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Impact of loading and work rest intervals on muscle micro-trauma

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A R T I C L E I N F O

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A B S T R A C T

Purpose: To examine whether rest intervals of different durations ("High Rest, Low Frequency" v. "Low Rest, High Frequency"), and load at different force exertion levels with different repetition frequencies ("High Load, Low Repetition" v. "Low Load, High Repetition") have an impact on muscle micro-trauma, as such micro-trauma over repetitive loading and long-term muscle overuse can lead to musculoskeletal disorders (MSDs).
Method: Twenty-four adult males (mean age: 24.1 years; 3.6 SD) were randomly assigned to one of 4 bicep muscle eccentric exercise treatment groups ($n = 6$; "High Load, Low Repetition; High Rest, Low Frequency", "High Load, Low Repetition; Low Rest, High Frequency", "Low Load, High Repetition; High Rest, Low Frequency", or "Low Load, High Repetition; Low Rest, High Frequency") with non-dominant arm to induce muscle micro-trauma reactions in serum. Subjects in all treatment groups had equivalent total work volume, total rest duration and total work duration for comparison of muscle micro-trauma between and within the treatment groups. Muscle micro-trauma biomarker serum Creatine Kinase (CK) level was measured pre-exercise (Day 0) and post-exercise on Days 1, 2, 4, and 8. ANOVA with repeated measures was used to examine significance of rest and load-repetition combination over pre and post experiment days, as well as possible interactions.
Result: CK levels fluctuated significantly across different "Day" ($P = 0.0115$). Interaction was disordinal and significant between "Day" and "Rest" ($P = 0.0000$), and "Load" and "Rest" ($P = 0.0322$). Under "High Load, Low Repetition" condition, CK levels on Day 4 were significantly higher than on Days 0 and 2; CK levels on Day 8 were significantly higher than Day 0. CK level peaked on Day 4. Under "Low Rest" Condition, CK level on Days 4 and 8 are significantly higher than Day 0.
Conclusion: Shorter but more frequent rest intervals led to more extreme muscle micro-traumatic responses than the longer but less frequent ones, especially under "High Load, Low Repetition" condition when non-dominant bicep brachii was subscribed with eccentric exercise regimen.
Relevance to industry: The exploration of how rest scheduling affects progression of microtrauma from a biomechanical and molecular level in this study furthers current understanding of the early stage development of WMSDs. With future studies' further research and confirmation, the findings of this study may be able to serve as a first attempt to guide shift scheduling and job design at manufacturing facilities.

1. Introduction

The US Department of Labor defines work-related Musculoskeletal Disorders (WMSDs) as musculoskeletal system and connective tissue diseases and disorders, involving overexertion, repetitive motion and vibration that lead to living tissue sprains, strains, tears, as well as pain, swelling, and numbness. MSDs represent one of the leading causes of lost workdays in industry and are associated with major economic costs. Occupational Safety and Health Administration (OSHA) estimated that "work-related MSDs in the United States account for over 600,000 injuries and illnesses and 34 percent of all lost workdays reported to the Bureau of Labor Statistics (BLS, 2016). These disorders now account for one out of every three dollars spent on workers' compensation. It is estimated that employers spend as much as 20 billion dollars a year (U.S.) on direct costs for MSD-related workers' compensation, and up to five times that much for indirect costs, such as those associated with hiring and training replacement workers" (OSHA, 2014). In

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addition, MSDs require long recovery time and pose significant challenges to affected worker's personal lives (American Academy of Orthopaedic Surgeons, 2008, 2009).

Several known MSD risks include high force demands, high repetition rates, the interaction between the two, awkward postures, and long durations (Bernard, 1997; Hoogendoorn et al., 1999; Gallagher and Heberger, 2013). Several well advocated treatment approaches include thermotherapy (usage of ice or heat at the site of pain) (Wyss and Patel, 2013), manual therapy (Bove et al., 2016), medications and dietary supplements such as protease enzyme that modulates the inflammatory response. Existing preventative measures include stretching and warm-up programs (Choi and Woletz, 2010). However, the efficacy of these therapeutic and preventative approaches has not been convincingly validated (Choi and Woletz, 2010Manufacturers; Wyss and Patel, 2013). It would also be costly to implement such program in a manufacturing facility. Compared to post hoc remedies, designing jobs with MSD prevention in mind would be an effective and affordable alternative (Smith and Gallagher, 2016).

The MSD development process starts with tissue micro-traumas occurring as a consequence of performing repetitive and/or forceful tasks, leading to local and maybe systemic inflammation, followed by structural tissue damage and eventually MSDs (Barbe and Barr, 2006). This study examined the beginning stage of MSD development – muscle micro-trauma, aiming to prove hypotheses that rest interval plays a significant role in MSD prevention and development, in addition to the known risk factors. Previous studies have demonstrated subjects assigned with longer rest intervals (3 min) between eccentric exercise work periods were able to perform a significant larger total work volume than the ones assigned with shorter rest intervals (1 min). Quantitative marker for skeletal muscle micro-trauma, Creatine Kinase (CK) level was significantly more elevated 48-h and 72-h post-experiment in the longer rest interval group than the shorter rest interval groups (Machado and Willardson, 2010; Evangelista et al., 2011). Such results indicated that rest intervals played a significant role in muscle strength endurance in eccentric exercise. Different durations of rest intervals could also lead to different levels muscle micro-trauma, although not all subjects compared in these previous studies performed equal amount of workload. To provide common ground for comparisons of different subjects' muscle micro-trauma, the authors of this study set up the experiment so all subjects share the same total work volume (equal number of multiples of their maximum voluntary isometric contraction of the non-dominant biceps, which are explained in the Method section), total work time and total rest time. If proven a significant contributor in MSD development, though requiring confirmation and extensive further research, the finding may serve as an initial evidence that select rest intervals could be implemented at manufacturing jobs to serve as an affordable MSD preventive measure without impeding the production rate or having to recruit additional employees.

