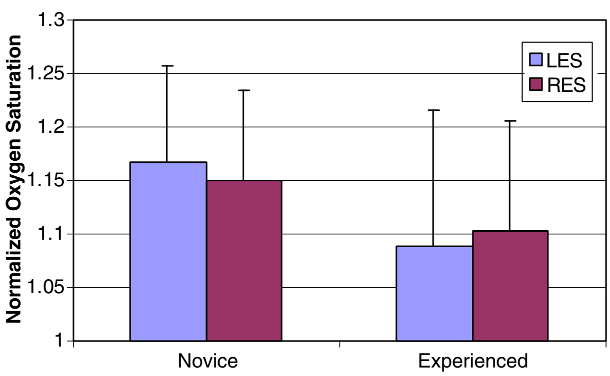

Fig. 1. The effect of work experience on normalized oxygen saturation of the erector spinae.

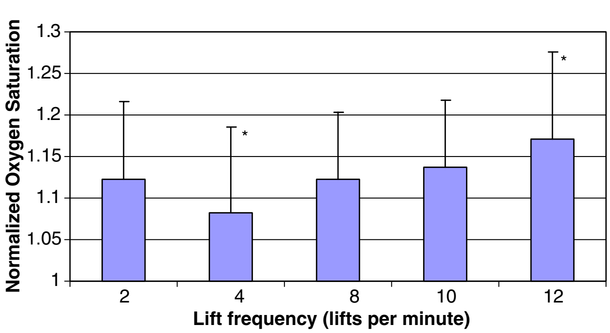

Fig. 2. The effect of lift frequency on normalized oxygen saturation of the RES. * Indicates that the oxygen level was statistically different from those at other lift frequencies ($P < 0.05$).

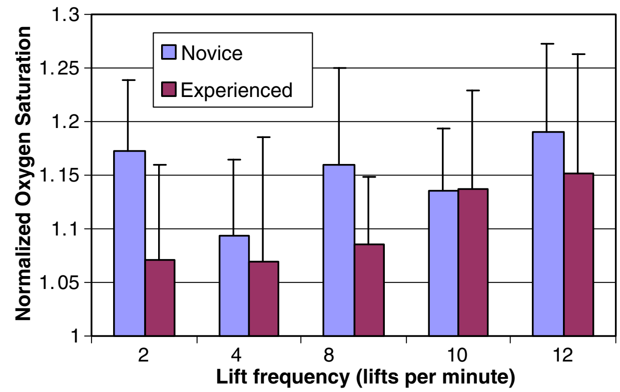

Fig. 3. The interaction effect of work experience and lift frequency on normalized oxygen saturation of the RES.

lowest lift frequency (2 lifts/min), the oxygen level was 12.2% higher than resting level. This level was not statistically different from those for 8 and 10 lifts/min (12.3% and 13.7% higher than resting level, respectively). The lowest oxygen level (8.2% higher than resting level) was seen at 4 lifts/min, whereas the highest RES oxygen saturation (17.1% higher than resting level) was observed at 12 lifts/min. The oxygen levels at these two lift frequencies were both statistically different from those at other lift frequencies ($P < 0.05$). With the exception of 2 lifts/min, there was an increasing trend of oxygen saturation level from 4 to 12 lifts/min.

The interaction effect of work experience and lift frequency was also found to be significant for the RES ($P = 0.0216$) (Fig. 3). For experienced subjects, there was an increasing trend of oxygen saturation from lower lift frequencies to higher frequencies. The oxygen levels for frequencies 10 and 12 lifts/min were significantly higher than those for frequencies 2, 4, and 8 lifts/min ($P < 0.01$). For novice subjects, no clear trend was exhibited between lift frequencies. But the oxygen level for 4 lifts/min was the lowest among all lift frequencies. At lift frequencies 2 and 8 lifts/min, novice subjects had significantly higher increased muscle oxygenation level than experienced subjects ($P = 0.0034$ and $P = 0.0188$, respectively).

Fig. 4 shows the normalized oxygen saturation trends of the LES and RES for a representative subject over an 8-h workday. It can be seen that during the first 2 h of lifts, muscle oxygenation level increased dramatically from the baseline. It dropped slightly after the 15-min break and continued to increase slowly during hours 2–4. The oxygen level decreased significantly after the 30-min break but did not go back to the baseline. It continued to increase during hours 4–6 and the second 15-min break made it slightly drop again. In the last 2 h, it increased to its highest level during the day.

