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# Rotation During Lifting Tasks: Effects of Rotation Frequency and Task Order on Localized Muscle Fatigue and Performance

Leanna M. Horton, Maury A. Nussbaum, and Michael J. Agnew

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*Though widely considered to reduce the risk of work-related musculoskeletal disorders, there is limited evidence suggesting that rotating between tasks is effective in doing so. The purpose of the current study was to quantify the effects of rotation and parameters of rotation (frequency and task order) on muscle fatigue and performance. This was done using a simulated lifting task, with rotation between two levels of loading of the same muscle groups. Twelve participants completed six experimental sessions during which repetitive box lifting was performed for one hour either with or without rotation. When rotation was present, it occurred every 15 minutes or every 30 minutes and was between two load levels (box weights). Rotation reduced fatigue and cardiovascular demand compared to the heavier load without rotation, with a mean reduction of ~33% in perceived discomfort and a ~17% reduction in percentage of heart rate reserve. Further, rotation increased fatigue and cardiovascular demand compared to the lighter load without rotation, with a mean increase of ~34% perceived discomfort and a ~19% increase in percentage of heart rate reserve. Neither rotation frequency nor task order had definitive effects, though maximum discomfort ratings were nearly 20% higher when starting with the lighter load task. These parameters of rotation should be further evaluated under more realistic task conditions.*

**Keywords** job rotation, manual material handling, muscle fatigue, performance

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## INTRODUCTION

Work-related musculoskeletal disorders (WMSDs), particularly those involving the back and upper extremities, are a considerable problem in the workplace. In 2010, the back and shoulder were frequently injured body parts, respectively accounting for roughly 45% and 15% of all WMSD cases in the United States.<sup>(1)</sup> Repetitive lifting is a risk factor for

lower back disorders,<sup>(2)</sup> and over half of the WMSD cases may result from lifting.<sup>(3)</sup> Costs associated with occupational injuries have been estimated at up to \$150 billion in the United States,<sup>(4)</sup> and of these, overexertion and repetitive motion-type cases account for ~30%.<sup>(5)</sup>

Rotation (aka “job rotation” or “task rotation”) is a common administrative control, in which workers rotate between a set of different tasks and with an underlying assumption that its use will reduce WMSD risk.<sup>(6)</sup> Limited evidence, however, supports this assumption. Previous investigations of job rotation have primarily focused on outcomes related to physical demands (e.g., kinematic and kinetic exposures) and physical exposure variation (e.g., temporal variability of physical demands), but with inconsistent outcomes. Decreases in physical demands have been found in few studies of implementation in occupational environments<sup>(7–9)</sup> and in a laboratory.<sup>(10)</sup> It has also been argued that increasing physical exposure variation can be beneficial because while one muscle is loaded, another muscle (or motor unit) can rest<sup>(11,12)</sup>; increased variability in muscle activity has been observed with rotation.<sup>(13)</sup> In contrast, however, several studies of rotation in occupational environments found increases in physical demands<sup>(14)</sup> and no changes in physical exposure variation<sup>(15,16)</sup> or WMSD rates.<sup>(17)</sup>

Contrasting effects of rotation could be ascribed to the tasks included in a rotation schedule. For example, tasks with high physical demands can, when included in a rotation schedule, expose more workers to the peak exposures associated with these tasks<sup>(14,18,19)</sup> and can increase the probability of workers reporting low back pain.<sup>(14,20)</sup> In one study<sup>(19)</sup> rotating between truck driving and refuse collecting reduced physical demands for workers who previously did only refuse collecting, but an opposite effect was observed for workers who had previously only performed truck driving. A recommended approach to reduce WMSD risk is to include tasks with different physical exposures within rotation schedules.<sup>(21)</sup> However, this approach may be challenging in practice, since many occupational tasks involve similar physical exposures.<sup>(15–17,22)</sup> For example, Keir et al.<sup>(22)</sup> found that the upper erector spinae and

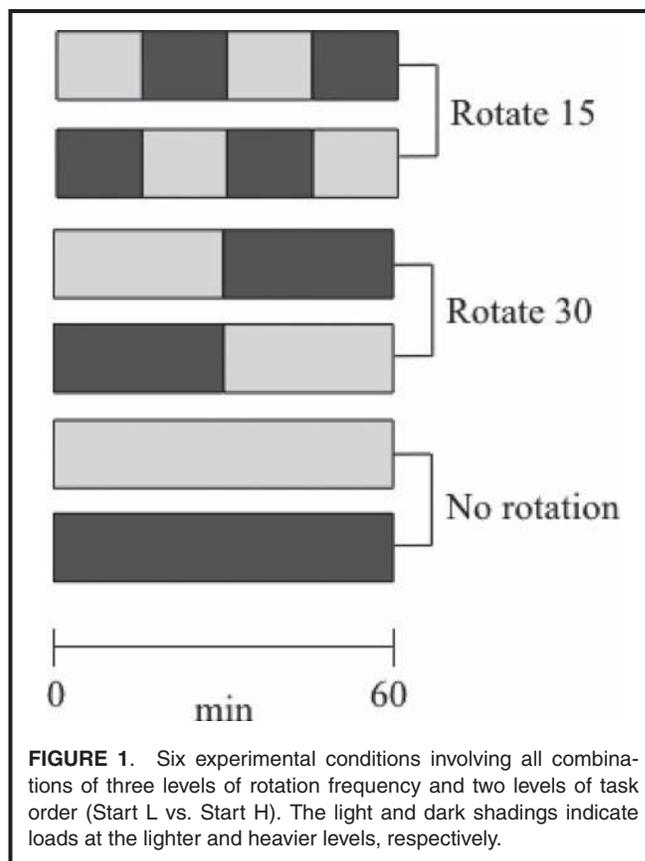
forearm musculature did not benefit from rotating between gripping and lifting tasks. This emphasizes the need to assess the effects of rotation when the included tasks have limited exposure variation.