2. Method

2.1. Subjects

After acquiring approval from Auburn University Institutional Review Board (IRB), 24 healthy men between the ages of 19 and 50 (mean: 24.1 years; standard deviation: 3.61 years) were recruited to participate in this study. Male subjects were selected because 70.1% of current 15,338 manufacturing workers are men (Bureau of Labor Statistics, 2014). In addition, significantly higher CK levels were reported in men than women despite their racial diversities (Wong et al., 1983). The age limit was decided based upon a previous study, which concluded that the healthy elderly (64–84 years) demonstrated a significant CK decline compared to its younger counterpart (24–47 years) (Steinhagen-Thiessen and Hilz, 1976).

Subjects submitted written confirmation for not using medical drugs, dietary supplements, or anabolic steroids, and being free of joint, muscular or cardiovascular diseases within the prior 6 months or during the week of the experiment (Evangelista et al., 2011). Subjects had also confirmed to have not performed eccentric, concentric, isometric or other forms of weight training six months prior to the experiment. Participants agreed not to perform weight training or strenuous physical activities during the week of and a week after the experiment, as significant increases of CK occurred after exercise are usually lower in healthy trained subjects compared to healthy untrained subjects (Brancaccio et al., 2007).

Qualified subjects of the above criteria filled out a medical screening form to ensure that no pain or discomfort was present in the non-dominant limb. Two levels of load-repetition combination regimens were studied: "High Load, Low Repetition" v "Low Load, High Repetition" (abbreviated as "High Load" v "Low Load" from here on); two levels of rest schedules were studied: "High Rest, Low Frequency" v "Low Rest, High Frequency" (abbreviated as "High Rest" v "Low Rest" from here on). Subjects were then randomly assigned to one of the four treatment combinations using a random number generator: "High Load; High Rest" (HLHR; n = 6), "High Load; Low Rest" (HLLR; n = 6), "Low Load; High Rest" (LLHR; n = 6), or "Low Load; Low Rest" (LLLR; n = 6) (Table 1). All 24 subjects completed the experiment. Subjects were compensated for their participation.

2.2. Eccentric exercise

Eccentric exercise was selected because it provided a basis for examining the impact of load-repetition combination and rest frequency on muscle tissue fiber damage and micro-trauma (Prasartwuth et al., 2005; Liao et al., 2010; Komi and Buskirk, 1972). The symptoms of such micro-trauma include muscle soreness and tenderness, known as delayed-onset muscle soreness (DOMS) (Schwane et al., 1983; Ebbeling and Clarkson, 1989; Jones et al., 1989; Clarkson et al., 1992; Cleak and Eston, 1992).

Table 1
Treatment combinations.

Treatment (a)	Treatment (b)	Treatment (c)	Treatment (d)
High Load; High Rest	Low Load; High Rest	High Load; Low Rest	Low Load; Low Rest
5 min, 90% MIVC, 2 rep/min	5 min, 22.5% MIVC, 8 rep/min	3 min, 90% MIVC, 2 rep/min	3 min, 22.5% MIVC, 8 rep/min
2 min Rest	2 min Rest	1min Rest	1min Rest
5 min, 90% MIVC,2 rep/min	5 min, 22.5% MIVC,8 rep/min	3 min, 90% MIVC,2 rep/min	3 min, 22.5% MIVC,8 rep/min
2 min Rest	2 min Rest	1min Rest	1min Rest
5 min, 90% MIVC, 2 rep/min	5 min, 22.5% MIVC, 8 rep/min	3 min, 90% MIVC,2 rep/min	3 min, 22.5% MIVC,8 rep/min
		1min Rest	1min Rest
		3 min, 90% MIVC,2 rep/min	3 min, 22.5% MIVC,8 rep/min
		1min Rest	1min Rest
		3 min, 90% MIVC,2 rep/min	3 min, 22.5% MIVC,8 rep/min

Although DOMS can be healed within weeks upon sufficient rest, its process and symptoms resemble the beginning stage of MSDs. As the micro-trauma prolongs and worsens, MSD will start to develop over time (Komi and Buskirk, 1972; Clarkson and Tremblay, 1988; Newham et al., 1985; Newham, 1988; Whitehead et al., 1998).

Each subject's maximum voluntary isometric contractions (MVICs), peak force produced by a muscle or muscle group, of the non-dominant elbow flexors were measured before the actual experiment to establish eccentric contraction exertions for different individuals. Each MVIC measurement was separated by a rest period of 2 min (Caldwell et al., 1974). The greatest MVIC of the three was used to determine the eccentric load levels for each and every subject.

