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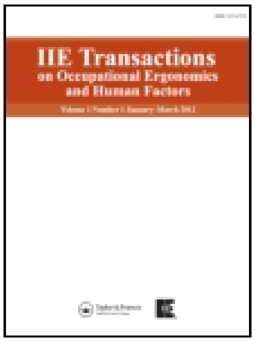

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ORIGINAL RESEARCH

Effects of Rotation Frequency and Starting Task on Localized Muscle Fatigue and Performance During Simulated Assembly Work

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OCCUPATIONAL APPLICATIONS This study simulated rotating between assembly tasks at two different intensity levels performed for a total duration of 1 hour, during which rotation occurred every 15 minutes, every 30 minutes, or not at all. Under the scenario studied here, rotation reduced shoulder muscle fatigue compared to only performing a higher intensity task and increased fatigue compared to only performing a lower intensity task. Neither rotation frequency nor starting task significantly affected fatigue or performance. Based on the results, rotation frequency and starting task may not need substantial consideration when designing rotation schedules or plans. Generalizing the current results to actual occupational tasks, however, may be limited due to the inclusion of only two tasks, the constrained nature of the task, and the small sample size.

TECHNICAL ABSTRACT ***Background:*** Rotating between tasks is widely used and considered to reduce the risk of work-related musculoskeletal disorders, though there is limited evidence that it is effective in doing so. ***Purpose:*** This study assessed the effects of rotation during assembly work involving the upper extremity, specifically focusing on rotation frequency and starting task, on shoulder muscle fatigue and task performance when included tasks loaded the same muscle group. ***Methods:*** Twelve participants completed six experimental sessions during which a simulated repetitive assembly task was performed for 1 hour either with or without rotation. When rotation occurred, it was between two intensity levels corresponding to two working heights. ***Results:*** As expected, rotating between the tasks reduced shoulder muscle fatigue compared to only performing the higher intensity task and increased fatigue compared to only performing the lower intensity task. Neither rotation frequency nor starting task had significant or consistent effects on fatigue or task performance. ***Conclusions:*** While varying the intensity level of tasks included

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in rotation schedules reduced muscle fatigue, this effect was not influenced substantially by either rotation frequency or starting task during the moderately demanding upper extremity assembly task examined here.

KEYWORDS Job rotation, rotation frequency, task order, muscle fatigue, performance

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) continue to be a substantial problem in the workplace, and the annual costs associated with such occupational injuries have been estimated at up to $150 billion in the United States (Anderson & Budnick, 2009). WMSDs account for roughly 30% of injuries or illnesses that require days away from work (Bureau of Labor Statistics [BLS], 2011), and of these, the shoulder accounts for around approximately 15% of the total cases and involves the most severe injuries, requiring a median of 21 days away from work (BLS, 2011). To reduce the prevalence of WMSDs, administrative controls, such as rotation (also known as "job rotation" or "task rotation"), are often adopted. Rotation involves workers rotating between a set of different tasks and is used by more than 40% of manufacturing companies in the U.S. Midwest, with the primary motivation being to reduce exposure to WMSD risk factors (Jorgensen et al., 2005). However, there is little evidence supporting the use of the rotation approach to reduce WMSD risk despite its widespread use (Mathiassen, 2006).

Much of the focus of rotation research has been on the effects on physical demands (e.g., kinematic and kinetic exposures) and physical exposure variation (i.e., temporal variability of physical demands). However, existing evidence has shown inconsistent effects. Some implementations of rotation have led to decreases in physical demands, specifically reducing exposure to non-neutral working postures (Hinnen et al., 1992; Kuijer et al., 1999), cardiovascular load (Kuijer et al., 1999), and muscle activation (Rissen et al., 2002). Raina and Dickerson (2009) demonstrated that rotation can also reduce muscle fatigue; in their study, performing shoulder abduction alone was more fatiguing than rotating between shoulder abduction and flexion. Regarding physical exposure variation, increases are thought to be beneficial, because while one muscle is resting, other muscles can be loaded (Wells et al., 2010). In their study, Wells et al. (2010) found that physical exposure variation can be increased when rotating between different grip tasks compared to performing only one grip task. Further, rotation at an automotive plant increased variability of the trapezius muscle activity (Möller et al., 2004). However, several studies have implemented rotation in work environments and found opposing results. Kuijer et al. (2005) found that rotating between refuse collecting and truck driving resulted in an increased risk of low-back complaints, and Aptel et al. (2008) found that rotating between tasks on electrical appliance assembly lines did not affect WMSD rates. Two additional studies on rotation at assembly lines found that rotating between tasks did not increase physical exposure variation (Jonsson, 1988; Wells et al., 1989).