How frequently workers rotate may influence the effectiveness of a rotation program. Workers on manufacturing assembly lines often rotate every two hours,<sup>(6,16,17)</sup> though this may be mainly out of convenience (e.g., rotating at rest breaks).<sup>(6)</sup> A few studies have analyzed rotation frequency, and found that rotating every 1–2 hours is beneficial.<sup>(23–25)</sup> In our earlier work,<sup>(26)</sup> however, we analyzed the effect of rotation frequency during static shoulder abduction tasks with two exertion levels and found no benefit of increased rotation frequency (in terms of reducing muscle fatigue). A method for assessing sequential lifting tasks has been proposed,<sup>(27)</sup> the sequential lifting index (SLI). In this, more frequent task rotation is assumed to reduce WMSD risk since greater risk values are generated for longer-duration tasks.<sup>(28)</sup>

Task order, or the sequence in which tasks are performed, may also be influential, though existing results are inconsistent. Raina and Dickerson<sup>(10)</sup> examined rotating between repetitive shoulder flexion and abduction tasks, and found that subjective ratings of exertion were higher when starting with the more demanding task (shoulder abduction). Our earlier work<sup>(26)</sup> found comparable effects of task order during shoulder abduction, in which discomfort ratings were higher when starting with a high-exertion task. In contrast, no effect of task order when rotating between gripping and lifting tasks has been reported,<sup>(22)</sup> and the noted SLI assumes no effects of task order.<sup>(27)</sup> Task order has been considered, however, when implementing rotation in the workplace,<sup>(18,29)</sup> such as not allowing sequential tasks with high exposures, and order effects have been found in exercise research.<sup>(30,31)</sup>

Another important consideration when designing rotation schedules is the effect of rotation and inherent parameters on task performance, particularly given its importance related to quality and productivity. Though rotation is thought to improve employee skill level,<sup>(6)</sup> some evidence suggests that it can have a detrimental effect on task performance.<sup>(32–34)</sup> As such, the effect of rotation on task performance needs more thorough evaluation.

The aim of the current study was to further assess the effects of rotation frequency and task order, and whether these effects might be influenced by gender. Earlier, we analyzed these effects during static shoulder abduction tasks<sup>(26)</sup> and during a simulated assembly task,<sup>(35)</sup> and in the current study do so for a repetitive box lifting task. Compared to the former upper extremity tasks, box lifting was used to represent more dynamic demands and to involve more and larger muscle groups. A controlled laboratory study was used to isolate the effects of rotation frequency and task order when included tasks loaded the same muscle groups, and simulated simplified working conditions using a box lifting/lowering task that differed in magnitude of the load handled. Outcome measures focused on localized muscle fatigue, due to its potential importance as a WMSD risk factor<sup>(36–41)</sup>; cardiovascular demand, to reflect



**FIGURE 1.** Six experimental conditions involving all combinations of three levels of rotation frequency and two levels of task order (Start L vs. Start H). The light and dark shadings indicate loads at the lighter and heavier levels, respectively.

physical work load; and task performance, given its practical relevance. Specific purposes of this study were to: 1) determine if rotation is effective in reducing muscle fatigue when the included tasks load the same muscle(s), 2) evaluate the effects of rotation on task performance, and 3) identify the specific effects of rotation frequency and task order on fatigue and performance. It was hypothesized that rotating more frequently would reduce fatigue but have adverse effects on performance, and that starting with a lighter load would be less fatiguing and have higher performance versus starting with a heavier load.

## METHODS

### Participants

A convenience sample of 12 volunteers (gender balanced) completed the study. Mean (SD) age, stature, body mass, and BMI for males were 21.3 (1.5) years, 1.82 (0.06) m, 79.3 (3.8) kg, and 23.9 (1.4) kg/m<sup>2</sup>, respectively, and for females were 22.5 (2.3) years, 1.66 (0.07) m, 57.5 (4.3) kg, and 21.0 (2.0) kg/m<sup>2</sup>. All reported being right-hand dominant and physically active, and having no recent history of musculoskeletal injury. Participants completed an informed consent procedure approved by the Virginia Tech Institutional Review Board.

### Experimental Design

Participants completed each of six experimental conditions (Figure 1). In each, participants performed repetitive box lifting/lowering over a 60-min work period. Independent variables



**FIGURE 2.** Top: postures used for torso reference contractions and MVCs (top left) and arm reference contractions (top right). Bottom: start/end postures used for the lifting task.

were three levels of *rotation frequency* and two levels of *task order*. Rotation frequencies included no rotation, rotating every 30 min (Rotate 30), and rotating every 15 min (Rotate 15). Two exertion levels were achieved with two loads, each based on participant body weight (BW): Lighter (10% BW) and Heavier (20% BW). Mean (SD) lighter and heavier loads lifted were 7.9 (0.4) kg and 15.9 (0.8) kg for males, and 5.8 (0.4) kg and 11.5 (0.9) kg for females, respectively. These levels were intended to represent low to moderate levels of occupational task demands and were pilot tested to confirm the load levels were high enough to induce perceived fatigue and low enough that a 60-min work period could be completed. The current task demands, though, may be higher than for a typical 8-hour work shift in practice. Rotation occurred between these two loads, and two task orders were evaluated: Lighter to Heavier, and Heavier to Lighter (hereafter denoted Start L and Start

H, respectively). Participants completed a practice session followed by six experimental sessions. All sessions occurred on separate days, with at least two full days between each to minimize carryover effects (e.g., due to residual fatigue). During each experimental session, participants completed one of the six experimental conditions. The order of exposure to conditions was counterbalanced using one  $6 \times 6$  balanced Latin square for each gender.