After MVIC measurement, each subject performed eccentric exercise with the elbow flexors of the non-dominant arm on a Biodex dynamometer (Fig. 1) to induce micro-traumatic reactions in the non-dominant arm's biceps. The non-dominant arm was chosen to ensure that the subject's daily personal tasks were not affected in case of DOMS.

The exercise period was 19 min, including 4 min of rest and 15 min of work. “High Load” was determined at 90% subject's bicep MVIC to induce CK contrast to the “Low Load” condition. “Low Load” was selected at 22.5% bicep MVIC (Barr and Barbe, 2002). “High Repetition” was set at 8 reps/min. “Low Repetition” was set at 2 reps/min. The “High/Low Load, Low/High Repetition” was considered a combined treatment factor as the “High Load, Low Repetition” and “Low Load, High Repetition” conditions share an equal total work volume per minute: 1.8 MVIC/min, providing ground for comparison to muscle micro-traumatic reaction under different rest schedules. In order to yield statistically distinctive and meaningful results, “High Rest” interval was set to be 2 min between 5-min work intervals in reference to past relevant experiments. “Low Rest” interval was set to be 1 min between 3-min work intervals (Evangelista et al., 2011). A timeline diagram was created to demonstrate the experiment plan for the “High Rest” and “Low Rest” groups (Fig. 2). Total work volume for each subject was 27 times his bicep MVIC. The total rest time for each subject was 4 min. Each subject practiced the timing of contractions with the non-dominant arm prior to the experiment.

During a repetition, the subjects began with their non-dominant arm flexed 90° at the elbow and ended with the elbow fully extended (Fig. 1), resisting the dynamometer handle bar from descending in an arc with a radius of subject's forearm length and a focus at his elbow. Each extension took 2 s. The experimenter monitored the subject's muscle activity on the Biodex Machine monitor and provide verbal feedback to encourage the subject to

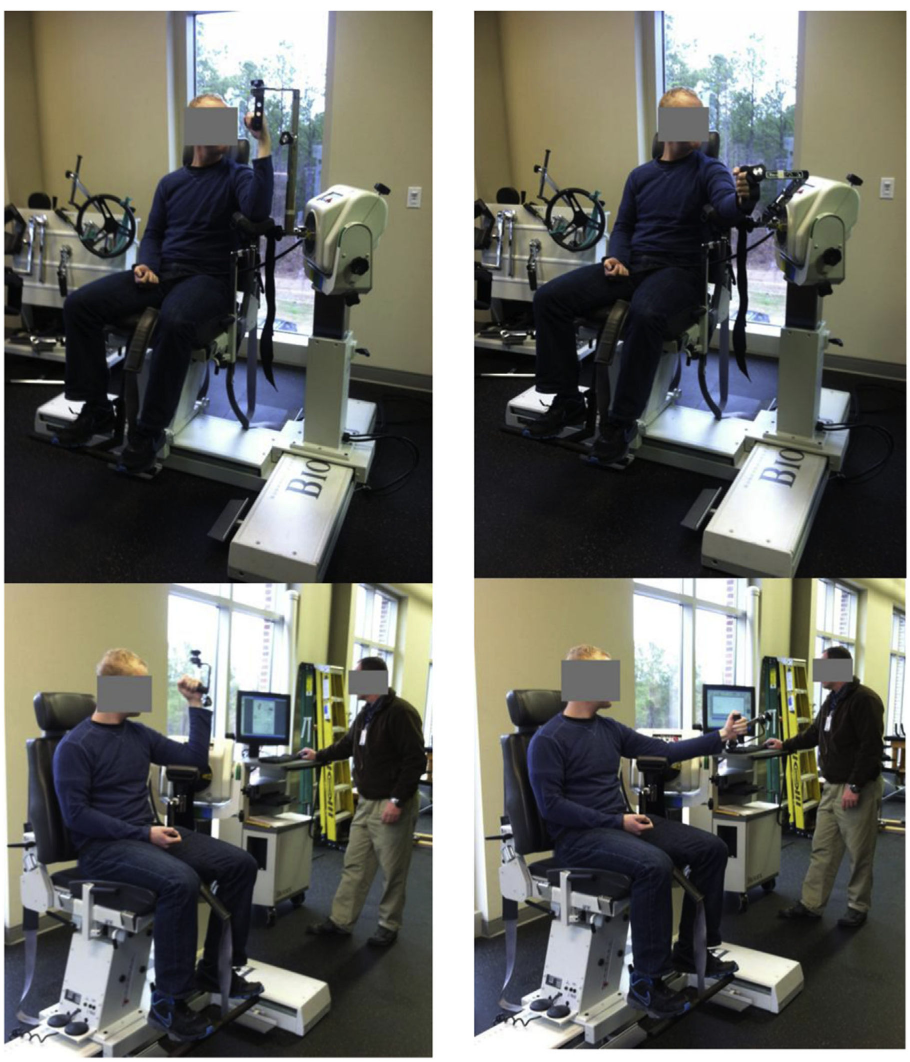


Fig. 1. Eccentric exercise. Left: Flexed posture; right: Extended posture.