There are some important parameters of rotation that need to be specified when developing rotation schedules, including which tasks to include, how frequently workers rotate between tasks, and the order in which tasks are performed. Differences in these parameters may explain some of the above-summarized inconsistent results. In terms of task selection, a common problem with rotation is that when highly demanding tasks are included, rotation can increase the number of workers who experience peak loading from these tasks (Henderson, 1992; Kuijer et al., 2004, 2005), as well as the likelihood of workers reporting low-back pain (Frazer et al., 2003; Kuijer et al., 2005). For example, when workers rotated between refuse collecting and truck driving, Kuijer et al. (2004) found that rotating reduced physical demands for workers that previously only collected refuse but increased physical demands among workers that had previously only performed truck driving. Another complexity with task selection for rotation schedules is that a recommended approach is to include tasks with different physical exposures, which in turn is thought to reduce WMSD risk (Mathiassen, 2006), but many occupational tasks involve comparable physical exposures (Jonsson, 1988; Wells et al., 1989; Aptel et al., 2008; Keir et al., 2011). For example, Keir et al. (2011) found that the upper erector spinae and forearm muscles did not benefit from rotating between gripping and lifting tasks. Therefore, there remains a need to assess the effects of rotation when the included tasks have limited exposure variation, such as between tasks that load the same muscle(s).

How frequently workers should rotate between tasks, i.e., rotation frequency, also may be influential. Few analyses have been done of effects of rotation frequency on physical demands. A study based on mathematical modeling of rotation schedules and effects on physical demands concluded that workers should rotate every 1–2 hours (Tharmmaphornphilas & Norman, 2004). However, in earlier work (Horton et al., 2012, 2013), the effect of rotation frequency during static shoulder abduction and box lifting tasks was analyzed, and no benefit was found from increased rotation frequency in terms of reducing muscle fatigue. Workers on manufacturing assembly lines often rotate every 2 hours (Wells et al., 1989; Jorgensen et al., 2005; Aptel et al., 2008), though it has been suggested this is out of convenience (e.g., rotating at rest breaks) rather than based on empirical evidence (Jorgensen et al., 2005). Similarly, some workers self-select rotating between tasks every 1 to 1.5 hours (Muramatsu et al., 1987).

The effect of task order (or starting task)–the sequence in which tasks are performed–is another important aspect of rotation schedules, although the few existing (lab-based) studies have found inconsistent results. Raina and Dickerson (2009) examined rotating between repetitive shoulder flexion and abduction tasks. Though no significant effect of task order was found on objective fatigue measures, subjective exertion ratings were higher when starting with the more demanding task (shoulder abduction) compared to starting with shoulder flexion. This effect was also found in Horton et al. (2012), which involved rotating between static shoulder abduction at two intensity levels; higher discomfort ratings resulted when starting with the higher intensity level compared to the lower intensity level. However, other studies have shown no effects of task order. Keir et al. (2011) found no effects of task order when rotating between gripping and lifting tasks, and no consistent effects of task order were found when rotating between lifting tasks of different intensity levels (Horton et al., 2013). Although the number of lab-based studies is limited and results are not yet conclusive, task order has been considered when implementing rotation in the workplace. For example, rotation schedules have been designed such that no sequential tasks have high exposures (Henderson, 1992), including the implementation of scheduling algorithms that reduce the likelihood of a worker having back-to-back tasks that require the same movement (Diego-Mas et al., 2009). Order effects have also been reported in exercise-based research (Simão et al., 2005; Spreuwenberg et al., 2006). The magnitude of performance decrements can depend on the sequence in which exercises are performed (Spreuwenberg et al., 2006), and performance (assessed through number of repetitions) can be higher during exercises performed earlier in a sequence compared to those at the end (Simão et al., 2005). It is currently unclear if similar effects exist for occupational tasks, particularly due to the relatively longer duration of occupational tasks compared to exercise.