### Procedures and Data Collection

During the preliminary session, and following warm-up exercises, static maximum voluntary contractions (MVCs) in torso extension were completed using a standardized lifting posture (Figure 2: top left). Warm-up exercises included torso extension and shoulder flexion exercises with and without a hand-held weight (amount of weight depended on



**FIGURE 3.** Illustration of correct box placement. Participants were asked to place the pointer (on front face of box) against the backboard such that the pointer lined up with the middle of two vertical lines and the box was parallel to the backboard.

participant strength); all participants completed the same number of warm-up exercises. In each MVC trial, participants grasped a handle and pulled upward with a maximal effort against a chain attached to the floor and were given non-threatening verbal encouragement. A uniaxial load cell (Interface, Inc., Model SM-500, Scottsdale, AZ) mounted in series with the chain was used to measure exertion forces. The chain length was adjusted to ensure torso flexion of 45 degrees with arms perpendicular to the floor, and participants were asked to maintain a straight back, preserving lumbar lordosis, and to stand with their feet at hip width. Participants were observed to ensure that they maintained lumbar lordosis, and all wore tight-fitting clothing to help with visual inspection of spine posture. Force data from the load-cell were sampled at 1024 Hz and low-pass filtered using a 3 Hz cutoff (Butterworth filter, 2nd order, bidirectional). At least three MVCs were performed, with 2 minutes of rest between each, until peak forces were non-increasing; the largest force output was recorded as the participant's MVC. Subsequently, participants completed 10 minutes of practice of the box-lifting task (5 minutes with each box weight).

During each experimental session, participants performed 20-minutes of warm-up exercise and additional practice; practice lifts were performed at both lighter and heavier load levels separated by rest. After resting briefly, participants performed three baseline reference contractions in each of two postures (Figure 2: top). The first posture isolated the lower back muscles, and was performed in the same posture as the MVCs. This posture involved a 10-sec sustained static contraction equivalent to 15% BW (mid-way between the Lighter and Heavier load levels); mean (SD) forces representing 15% BW were 116.6 (5.5) N for males and 84.6 (6.3) N for females. Participants pulled on the chain to match a target force value and were given continuous visual feedback of their current and target force. The second posture isolated the arm muscles, and involved a 10-sec sustained posture holding a box weighted

at 15% BW (midway between the Lighter and Heavier load levels), with the shoulders flexed 20 degrees from vertical; mean (SD) loads representing 15% BW were 11.9 (0.6) kg for males and 8.6 (0.6) kg for females. Participants stood upright with their feet at hip width, elbows straight, and looking forward during these exertions. Postures for the reference contractions were intended to represent the middle of the task range of motion, in which the torso flexed from 0 (standing upright) to 90 degrees (torso parallel to floor), and the shoulder moved from 0 to 40 degrees forward flexion.

The experimental tasks involved repetitive box handling at 12 lifts/lowers per minute over a 60-minute work period, with pace controlled using metronome. The box was lifted to a table set at mid-thigh height (Figure 2; bottom) using handles 34.3 cm from the floor. During each lift/lower, participants kept their knees straight (i.e., stoop lift) and foot placement was controlled (at shoulder width apart). Weights inside the box were hidden by a false bottom, and over the 60-minute work period the load changed (or did not) as determined by the treatment condition (Figure 1). Between each lift/lower, participants returned to neutral standing (standing upright, looking forward). Participants were instructed to place the box such that a pointer (physical marker) attached to the middle of the front of the box was aligned as closely as possible with the center of two lines on the backboard of the table, and that the box was aligned parallel to the face of the backboard (Figure 3). The box placement task was designed to assess gross motor control, a common component of many occupational tasks.

One reference contraction in each of the two postures was completed every 15 minutes during the work period. Unilateral (right side) electromyographic (EMG) activity was collected continuously during these contractions from the anterior deltoid, middle deltoid, biceps brachii, trapezius, and two erector spinae locations (L1 and L3 levels). EMGs were obtained using pre-gelled Ag/AgCl electrodes placed 2 cm apart on the belly of the muscle.<sup>(42)</sup> Raw EMGs were pre-amplified

(Measurement Systems Inc., Ann Arbor, MI—), hardware band-pass filtered (10–500 Hz), and sampled at 1024 Hz. Ratings of perceived discomfort (RPD) were collected every 5 min during the work period (a total of 12 ratings were collected during the 60-min work period), from the right shoulder and upper arm, and the upper and lower back, using a modified CR-10 scale.<sup>(43)</sup> The scale ranged from 0 (no discomfort) to 10 (extremely strong, almost maximal discomfort) and was visible continuously. Cardiovascular demand was monitored continuously during the work period using a Polar heart rate monitor (Model RS800, Polar USA, Lake Success, NY) and collected as inter-beat (RR) intervals. Task performance was monitored using a seven-camera motion capture system (Vicon MX, Vicon Motion Systems Inc., Denver, CO) to track (at 60 Hz) markers placed on the box and backboard.