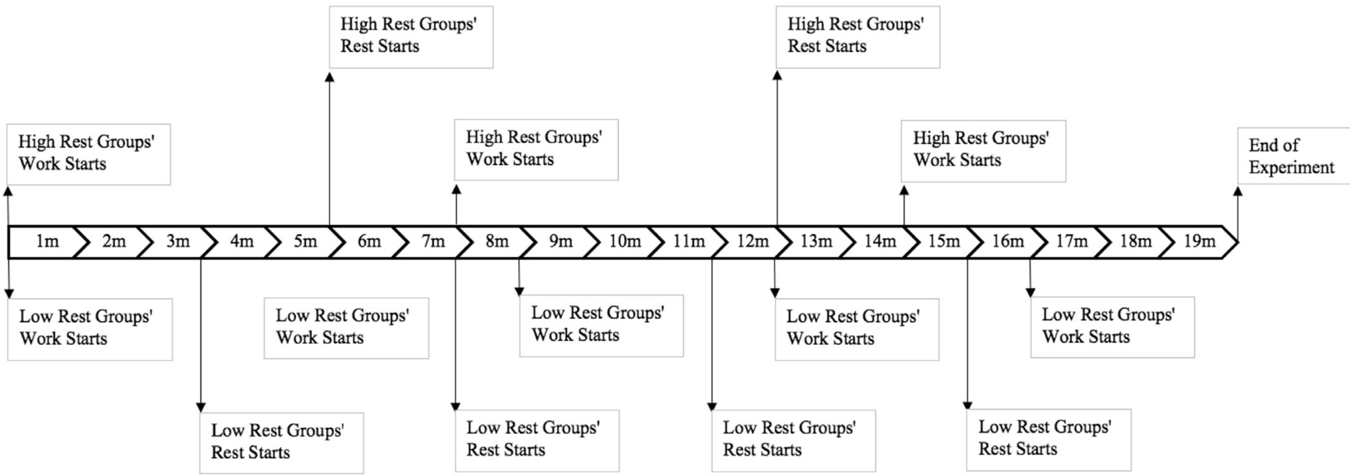


Fig. 2. Time diagram of "high rest" and "low rest" groups' experiment plan.

exert and to maintain the assigned percentage of MVIC during the repetition. The dynamometer automatically returned the bar back to the starting position after each repetition, getting ready for the next. Subjects were given permission to terminate the exercise at any point of the exercise if discomfort arose.

2.3. Serum creatine kinase sample collection and analysis

Serum CK activity has been extensively studied and considered a quantitative biomarker for skeletal muscle micro-trauma (Machado and Willardson, 2010; Evangelista et al., 2011). Serum CK measurement is an important aid in the diagnosis of skeletal disorders (Wong et al., 1983). It has been reported that post-exercise CK elevates in the following 24 and 48 h, peaks at 96 h and decreases between days 4 and 10 (Brancaccio et al., 2007). Therefore, CK was selected as a quantitative biomarker for muscle-trauma in this study and was measured pre-exercise and post-exercise at days 0, 1, 2, 4 and 8.

Five-milligram samples of blood were obtained from the subject's non-dominant arm's antecubital vein while they were in a seated position. Samples were collected immediately prior to exercise (day 0) as baseline, then post-exercise on days 1, 2, 4 and 8 (Chiang et al., 1998; Evangelista et al., 2011; Evangelista et al., 2011, 2011). The blood samples were then sent to the Laboratory Services at East Alabama Medical Center (Opelika, AL) on the same day as the samples were collected for CK measurements. CK levels pre- and post-exercise were recorded for comparison within and between different treatment groups.

2.4. Statistical analysis

The number of replicates for each treatment combination was determined with the assistance of the operating characteristic curve for this two-factor factorial design (Montgomery, 2012). Previous studies that used CK as muscle micro-trauma indicator were referenced to decide population standard deviation: 500 $U \cdot L^{-1}$ (Chiang et al., 1998; Evangelista et al., 2011). The desirable power for this study was decided to be 0.70. The number of replicates to achieve a power of 0.70 would be 5 replicates per treatment combination. This study used 6 replicates per treatment combination due to budget permission. With 6 replicates per treatment combination, statistical power was boosted to close to 1.00.

Statistical analysis of the change and trending of serum CK level over time were conducted to examine the significance of loading-repetition combination, and rest. A double natural logarithmic transformation (Ln(Ln(Original Data))) was conducted on the original CK records due to the non-normal characteristic of the original data's residuals. Residuals of the transformed data demonstrated normal pattern (Shapiro-Wilk test: $P = 0.1460$). Two-way repeated measures ANOVA and Tukey pair-wise comparisons were conducted via Statistix 8.0 to examine significance of different rest and loading patterns, as well as possible interactions between the two over time. The Type I error rate was set at 0.05 for ANOVA tests and also for *post hoc* tests. Tables and figures are generated using GraphPad Prism 7.

3. Results

Table 2 summarizes average observed CK levels and standard deviations by treatment group by day. HLLR group's average CK level climbed up on Day 1 and 2, compared to Day 0, peaked on Day 4, then sharply declined on Day 8, although CK on Day 8 still was higher than Day 0, 1, and 2's values. HLHR group's average CK level

Table 2
CK daily average and standard deviation within each treatment group with original data.