Statistical analyses showed that time had the most significant main effect on the oxygenation level of the erector spinae on both the right and left sides ($P < 0.0001$) (Fig. 5). During the first 2 h (0–2), the average increase in oxygena-

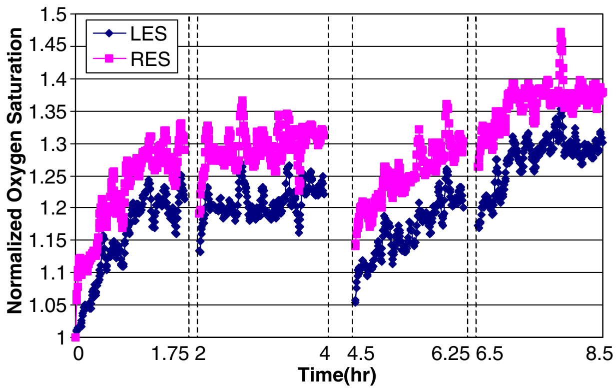

Fig. 4. Normalized oxygen saturation trends of the LES and RES from a representative subject's data (load = 1.1 kg, lift frequency = 8 lifts/min) over an 8-h workday.

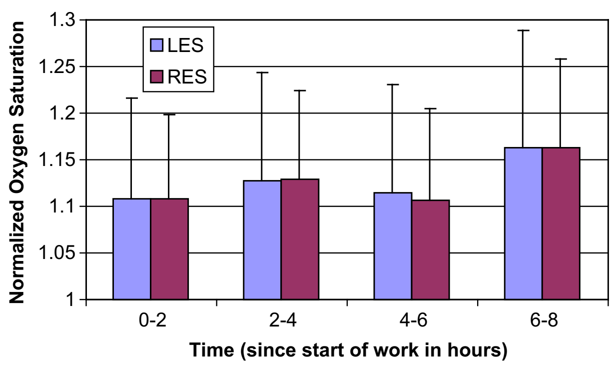

Fig. 5. The effect of time on normalized oxygen saturation of the erector spinae.

tion level was 10.8% for both sides. The oxygenation level increased significantly during hours 2–4 ($P < 0.01$ compared to the first 2 h), averaging a 12.7% and 12.9% increase for the LES and RES, respectively. After a 30-min break, the average increase in oxygenation level during hours 4–6 dropped to 11.4% for the LES ($P = 0.0624$ compared to hours 2–4) and 10.7% for the RES ($P = 0.0018$ compared to hours 2–4), which was not statistically different from that in the first 2 h. During the last 2 h, the oxygenation increased to its highest level, which was 16.2% and 16.4% higher than the resting level for the LES and RES, respectively ($P < 0.0001$ compared to hours 4–6).

4. Discussion

This is the first study to observe low back muscle oxygenation change over an entire typical workday. It shows that oxygen saturation in the erector spinae increased throughout the day during repetitive lifting for both novice and experienced subjects. However, the increase was significantly less in experienced workers. It also shows that lift frequency and work experience had interaction effect on muscle oxygenation level. Experienced workers showed an increasing trend of oxygen saturation as lift frequency increased, which was not shown in novice subjects.

The general trend of oxygen saturation in the erector spinae increased during the 8-h lifting period. This agrees with the study by Maronitis et al. (2000), but differs from the study by Kell and Bhambhani (2003). The discrepancy could be due to the differences in the design of the tasks performed by the subjects. In Kell and Bhambhani (2003) study, subjects lifted and lowered the box from the floor to a waist height table. The box weight or the lift frequency was increased until the subjects reached volitional fatigue. The total test duration was less than 15 min on average. This test protocol is much more stressful to the low back muscle compared with that used in the current study, in which subjects only lifted a certain weight at a constant rate. The purpose of our study was to monitor back muscle oxygenation trend in a typical industrial lifting job setting, not to necessarily create muscle fatigue.

The oxygenation trend is also different from the results of back muscle isometric contraction studies (Jensen et al., 1999; Kell et al., 2004; McGill et al., 2000; Yoshitake et al., 2001). It is believed that the decrease of oxygen saturation in these studies is caused by occluded blood flow to the erector spinae due to increased intramuscular pressure. The static contractions were between 30 s and 2 min, whereas dynamic lifts usually take less than 3 s. The shorter period of contraction and frequent relaxing between each lift may not increase the intramuscular pressure. Vedsted et al. (2006) recently found that intramuscular pressure measured from the biceps brachii was lower during dynamic concentric and eccentric contractions than intermittent static contractions. They suggested that this could facilitate oxygen supply to compensate for the greater energy consumption during dynamic muscle contractions. As opposed to static contractions, dynamic cyclic exertions may also increase the venous return and therefore the arterial blood flow to the muscle via the muscle pump effect.

The overall increase in the erector spinae oxygen saturation is most likely attributed to the increase in blood volume at local muscle tissue. Grassi et al. (1999) reported that during incremental cycling exercise muscle blood volume increased up to 60–65% of VO_2max. In the study by Maronitis et al. (2000), blood volume of the erector spinae also increased during the first 20 min of lifts and then leveled off. Although blood volume was not measured in the present study, it is highly possible that blood volume increased throughout the lifting period to provide more oxygen to the erector spinae as the demands for oxygen increased as a result of prolonged lifting exertions. The demands for oxygen might have reached the peak at the end of the day, as indicated by the highest level of oxygen saturation during hours 6–8 of lifts.