### Data Processing and Dependent Measures

EMG-based measures of fatigue were obtained from a 6-sec window in each 10-sec reference contraction; the first three seconds and last second were removed to reduce transition effects. Three fatigue measures were obtained from the EMG data (normalized to the baseline reference contractions), then means determined across the 6-sec windows. *EMG amplitude (AEMG)* was obtained after full-wave rectification, low-pass filtering (Butterworth, 3 Hz cut-off, 4th-order, bidirectional), and correction of the EMG signal for resting amplitudes. *EMG mean power frequency (MnPF)* was determined using a Fast Fourier Transform of the EMG signal at each 1-second interval with a 50% overlapping Hamming window. The *Dimitrov Spectral Index (DSI)* was calculated from the raw EMG as described earlier,<sup>(44,45)</sup> using a bandwidth of 30–450 Hz. Previous studies have found the DSI to be more sensitive to fatigue compared to the more traditional mean or median power frequency.<sup>(26,44,45)</sup> For each experimental session, EMG measures were normalized to mean values determined from the baseline reference contractions; reference contractions were used for normalization instead of MVCs to improve reliability over multiple days, and to better represent the muscle activation levels during the task. Muscle fatigue was indicated by AEMG increases and MnPF decreases<sup>(46–48)</sup> along with increases in DSI.<sup>(44)</sup> Fatigue was also assessed from RPDs, specifically using the mean and maximum ratings over each 60-minute work period.

Heart rate was analyzed using percentage of HR reserve (%HRR), calculated as  $(HR_{\text{mean}} - HR_{\text{rest}}) / (HR_{\text{max}} - HR_{\text{rest}})$ , where:  $HR_{\text{mean}}$  = mean HR across the four 15-min segments within a work period;  $HR_{\text{max}} = 220 - \text{age}$ ,<sup>(49,50)</sup> and  $HR_{\text{rest}}$  was determined from the mean of the last minute of a 6-min rest period in a supine posture that was collected before the experiment began.<sup>(51)</sup> Higher %HRR values reflect increased cardiovascular demand<sup>(52)</sup> and indirectly represent increased physical work load.<sup>(7)</sup>

Using marker locations, two measures of performance were derived: box Distance and Angle. Distance was calculated as the absolute distance from the pointer to the center of the two vertical target lines at the end of each lift (along the x-axis;

Figure 3). Angle was determined between vectors indicating the edge of the box and the platform (Figure 3), and reported as the absolute value. Increased Distance and Angle were interpreted as indicating decreased task performance. Both mean and maximum Distance and Angle were calculated as they were considered to represent different aspects of task performance, both with practical relevance (i.e., mean represents overall performance, maximum represents worst performance); these performance criteria were explained to participants during the practice at the beginning of each experimental session.

Specific dependent measures were thus: mean AEMG, EMG MnPF, and EMG DSI from each of the muscles tested, mean and maximum RPDs from each body part, %HRR, and mean and maximum box Distance and Angle. EMG-based measures were available from the reference contractions, while heart rate and performance were available continuously during the work period. All dependent measures were calculated across the available data from a given condition: mean heart rate and performance were obtained across all 60-min of repetitive lifting/lowering; mean RPDs were obtained across all 12 collected ratings; and mean EMG-based measures were obtained across all four reference contractions. The mean of each measure was used to represent the accumulation of fatigue (or effects of fatigue); here, since each condition had the same duration, the integral of each measure over the work period is equivalent to the product of the mean of each measure and the duration.

### Statistical Analysis

Two-way, mixed factor analyses of variance (ANOVAs) were performed separately to assess the effects of condition and gender on each of the dependent measures. Post-hoc contrasts were used for several planned comparisons when there was a significant main effect of condition. In the following, “L” denotes the Lighter load task, “H” denotes the Heavier load task, and each letter represents one 15-min period. Planned comparisons were: 1) between no-rotation and rotation conditions (LLLL vs. pooled rotation conditions, and HHHH vs. pooled rotation conditions); 2) between the two no-rotation conditions (LLLL vs. HHHH); 3) between rotating every 15 versus 30 min (rotation frequency; i.e., pooled LHLH + HLHL vs. pooled LLHH + HHLL); and 4) between Start L vs. Start H (task order; i.e., pooled LHLH + LLHH vs. pooled HLHL + HHLL). Simple effects analyses were used to explore significant gender x condition interactions. All statistical analyses were performed using JMP 9.0 (SAS Institute Inc., Cary, NC), and significance was concluded when  $p < 0.05$ . Summary statistics are presented as means (SD).

## RESULTS

### Effects on EMG Measures

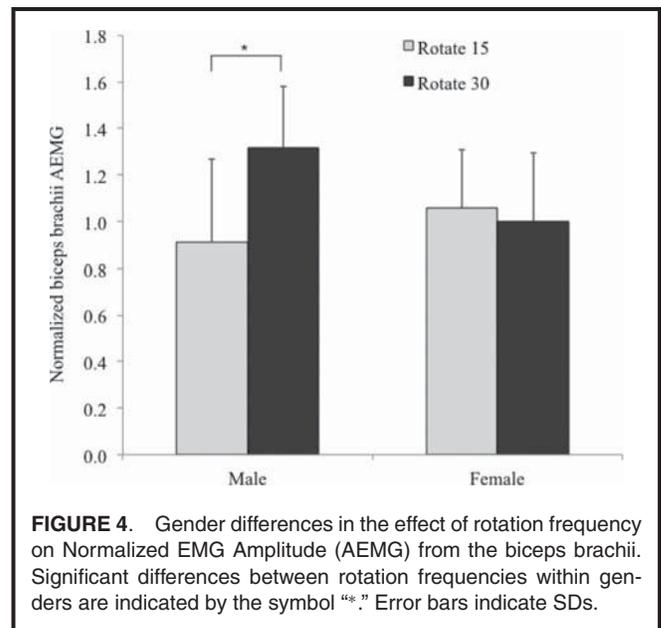
There were significant main effects of condition on many of the EMG measures. Though a few EMG-based measures indicated less fatigue for LLLL compared to the rotation conditions and more fatigue for HHHH than the rotation

conditions, these effects were inconsistent and were only seen for a few of the muscles and measures tested. As all EMG-based measures were normalized to baseline measures, presented EMG results are unitless. There was a main effect of condition on anterior deltoid MnPF ( $p = 0.031$ ), such that during HHHH (1.00(0.02)) it was lower ( $p = 0.047$ ) than during the rotation conditions (1.02(0.03)). However, there were also main effects of condition on anterior deltoid DSI ( $p = 0.029$ ) and biceps brachii DSI ( $p = 0.015$ ) that indicated more fatigue for LLLL compared to the rotation conditions; DSI values were higher for LLLL (1.05(0.17) and 1.08(0.14), respectively) compared to the rotation conditions (0.93(0.14);  $p = 0.006$  and 0.96(0.15);  $p = 0.011$ , respectively).