Treatment Group	Day 0 CK Average	Day 0 CK Stdev	Day 1 CK Average	Day 1 CK Stdev	Day 2 CK Average	Day 2 CK Stdev	Day 4 CK Average	Day 4 CK Stdev	Day 8 CK Average	Day 8 CK Stdev
(a) High Load; High Rest	174.67	155.35	163.00	132.92	155.83	133.30	682.67	1200.47	536.50	1026.35
(b) High Load; Low Rest	90.50	37.13	119.83	37.59	234.00	197.96	931.50	1278.06	470.00	496.71
(c) Low Load; High Rest	195.50	193.00	149.50	119.20	106.17	59.77	107.50	60.81	107.67	65.35
(d) Low Load; Low Rest	99.83	44.81	115.83	81.66	107.50	48.03	96.00	33.45	117.00	53.25

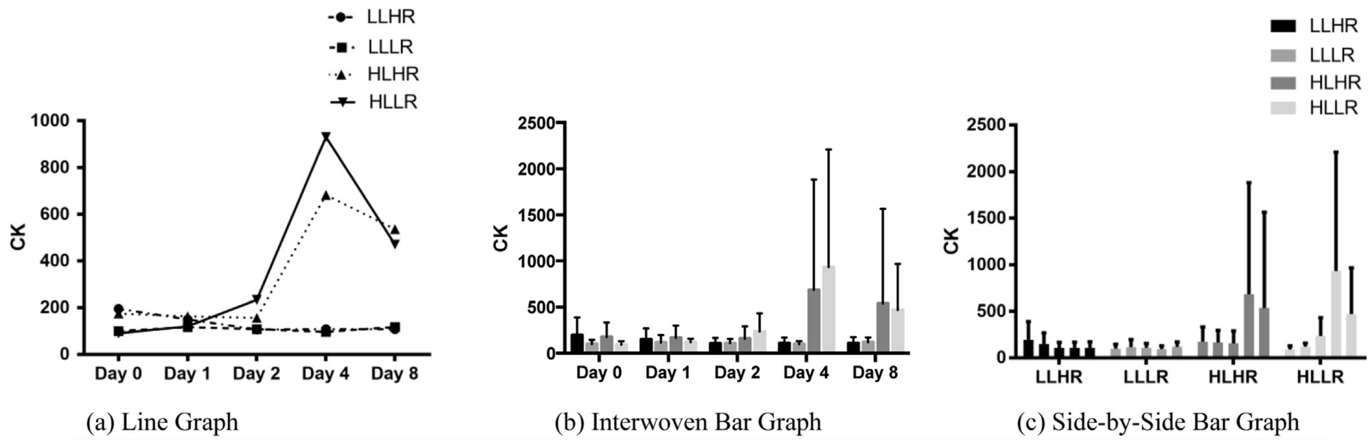


Fig. 3. Original CK levels in U·L-1 by treatment group by day; HLLR: High Load, Low Repetition, Low Rest; HLHR: High Load, Low Repetition, high Rest; LLLR: Low Load, High Repetition, High Rest; LLLR: Low Load, High Repetition, Low Rest; LLHR: Low Load, High Repetition, High Rest.

Table 3
CK daily average and standard deviation within each treatment group with transformed data.

Treatment Group	Day 0 CK Average	Day 0 CK Stdev	Day 1 CK Average	Day 1 CK Stdev	Day 2 CK Average	Day 2 CK Stdev	Day 4 CK Average	Day 4 CK Stdev	Day 8 CK Average	Day 8 CK Stdev
(a) High Load; High Rest	1.59	0.15	1.58	0.64	1.57	0.13	1.69	0.23	1.64	0.21
(b) High Load; Low Rest	1.49	0.08	1.55	0.33	1.63	0.17	1.73	0.28	1.70	0.23
(c) Low Load; High Rest	1.58	0.17	1.56	0.63	1.52	0.09	1.51	0.11	1.51	0.10
(d) Low Load; Low Rest	1.51	0.08	1.52	0.52	1.53	0.08	1.51	0.07	1.54	0.08

experienced a slight decline on Day 1 and 2, compared to Day 0, drastically increased to a peak value, then declined to a level that was still higher than Day 0, 1, and 2's values. HLLR group's peak value on Day 4 is higher than HLHR's, while HLLR's CK on Day 8 dropped to slightly lower than HLHR's. LLHR and LLLR's CK levels stayed at or below 200 $U \cdot L^{-1}$. CK level even dropped slightly over the post-exercise days in LLHR group (Fig. 3a). Standard deviation of CK remained low in all treatment groups from on Day 0, 1, and 2 ranging between 37 $U \cdot L^{-1}$ and 198 $U \cdot L^{-1}$, but increased to above 1000 $U \cdot L^{-1}$ on Day 4 and 8, particularly in the "High Load, Low Repetition" groups (Table 2, Fig. 3b and c).