Another consideration for using rotation is its effect on task performance. Although rotation is thought to improve employee skill (Jorgensen et al., 2005), some evidence suggests that it can have a detrimental effect on task performance (Kher et al., 1999; Allwood & Lee, 2004; Azizi et al., 2010). Previously, it was reported that a higher rotation frequency (rotating every 15 minutes versus every 30 minutes) resulted in higher peak errors made during an isometric shoulder abduction task (Horton et al., 2012). This study involved tracking a target torque level, and peak errors were defined as the maximum deviation from the target torque. Evidence that rotation overall resulted in worse performance in a lifting task compared to not rotating was also obtained (Horton et al., 2013); performance on this task was measured by ability to precisely place the box at a target location. Given the potential impact of rotation schemes with respect to quality and productivity, the effect of rotation on task performance needs more thorough evaluation.

The overall purpose of the current study was to provide additional information regarding the effects of rotation frequency and starting task. A controlled laboratory study was used to isolate these effects, involving rotation between two simulated assembly tasks that differed in the level of exertion. As in prior studies (Horton et al., 2012, 2013), a compressed timeframe was used to facilitate implementation in a laboratory setting. A Purdue Pegboard Test was used to simulate the assembly tasks; this test was chosen as it requires fine motor control (Tiffin & Asher, 1948) and simulates a complex, dynamic task requiring demands commonly found in occupational work. The Purdue Pegboard Test is perhaps most representative of “bench” assembly work in that it is self-paced, versus “line” assembly work with more controlled performance demands. Outcome measures included localized muscle fatigue, due to its potential importance as a risk factor for WMSD development (Winkel & Westgaard, 1992; Dugan &

Frontera, 2000; Allison & Henry, 2002; Gorelick et al., 2003; Weist et al., 2004; Granata & Gottipati, 2008); cardiovascular demand, due to its relationship with physical workload levels; and task performance, due to its practical relevance. Specific purposes of this study were (1) to determine if rotation is effective in reducing muscle fatigue when the included tasks load the same muscle(s), (2) to evaluate the effects of rotation on task performance, and (3) to identify the specific effects of rotation frequency and starting task on fatigue and performance. It was hypothesized that rotating more frequently would reduce fatigue but have adverse effects on performance, and that starting with the lower exertion task would be less fatiguing and have higher performance versus starting with the higher exertion task.

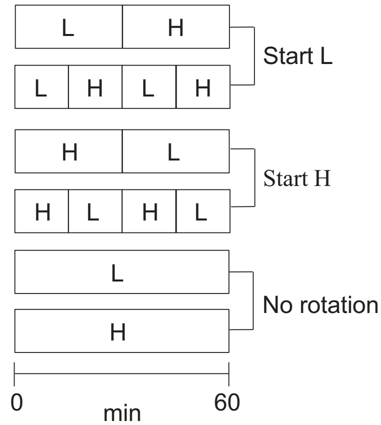

FIGURE 1 **Six experimental conditions involving all combinations of three levels of rotation frequency and two levels of starting task, where "L" denotes the lower exertion task and "H" denotes the higher exertion task. Figure adapted from Horton et al. (2012).**

METHODS

Participants

Twelve participants (gender balanced) were recruited from the local community using convenience sampling. Respective mean (*SD*) age, stature, and body mass for males were 22 (1.7) years, 1.77 (0.08) m, and 73.1 (6.6) kg, and for females were 22.5 (2.3) years, 1.62 (0.04) m, and 56.3 (3.4) kg. All participants reported being physically active and having no recent history of musculoskeletal injury, and all indicated being right-hand dominant. Participants completed an informed consent procedure approved by the Virginia Tech Institutional Review Board.