There were also several significant gender x condition interaction effects, specifically on AEMG from the biceps brachii ( $p = 0.0017$ ), L1 erector spinae ( $p = 0.016$ ), and L3 erector spinae ( $p = 0.024$ ). For the biceps brachii, AEMG was lower for HHHH (0.91(0.19)) than the rotation conditions for males (1.11(0.36);  $p = 0.067$ ), yet the opposite effect was seen for L1 erector spinae AEMG for females ( $p = 0.063$ ; Rotation: 1.11(0.18); HHHH: 1.21(0.14)). For the L3 erector spinae, AEMG was lower for LLLL (1.09(0.10)) compared to the rotation conditions (1.20(0.21);  $p = 0.067$ ) and lower for HHHH (1.15(0.21)) compared to the rotation conditions ( $p = 0.026$ ), though this effect was only seen for males.

There were several significant effects of rotation frequency and task order; however, these effects differed between muscles and genders. Regarding rotation frequency, there was a main effect of condition on trapezius AEMG ( $p = 0.032$ ), which was higher for Rotate 15 (1.43(0.71)) than Rotate 30 (1.08(0.13);  $p = 0.011$ ). However, the gender x condition interaction effect on biceps brachii AEMG indicated that Rotate 15 resulted in lower biceps brachii AEMG than Rotate 30 ( $p = 0.0002$ ; Figure 4) for males, though this difference was not evident for females. Further, the biceps brachii DSI was higher for Rotate 30 (1.01(0.13) compared to Rotate 15 (0.91(0.15);  $p = 0.023$ ). Effects of task order that approached significance were seen for anterior deltoid ( $p = 0.066$ ) and biceps brachii DSI ( $p = 0.098$ ), both of which were higher for Start L (0.97(0.14) and 0.99(0.12), respectively) compared to Start H (0.90(0.12) and 0.92(0.17), respectively). Analysis of the interactive effect between gender and condition for L3 erector spinae AEMG showed that effects of task order approached significance for both genders but was inconsistent between genders. For males, Start L had lower L3 erector spinae AEMG than Start H ( $p = 0.061$ ), while the opposite occurred for females ( $p = 0.088$ ; Figure 5).

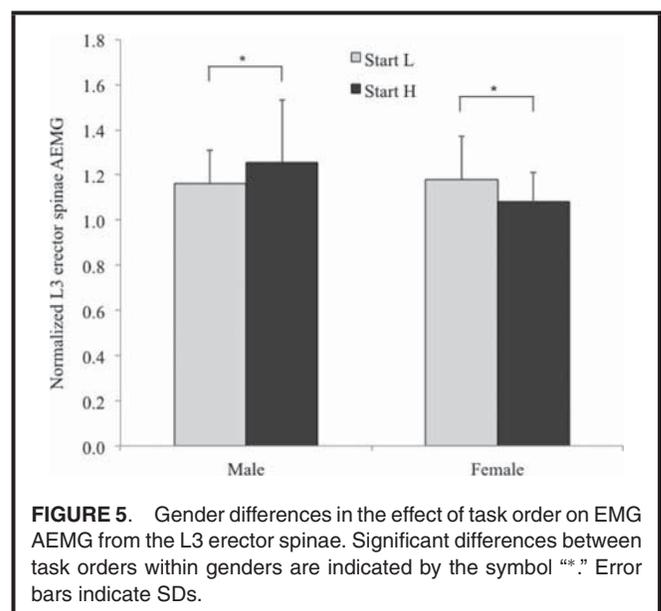
There were also several main effects of gender on EMG measures. Males had lower AEMG for the anterior deltoid (1.02(0.13);  $p = 0.026$ ) and lower MnPF for the middle deltoid (1.00(0.04)) compared to females (1.11(0.13) and 1.02(0.04), respectively), though the latter difference only approached significance ( $p = 0.063$ ). Further testing of gender x condition interaction effects indicated males had lower biceps brachii AEMG for HHHH (0.91(0.19)) compared to females (1.19(0.34)), which again only approached significance ( $p =$



**FIGURE 4.** Gender differences in the effect of rotation frequency on Normalized EMG Amplitude (AEMG) from the biceps brachii. Significant differences between rotation frequencies within genders are indicated by the symbol “\*.” Error bars indicate SDs.

#### Effects on RPDs and %HRR

All RPDs differed significantly between conditions, in that LLLL was less fatiguing than the rotation conditions and HHHH was more fatiguing than the rotation conditions (Table I). Across all body parts, respective mean and maximum RPDs for LLLL were ~25% and ~38% less than the rotation



**FIGURE 5.** Gender differences in the effect of task order on EMG AEMG from the L3 erector spinae. Significant differences between task orders within genders are indicated by the symbol “\*.” Error bars indicate SDs.