It is noticeable that the 30-min break after the first 4 h of lifts significantly brought down oxygen saturation after the break, which made the average oxygenation during hours 4–6 similar to hours 0–2 (Fig. 5). On the other hand, the two 15-min breaks after hours 0–2 and 4–6 were not as effective as the 30-min break to help the muscle recover from the high oxygen saturation status. Recently, Courville et al. (2005) showed that longer rest at 1:1 and 1:2 load-to-rest ratio reduced the development of cumulative low back disorders after their feline model was exposed to static loads. Although our study involved dynamic exertions, it is also indicative that longer rest period is beneficial to the muscles, allowing them to settle down to physiological baseline. It is possible that with shorter rest and continued work, the muscle cannot recover and at some point will not be able to keep pace with the increased oxygen demand. Due to the rigid experimental protocol, the breaks were not extended to observe the recovery time after each lifting session. It is also not possible to tell the recovery time at the end of the experiment, because muscle oxygen saturation was not measured after 8 h of lifts.

The overall increase in oxygen saturation for experienced subjects was lower than that for novice subjects. This is expected because the same workload may represent lower oxygen demand for experienced subjects than for novices. Experienced subjects may have developed more efficient motor strategy to use less oxygen for certain type of work, or their back muscles are more adapted to the lifting task. Recently, Costes et al. (2001) found that endurance training could decrease blood lactate and change muscle oxygen saturation during mild- to hard-intensity exercise, and NIRS could be used to monitor the training-induced adaptations. It is possible that in experienced subjects there is less accumulation of blood lactate as well as other vasodilators, such as H^+, K^+, or nitric oxide. Thus, the increase in blood flow in their back muscles is less than that in novice subjects, resulting in lower muscle oxygenation. However, we could not directly measure the usage of oxygen and blood flow in the current study. The fact that the difference between experienced subjects and novices was only marginally significant could be due to the small sample size. Future study measuring muscle oxygen consumption and blood flow with larger sample size will further elucidate the mechanism.

The effects of frequency and experience × frequency interaction were only significant for the RES. This might be related to the asymmetry of the lifting task, in which the subjects always lifted the load and turned to the right side. The increasing trend of oxygen saturation in experienced subjects from low to high lift frequencies might be explained by the fact that at higher frequencies the working muscle has a higher demand for oxygen and this demand could be met by increasing blood flow to the muscle, thus providing more oxygen for the production of adenosine triphosphate (ATP), which supplies large amounts of energy for muscle contraction. The reason why in novice subjects there was no distinct pattern of oxygenation trend over lift frequencies is not clear. It could be due to the smaller number of subjects in this group, or the muscles in the novices are less adapted to the lifting task, resulting in disproportionately high oxygen saturation even at low lift frequency, such as 2 lifts/min.

Maronitis et al. (2000) found poor correlation between local muscle oxygenation, whole body oxygen uptake, and heart rate, indicating that whole body physiological measures do not necessarily reflect changes at a localized level. As there is a delay between the systemic response and the muscle site, workers may increase energy expenditure or oxygen consumption well after the point where there is risk to the local tissue. Therefore, it is important to monitor oxygen saturation at the tissue level if one is to gain more direct information to assess the risk of injury to the low back associated with prolonged repetitive work. The findings in the current study suggest that the requirement of oxygen for the working back muscle in a typical industrial lifting job increases over time and reaches the peak at the end of a workday. As time goes on, even though the subjects lift the same load, their physiological response is different from the beginning of the day. This may impose potential risk of muscle injury on industrial workers if they are not capable of meeting the high oxygen demand. It is possible because the current study only tested weight up to 11.7 kg. Industrial workers may need to lift heavier weights or at a higher frequency, which can push their ability to the limit where they cannot satisfy the increased oxygen need of the working muscle, especially at the end of the workday. The study also suggests that the current work schedule for breaks is not effective enough to let the muscle rest and recover. Further study is needed to determine the recovery time after each lifting session to develop a more effective break schedule. Moreover, novice lifters may have a higher risk of developing muscle injury because they seem to use their back muscle less efficiently than experienced lifters. Higher muscle oxygenation level in novices even at low frequencies indicates that they are less adapted to the work and more prone to injury.

There were several limitations to the study. Firstly, we have a relatively small sample size, especially in the novice subjects group. This has limited our experimental power to compare the difference between the two work experience groups as well as test three- or four-way interactions between the independent variables. Secondly, blood volume and oxygen recovery data were not available. These information could help us understand the mechanism of oxygenation increase. Future study with larger sample size and blood volume measurement is needed to further explore the mechanism of changes in back muscle oxygenation during prolonged repetitive lifting.

5. Conclusions

This study shows that during prolonged repetitive lifting the erector spinae muscle oxygenation increased over an entire 8-h workday for both novice and experienced subjects. However, the increase was significantly less in experienced workers. Experienced workers also showed an increasing trend of oxygen saturation as lift frequency increased, which was not shown in novice subjects. These findings suggest that novices and workers at the end of the workday could be at a higher risk of muscle injury and better break schedule should be developed to mediate the risk.

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