Experimental Design

Participants completed each of six experimental conditions (Fig. 1); during each condition participants performed repetitive assembly tasks over a 60-minute work period. Three levels of *rotation frequency* were used: 0 (no rotation), 15, and 30 minutes. Assembly tasks were performed at two exertion levels, based on working height, which was based on each individual participant's height. The two exertion levels were lower (waist height) and higher (shoulder height). Where rotation occurred, it was between these two levels, and two *starting tasks* were evaluated: lower and higher (hereafter denoted Start L and Start H, respectively). Participants completed a screening session followed by six experimental sessions; all sessions occurred on separate days, and there were at least 2 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 the conditions was counterbalanced using one 6×6 balanced Latin square for each gender.

Procedures and Data Collection

In the preliminary session, and following initial warm-up exercises, isometric maximum voluntary contractions (MVCs) of shoulder flexion were collected using a commercial dynamometer (System 3 Pro, Biodex Medical Systems, Shirley, NY, USA). During MVCs, the right shoulder was flexed 90°, and the upper body and waist were secured to the dynamometer chair using padded straps. Participants were instructed to exert maximally against a padded fixture and were given non-threatening verbal encouragement. Moments output by the dynamometer were hardware low-pass filtered (15 Hz) and sampled at 1024 Hz. At least three MVCs were performed, with 2 minutes of rest between each, until peak moments were non-increasing. Gravitational effects on the fixture were corrected for by zeroing the torque reading with the fixture attached. After accounting for gravitational effects on the fixture and upper extremity mass, the largest shoulder moment across MVC efforts was recorded. Though MVCs were not used in the analysis, they were collected to characterize the level of physical demands on participants.

During each experimental session, participants performed a 20-minute period of warm-up exercises and