**TABLE I. Summary of the Main Effects of Condition and Results of Post-Hoc Testing on HR and RPDs**

Measure	means / standard deviations										p-values				Task Order
	Rotation	LLLL	HHHH	Rotate 15	Rotate 30	Start L	Start H	Condition	LLLL vs. Rotation	HHHH vs. Rotation	LLLL vs. HHHH	Rotation Frequency			
	Mean														
Lower Back	1.15 (0.88)	0.88 (0.88)	1.78 (1.18)	1.12 (0.93)	1.17 (0.84)	1.17 (0.87)	1.13 (0.91)	<0.0001*	0.0061*	<0.0001*	<0.0001*	0.58	0.66		
Upper Back	1.05 (1.00)	0.89 (1.06)	1.57 (1.43)	1.03 (0.99)	1.08 (1.04)	1.05 (1.04)	1.05 (0.99)	0.0003*	0.14	<0.0001*	<0.0001*	0.61	0.97		
Shoulder	0.89 (0.75)	0.64 (0.72)	1.14 (0.93)	0.87 (0.80)	0.90 (0.71)	0.87 (0.72)	0.91 (0.79)	0.0005*	0.0067*	0.0005*	<0.0001*	0.73	0.62		
Upper Arm	0.86 (0.72)	0.56 (0.54)	1.41 (1.21)	0.83 (0.78)	0.90 (0.66)	0.85 (0.69)	0.88 (0.76)	<0.0001*	0.010*	<0.0001*	<0.0001*	0.53	0.82		
	RPD														
Lower Back	2.36 (1.43)	1.48 (1.22)	3.23 (1.67)	2.38 (1.43)	2.33 (1.46)	2.57 (1.46)	2.15 (1.40)	<0.0001*	0.0001*	0.0004*	<0.0001*	0.85	0.014*		
Upper Back	2.00 (1.59)	1.43 (1.43)	2.92 (2.08)	1.85 (1.45)	2.15 (1.75)	2.16 (1.71)	1.85 (1.48)	<0.0001*	0.012*	0.0001*	<0.0001*	0.13	0.12		
	Maximum														
Shoulder	1.80 (1.20)	1.10 (1.18)	2.63 (1.92)	1.71 (1.19)	1.89 (1.22)	1.96 (1.28)	1.64 (1.11)	<0.0001*	0.0003*	<0.0001*	<0.0001*	0.26	0.053		
Upper Arm	1.78 (1.16)	0.93 (0.87)	2.60 (1.81)	1.67 (1.17)	1.90 (1.16)	1.95 (1.27)	1.62 (1.04)	<0.0001*	<0.0001*	0.0001*	<0.0001*	0.16	0.045*		
	Heart Rate														
%HRR	37.2 (9.09)	31.3 (7.70)	45.0 (9.83)	37.3 (9.02)	37.1 (9.36)	37.3 (10.2)	37.2 (8.11)	<0.0001*	0.0002*	<0.0001*	<0.0001*	0.90	0.96		

Notes: Corresponding mean (SD) values are shown for distinct conditions (shown on left) along with results from testing of the main effect of condition and post-hoc comparisons (shown on right). Significant effects are indicated by the symbol \*.

**TABLE II. Descriptive statistics (Mean (SD)) for RPDs by Gender and Condition**

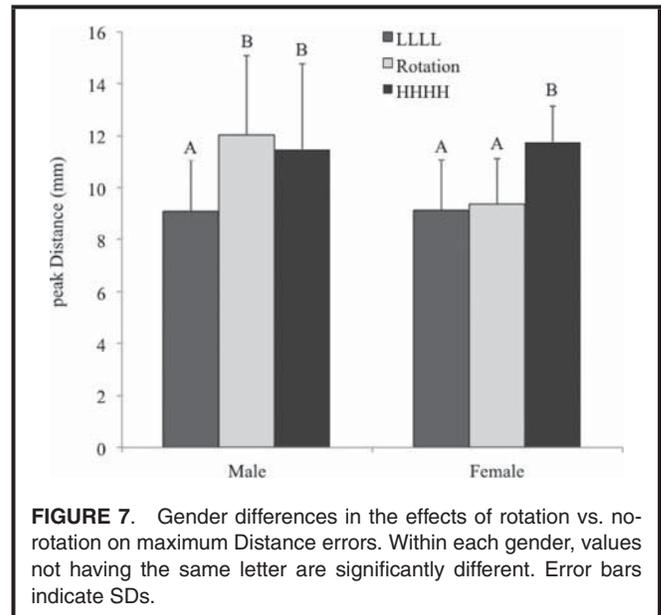
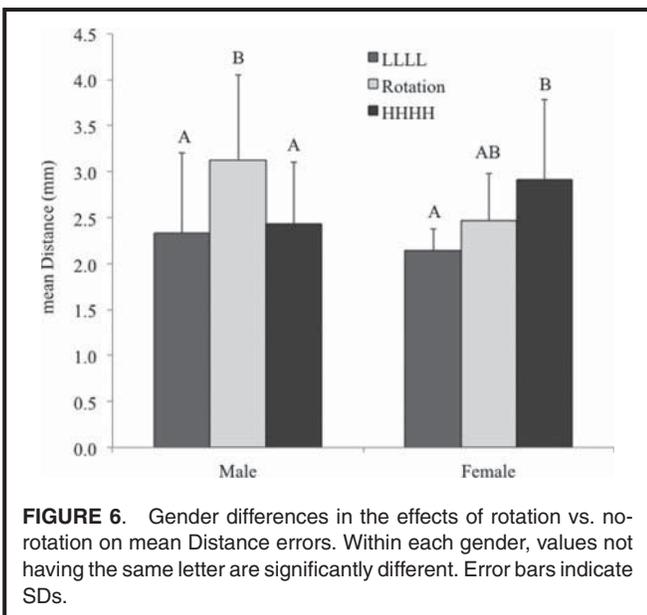
	Shoulder (mean)		Upper Arm (mean)		Shoulder (maximum)	
	Male	Female	Male	Female	Male	Female
LLLL	0.74 (0.93)	0.54 (0.49)	0.52 (0.60)	0.61 (0.52)	1.29 (1.57)	0.91 (0.73)
Rotation	0.95 (0.84)	0.82 (0.65)	0.80 (0.71)	0.93 (0.73)	1.86 (1.34)	1.74 (1.06)
HHHH	0.62 (0.52)	1.58 (1.01)	0.95 (0.83)	1.87 (1.43)	2.14 (1.90)	3.13 (1.97)