Table 3 summarizes transformed CK averages and standard deviations by treatment group by day. Graphic illustrations are shown in Fig. 4. Table 4 presents the results of two-way ANOVA with repeated measures based on the transformed data. "Day" was a significant factor ($P = 0.0115$), which confirms a previous study's findings that post-exercise CK fluctuates significantly, peaking in the following 96 h and declining between Days 4 and 10 (Brancaccio et al., 2007). Significant disordinal interaction was discovered between load-repetition combination and "Day" (Table 4, $P = 0.0000$; Fig. 5a) with respect to CK expression (Kirk, 1995). Tukey pairwise comparisons of CK levels on different days were conducted for load-repetition-combination by Day. Results showed that for the "High Load, Low Repetition" groups, CK level on

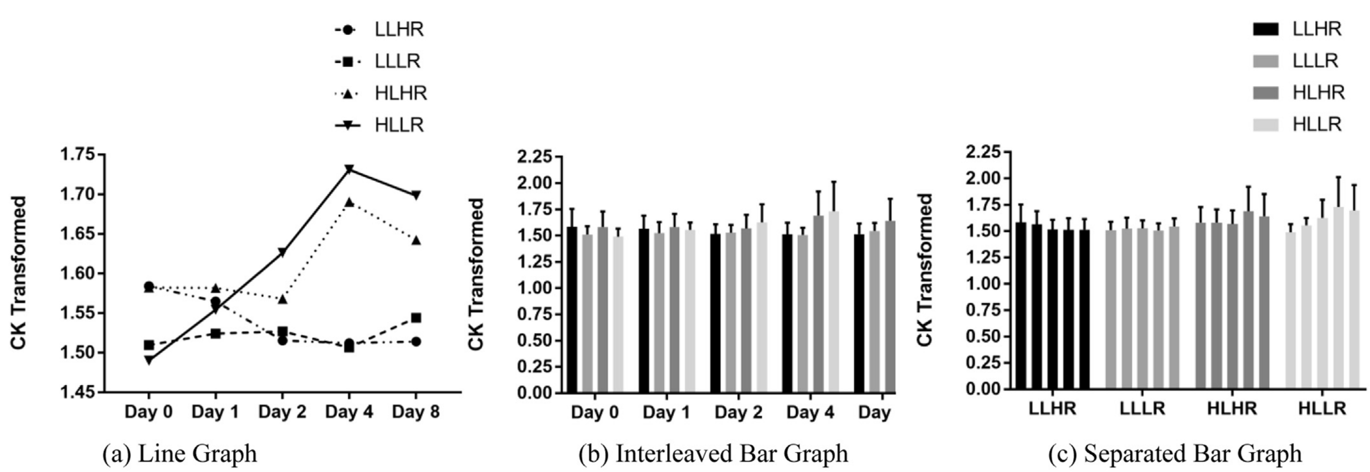


Fig. 4. Transformed CK levels in $U \cdot L^{-1}$ by treatment group by day.

Table 4
Two-way ANOVA with repeated measures on days 0, 1, 2, 4 and 8.

SV	SS	df	MS	F	P
Between Blocks	1.9268	23	0.0838		
Load	0.2230	1	0.2230	2.62	0.1209
Rest	0.0006	1	0.0006	0.01	0.9343
Load * Rest	0.0039	1	0.0039	0.05	0.8325
Error (Between Blocks)	1.6993	20	0.0850		
Within Blocks	0.8244	96	0.0086		
Day	0.0849	4	0.0212	3.47	0.0115
Load * Day	0.1776	4	0.0444	7.26	0.0000
Rest * Day	0.0681	4	0.0170	2.78	0.0322
Load * Rest * Day	0.0043	4	0.0011	0.17	0.9513
Error (Within Blocks)	0.4895	80	0.0061		

Day 4 was significantly different than the ones on Day 0 and 2; CK level on Day 8 was significantly different than Day 0. Fig. 5a demonstrated disordinal interaction between load-repetition-combination and Day.

Statistically significant interaction between Rest and Day were shown in Table 4 (P = 0.0322). Tukey pairwise comparisons of CK levels on Rest by Day was conducted. Results indicated that CK levels on days 4 and 8 are significantly higher than Day 0 under "Low Rest" conditions. Disordinal interaction between Rest and Days was observed from Fig. 6a.

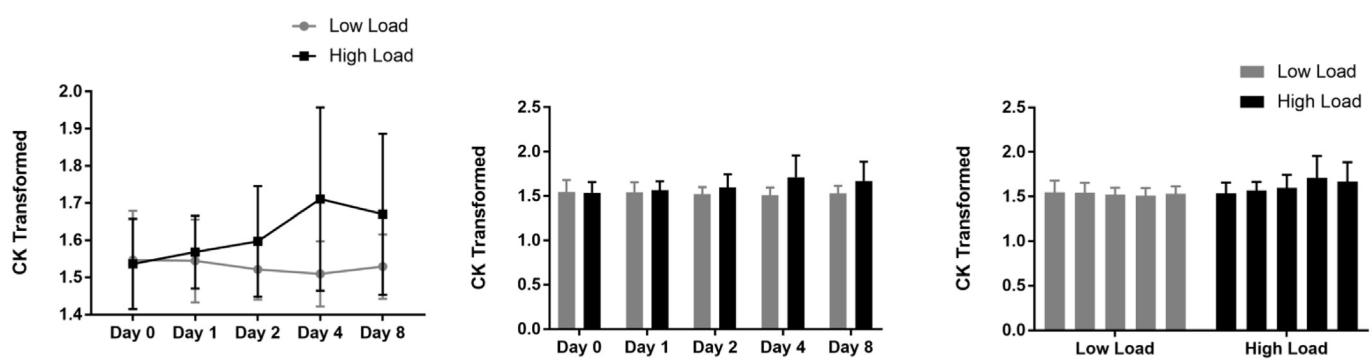
The results of the study indicated that shorter but more frequent rest intervals ("Low Rest") led to greater CK response, indicating greater muscle micro-trauma and MSD risk, than the longer but less frequent ones ("High Rest"), when subjects' non-dominant biceps underwent eccentric exercise and were given equal total work time, total rest time and total work volume, especially when loading level was high ("High Load, Low Repetition"). CK level remained relatively low and steady when load level was low ("Low Load, High Repetition") and rest level was high ("High Rest").