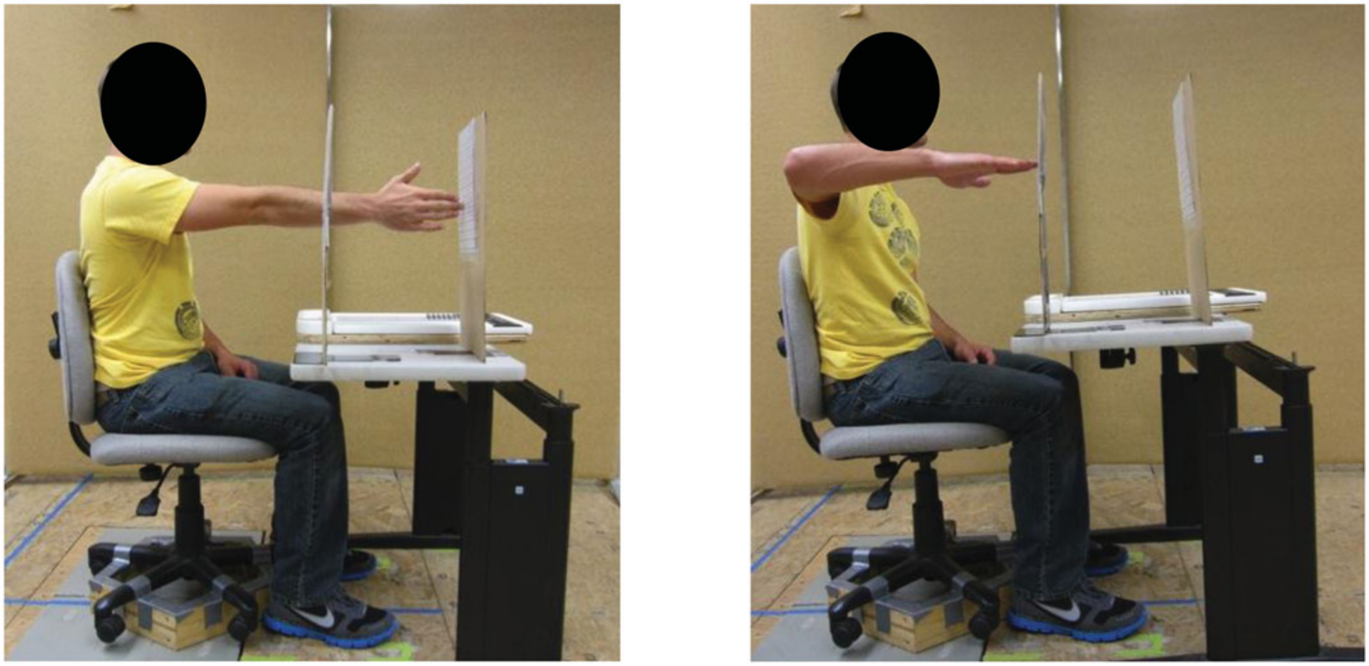

FIGURE 2 Postures used in reference contractions to assess the AD (left) and the MD+TR (right) (color figure available online).

practice of the tasks. After resting briefly, participants performed three baseline reference contractions in each of two postures (Fig. 2); these reference contractions were collected for normalization of subsequent EMG measures obtained during the experimental task. The first posture partially isolated the anterior part of the deltoid muscle and involved a 10-second sustained static posture with the shoulder flexed 90° (Figure 2: left). The second posture partially isolated the middle deltoid and trapezius (Fig. 2: right) and involved a 10-second sustained posture with the shoulder abducted 90° and the elbow flexed 90°; shoulder abduction was controlled by measuring the angle of the flattest part of the upper arm and ensuring that it was at 0° (parallel to the floor). Vertically oriented boards were attached to a table in front of participants, on which a mark was placed giving participants a target with which to line up their hand for each posture; this was performed to ensure consistent positioning between each reference contraction.

Participants then began the experimental task, which involved performing a repetitive pegboard task over a 60-minute work period. The task involved sequential cycles, using a cycle time of 3:50 minutes with 3:30 minutes of work and a 20-second rest, and it was performed using a Purdue Pegboard Test (Model 32020, Lafayette Instrument Company, Lafayette, IN, USA; Fig. 3). The pegboard was placed at waist or shoulder height (Fig. 4), corresponding to the lower and higher exertion levels, respectively. When placed at shoulder height, the pegboard was angled 45° to ensure the entire board could be reached. The seat distance from the table was adjusted to ensure that all participants had to fully extend their elbow to reach the end of the board (without bending their back). The task involved placing four pieces (one pin, two washers, and one collar) in holes on the pegboard. Participants were instructed to place the pieces in a specific order, beginning with one pin placed in the pegboard (right hand), followed by one washer (left hand), one collar (right hand), and one washer (left hand), each placed over the pin. Participants were asked to complete the assemblies as quickly as possible during each 3:30 work period without making any mistakes, and to keep their feet on the floor at shoulder width and back vertical during the tasks. Over the 60-minute work period, the exertion level (i.e., working height) changed (or did not change) as determined by the treatment condition (Fig. 1).

During the work period, reference contractions, as described above, were completed every 15 minutes. Electromyographic (EMG) activity was collected continuously during the reference contractions from the anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), and trapezius (TR), all on the right side.