conditions. Further, mean and maximum RPDs for HHHH were ~50% and ~43% higher than the rotation conditions, respectively. However, there were also significant gender × condition interactive effects, on mean ratings from the Shoulder ( $p = 0.0010$ ) and Upper Arm ( $p = 0.021$ ) and on maximum ratings from the Shoulder ( $p = 0.041$ ). For all three, females had lower ratings for LLLL compared to the rotation conditions ( $p = 0.026, 0.049,$  and  $0.002$ , respectively) and higher ratings for HHHH compared to the rotation conditions ( $p < 0.0001$  for all; Table II). For males, mean ratings from the Shoulder and Upper Arm and maximum ratings from the Shoulder were also lower for LLLL compared to the rotation conditions, though not all differences were significant ( $p = 0.095, 0.083,$  and  $0.030$ , respectively; Table II). Further, both mean Upper Arm and maximum Shoulder ratings were lower for LLLL compared to HHHH for males ( $p = 0.041$  and  $0.011$ , respectively; Table II). For all muscles, Start L led to higher maximum RPDs than Start H, though some of the differences only approached significance (Table I). There was also a main effect of condition on %HRR. LLLL was less demanding than the rotation conditions, with ~16% lower mean%HRR, and HHHH was more demanding than the rotation conditions, with ~21% higher mean%HRR (Table I).

**Effects on Performance**

Though there were no main effects of condition, there were main effects of gender and interactive effects of gender and condition on mean and maximum Distance ( $p = 0.034$  and  $0.046$ , respectively). Overall, performance was better for LLLL and worse for HHHH, but males and females responded differently to the rotation conditions. For males, mean Distance was lower for both LLLL and HHHH compared to the rotation conditions ( $p = 0.026$  and  $0.064$ , respectively; Figure 6), suggesting that rotation overall had a detrimental effect on task performance. Females, however, had only lower mean Distance for LLLL ( $2.14(0.24)$ ) compared to HHHH ( $2.92(0.86)$ ), and this effect only approached significance ( $p = 0.069$ ). Further, maximum Distance for males was lower for LLLL ( $9.10(1.95)$ ) than both the rotation conditions ( $12.04(3.02)$ ;  $p = 0.0052$ ) and HHHH ( $11.48(3.28)$ ;  $p = 0.063$ ), again suggesting that rotating had a detrimental effect on task performance for males. For females, however, maximum Distance was lower for both LLLL ( $p = 0.041$ ) and the rotation conditions ( $p = 0.020$ ) compared to HHHH (Figure 7).

Both mean and maximum Distance were higher for males ( $p = 0.061$  and  $0.045$ , respectively) than females; mean and maximum Distance for males were  $2.91(0.93)$  and  $11.42(3.04)$ ,



**TABLE III. Descriptive Statistics (Mean (SD)) for Performance by Gender and Condition**

	Mean Distance (mm)		Maximum Distance (mm)	
	Male	Female	Male	Female
LLLL	2.33 (0.87)	2.14 (0.24)	9.10 (1.95)	9.14 (1.91)
HHHH	2.44 (0.67)	2.92 (0.86)	11.48 (3.28)	11.76 (1.39)
Rotate 15	3.05 (0.77)	2.44 (0.54)	12.08 (3.19)	9.53 (2.06)
Rotate 30	3.34 (1.04)	2.50 (0.51)	12.49 (2.69)	9.22 (1.38)
Start L	3.07 (1.08)	2.49 (0.54)	11.78 (2.56)	9.96 (1.92)
Start H	3.19 (0.79)	2.45 (0.51)	12.30 (3.54)	8.79 (1.31)

and for females were 2.49(0.58) and 9.73(1.90), respectively. However, testing of gender effects in the interactions showed that, while this relationship was present for all contrast levels representing the rotation conditions (Rotate 15, Rotate 30, Start L, and Start H), there were no differences in performance between genders for either of the no-rotation conditions (Table III).

## DISCUSSION

### Effects of Rotation Versus No Rotation

We investigated the effects of rotation frequency and task order on localized muscle fatigue, cardiovascular demand, and performance during repetitive box lifting. As expected, rotation between a lighter and heavier load reduced fatigue compared to only performing the heavier load task, evident as reductions in mean discomfort (~33%) and cardiovascular demand (~17%). Further, rotating between the lighter and heavier load increased fatigue compared to only performing the lighter load task, with a ~34% increase in mean discomfort, and increased cardiovascular demand (~19%). These effects were evident through subjective measures of fatigue and heart rate, and similar effects have been reported in prior studies of rotation.<sup>(10,19)</sup> These effects were also seen in some EMG measures, however EMG effects were fairly inconsistent across muscles tested and between genders, and were typically non-significant. Comparing rotation versus no rotation conditions overall, however, does indicate that the two included tasks were distinct in terms of physical work load.