4. Discussion

Statistical significance of "Day", and the disordinal interaction between "Load" and "Day", and "Rest" and "Day" respectively suggest muscle micro-traumatic reaction fluctuates and peaks significantly, especially when load level is high ("High Load, Low Repetition") and rest level is low ("Low Rest"). Had subjects continued to work at the same exertion level and was not given sufficient time to recover, the micro-trauma could accumulate and compound, leading to fatigue, further tissue wear and tear, and possibly eventually MSDs (Finsterer, 2012).

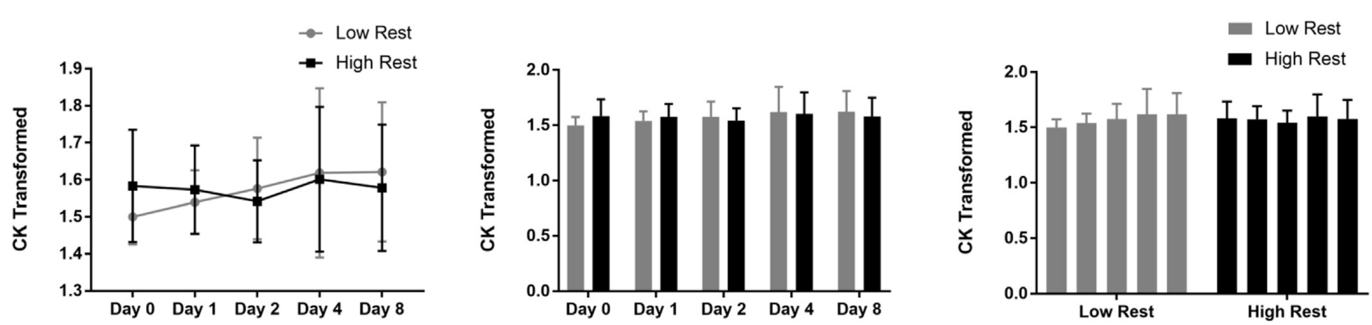
CK on Day 4 of the "High Load, Low Repetition" regimen saw a significant increase (Fig. 4a), compared to measurements on Day 0 and 2. Day 8's measurement was also significantly different from Day 0. However, CK level remained low in the "Low Load" condition throughout the 5 measured days, and even experienced a small drop on Day 4. At low loading level, the muscle was not micro-traumatized, but instead could have been exercised to a greater strength. Ck continued to increase over the 5 observation days under "Low Rest" condition, leading to a significant difference between Day 4 and Day 0, and Day 8 and Day 0 respectively (Fig. 6a). Under "High Rest" condition, however, CK mildly fluctuated and its measurements did not display statistically significant difference. Such observation may indicate that duration and frequency of the rest intervals indeed have an impact on muscle micro-trauma development and healing. Shorter but more frequent rest breaks may be more injury conducive than longer but less frequent ones.

According to previous research, if load is not significant enough



(a) Line Graph (b) Interleaved Bar Graph (c) Separated Bar Graph

Fig. 5. CK levels in U·L-1 by day at "High" and "Low" Load Levels.



(a) Line Graph (b) Interleaved Bar Graph (c) Separated Bar Graph

Fig. 6. CK levels in U·L-1 by day at "High" and "Low" Rest Interval Levels.

to cause acute and severe damage, sufficient rest and recovery will repair damaged tissue with fibers almost identical in nature to those damaged, making them more resistant to subsequent eccentric damage. This eccentric training effect has been shown in both human (Komi and Buskirk, 1972; Newham et al., 1985; Newham, 1988; Clarkson and Tremblay, 1988) and animal (Faulkner et al., 1992, 1993) studies. Therefore, the authors suspect that the “Low Load, High Repetition” condition stimulated CK reaction in the first couple days but, given days to recover, the damaged tissues had been remedied to a stronger state.

Such indications coincide with the Fatigue Failure Theory, which advocates for more repetitions and lower loads to tackle a set total volume, as lower loading per repetition can withstand much greater number of cycles to tissue failure compared to higher loading per repetition (Nash, 1966). Further explorations of how and why the “Low Load” conditions yield statistically non-significant muscle micro-traumatic responses could provide guidance to job allocation at manufacturing plants in regards to MSD prevention.