Task performance was generally better for the lighter load task without rotation and worse for the heavier load task without rotation. However, males and females responded differently to the rotation conditions in terms of performance. Specifically, rotation had a detrimental effect on task performance for males, yet this effect was not seen for females. This is consistent with some previous research that suggests rotation can detrimentally affect task performance,<sup>(32-34)</sup> and supports results from our earlier work on simple static shoulder efforts.<sup>(26)</sup> Males overall had lower performance than females, also consistent with previous evidence that females have greater motor control.<sup>(53)</sup>

### Effects of Rotation Frequency and Task Order

We expected that rotating between tasks more frequently would be beneficial in reducing accumulated fatigue compared to rotating less frequently. Low exertion levels can allow for increased blood flow,<sup>(54-56)</sup> which can reduce the concentration of H<sup>+</sup> ions that result from anaerobic glycolysis and the breakdown of lactic acid. An existing tool for assessing lifting tasks (the SLI) implicitly assumes an effect of rotation frequency, in that rotation sequences containing longer duration tasks are given higher risk values.<sup>(27)</sup> More frequently occurring periods of lower-level loading should thus reduce accumulated fatigue. Though there were some effects of rotation frequency on EMG-based measures, the directions of these effects were inconsistent. Further, no significant or substantial effects of rotation frequency were seen in any other measure. Therefore, it is likely that the lower loading periods (i.e., lighter box weight) did not allow for measurable recovery from the heavier loading periods, similar to our earlier results for repetitive static shoulder efforts.<sup>(26)</sup>

We also expected that starting with the lighter load task would reduce fatigue, since the lighter load task could serve as a prolonged warm-up period and thereby improve performance and increase endurance time.<sup>(57)</sup> This effect was observed in one EMG measure, though opposing effects were evident in discomfort ratings and other EMG measures. Maximum discomfort ratings were consistently higher when starting with the lighter load task, but this effect was not seen for mean discomfort ratings. The observed effects for maximum ratings opposes some prior research on rotation, in which ratings were lower when starting with a lesser demanding task<sup>(10,26)</sup> or in which there were no effects of task order.<sup>(22)</sup> The latter work, however, agrees with most measures here, which showed no consistent effects of task order, and with the SLI which does not include an effect of task order.

A high-level comparison of the experimental conditions was done based on the current results and the SLI method of Waters et al.<sup>(27)</sup> The former included RPD and HR, as these measures, in contrast to EMG and performance as discussed below, provided the most consistent and/or significant results regarding the effects of rotation. This comparison, using a ranking of the six conditions (Table IV) suggests a general level of consistency. However, and as noted earlier, the SLI differentiates tasks based on rotation frequency.

**TABLE IV. Ranked Conditions According to a Subset of the Current Results and the Sequential lifting index (SLI) Method of Waters et al.<sup>(27)</sup>**

	RPD	HR	SLI
LLLL	1	1	1
LHLH	3.5	3.5	2.5
HLHL	3.5	3.5	2.5
LLHH	3.5	3.5	4.5
HHLL	3.5	3.5	4.5
HHHH	6	6	6

Note: The subset of the current results includes ratings of perceived discomfort (RPD) and heart rate (HR). Lower ranks indicate smaller observed effects or lower risk; means are given for the ranks of tied conditions.

### Limitations

Though some EMG measures showed changes indicative of fatigue, overall they responded inconsistently to the task conditions. EMG was only available during the reference contractions, with mean values of ~19% MVC for the torso reference contraction across participants. At this level of activity EMG may not be sufficiently sensitive to fatigue.<sup>(58–63)</sup> Further, although posture was controlled in the reference contractions slight changes in posture could have affected muscle activation levels and masked fatigue-induced changes.<sup>(64)</sup> Increases in muscle temperature over the work periods could also have masked fatigue effects.<sup>(65)</sup>

This study involved a controlled lifting task performed in a laboratory setting. Though lifting is a common occupational task, the constrained, symmetric, stoop-style lift used here may not reflect lifting performed in real work environments. Further, a sample of healthy young adults was used, who may differ in their responses to fatiguing tasks compared to older workers.<sup>(66–70)</sup> Our participants may also have had lower motivation than actual workers, and while our performance measures likely reflected gross motor control the task was relatively simple. As such, the performance effects seen here may not be generalizable to actual workers performing complex occupational tasks. In addition, the small sample size used here may have been underpowered to detect subtle effects related to rotation frequency and task order. Further, with only six participants of each gender, any conclusions regarding gender differences are necessarily limited. Since box weights were set relative to body weight, there were slight differences in the relative task demands between participants. These differences were relatively small, however, and thus unlikely to have affected the major outcomes. Specifically, the 10% BW task was equivalent to 12.3 and 12.8% MVC for males and females, respectively, and the 20% BW task was equivalent to 24.6 and 25.7% MVC for males and females, respectively.

Several task constraints were used that may affect generalizability to actual work environments. We isolated the specific effects of rotation in a situation wherein the included tasks

loaded the same muscle groups, and thereby simulated a rather extreme case in which the task was identical but varied in terms of the level of muscular demands. As such, the current results may not be fully representative of rotation in an actual work environment. A compressed time period was used and only within-session effects of fatigue were evaluated; a longer duration task and/or consideration of cumulative effects of day-to-day work may be more representative of fatigue experienced in actual work environments. Finally, the current results may be limited to the specific combination of task levels and rotation frequencies used.

### CONCLUSION

Rotation between lifting tasks that vary in load level can reduce/increase fatigue compared to performing only a heavier/lighter load task. For the specific conditions examined here, there were no consistent effects of either rotation frequency or task order across several outcome measures. There was some evidence that rotation had a detrimental effect on task performance, though this effect differed between genders. As a whole, and consistent with existing evidence, these findings do not provide conclusive information regarding the effects of rotation frequency or task order on fatigue or performance. If there are effects of these rotation parameters, they may be relatively small. Further work is clearly needed to explore the effects of rotation under more diverse and realistic task conditions, and with a more diverse sample.

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