Significance of “Rest” and “Day” interaction confirmed the authors' hypothesis that the healing and recovery that occurred during the rest intervals have an impact on muscle micro-trauma development. The healing rate, as the fatigue failure theory had suggested, may not follow a linear pattern but could be exponential over time, as the CK levels demonstrated significant difference post-exercise when subjects were given different rest schedules despite the total rest time being equal. Such results might also be explained by considering cyclic loading material failure using the mean stress concept commonly used in materials science and mechanical engineering (Gallagher and Schall, 2016). Mean stress is the time average of principal stress; principal stress is force exerted per unit area. In this study, mean stress for the “High Rest” groups are 1.285 MVIC per unit area over a work-rest cycle (5-min work followed by 2-min rest); mean stress for the “Low Rest” groups are 1.35 MVIC per unit area over a work-cycle (3-min work followed by 1-min rest), greater than the “High Rest” groups' mean stress. Mean stress is an important factor with respect to the rate of damage accrual in material's fatigue failure (Stephens et al., 2001). The greater the mean stress on tissues during a loading cycle (assuming an equivalent stress range), the faster damage would accrue. The higher mean stress of the “Low Rest” group might be able to explain the continuous increase of CK levels and the significant differences between Days 0, 2 and 4, and Days 0 and 8 (Fig. 6a). A previous study discovered that CK response of eccentric exercise was not as sensitive among trained weightlifters who had a minimum of three years weightlifting experience compared to the untrained weightlifters had not participated in eccentric exercise for the past three years. This previous study also found trained subjects developing severe muscle soreness without displaying matching degree of CK activities compared to the untrained individuals (Vincent and Vincent, 1997). The current study selected subjects who had not been involved in any form of weight training for the previous 6 months due to the above-mentioned reasons, as well as budget restrictions.

Many factors such as ethnicity, muscle mass, and body size could be determinants of CK levels in addition to the age and gender effects that are limited and ruled out in this study respectively. Although all subjects read and signed the agreement of not conducting any form of training and strenuous physical activities immediately 6 months prior, during and after the experiment, it was impossible for the authors to ensure and confirm that the requirement was fulfilled by all subjects, which would leave a possibility for the data to be unknowingly influenced.

Individual MVIC differences existed. However, the authors decided to use the set percentages of the individual MVICs to represent the “High Load” and “Low Load” conditions as the study was aiming to compare the bicep muscles' micro-traumatic status when similar capacities of the muscles, though from different subjects, were engaged. A set high load for one with a lower bicep MVIC might be too high yet not high enough for one with a higher bicep MVIC.

There are several limitations of this pilot study. The experiment subject were mostly Auburn University students, who do not perform repetitive and strenuous job tasks on a regular basis. Therefore, characters and conditions of manual material handling workers that may be influential to development of muscle micro-trauma or MSDs, such as work history or injury history relevant to WMSDs, were not captured. Different tissue types, including bones, fibrous tissues, and muscles from different parts of the body, follow similar but different mechanisms of injury and recovery in response to repetitive loading (Buckwalter and Grodzinsky, 1999). These different tissues may react to different work-rest regimens (e.g. of different duration or exertion level) differently.

In the future, different tissue types and durations of rest intervals could be used, and subjects from a real manufacturing setting could be considered to be recruited in order to associate experiment results more accurately to industrial and human performance applications. Future studies could also recruit subjects that carry more homogenous traits such as age, gender, BMI, ethnicity, sleep patterns, diet habits, smoking preferences and occupation, since such individual variability could influence study results (Wong et al., 1982), or to design studies to specifically compare and contrast subject groups that carry two or more distinct traits. Animal studies could be a promising direction to experiment as well because of the much more controlled experiment scenarios. Animal subjects such as mice or rats, could be trained to exercise over a long period time in order to observe long-term effects (Barbe and Barr, 2006). The homogeneity of the animal subjects will also rule out the above-mentioned individual differences, as well as the possible high responders, which could be a contributor of CK high variances on Days 4 and 8 especially for the “High Load, Low Repetition” condition (Machado and Willardson, 2010). In addition, future studies could look into more types of different loading and work rest patterns. Researchers could also expand the difference between high and low levels of MVIC, as well as the length of high and low levels of rest intervals to explore possible significant impacts.

5. Conclusion

To the authors' knowledge, this was the first time for rest interval to be taken into consideration when assessing human tissue micro-trauma (via CK) *in vivo* with different loading and rest regimens, when total work volume, work time and rest time were predetermined. Although load and rest alone did not manifest as significant risk factors in this study, the interaction of load and day, as well as rest and day had significant contribution to muscle micro-trauma, and MSDs if insufficient rest was not adopted after the initial micro-trauma but forceful and repetitive exertions prolong.

Longer though less frequent rest breaks are more trauma suppressive than shorter but more frequent rest breaks, when total rest time is limited. The authors recommend to break a large workload to smaller ones, even though it may require more repetitions to complete if possible, as lower load exerted with more repetitions that sum up to the same total work volume as higher load exerted over fewer repetitions help keep the mean muscle micro-trauma response low throughout the post exertion days, although more extensive future studies on trauma development and its recovery course of different exercise and rest period and/or of different parts of the body is required.

The findings of this study add to the growing body of knowledge of human body's biochemical responses to eccentric muscle exertions at different load-repetition levels, and when given different rest breaks. Relevance of these research findings are applicable, but are not limited to, understanding of early stages of musculoskeletal injury development and recovery, design and scheduling of manufacturing jobs if future studies expand the research scope to various tissue types and different work-rest regimens and confirm the findings of this study, as well as development of ergonomic assessment tools that incorporate rest intervals to better diagnose musculoskeletal injury risk in the occupational setting.

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