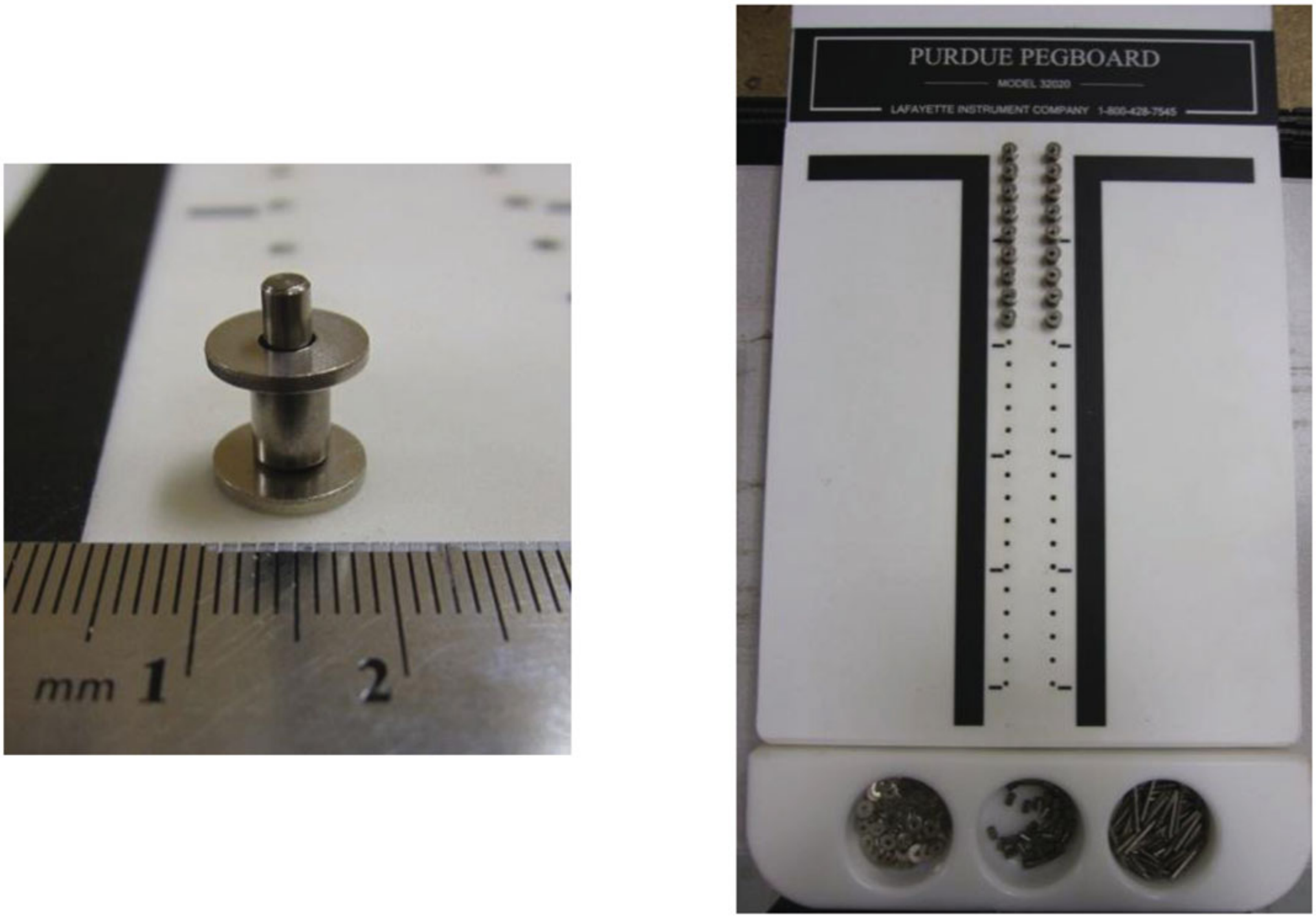

FIGURE 3 **Purdue Pegboard Task. Participants assembled pieces (left) into holes in a pegboard (right) (color figure available online).**

EMGs were obtained using pre-gelled Ag/AgCl electrodes placed 2 cm apart at locations described earlier (Perotto, 1994). Raw EMG from the muscles were preamplified (Measurement Systems Inc., Ann Arbor, MI, USA), hardware band-pass filtered (30–1000 Hz), and sampled at 1024 Hz. Ratings of perceived discomfort (RPDs) were collected every 3.5 minutes during the work period from the right shoulder, upper arm, and upper back, using a 10-point scale (Borg, 1990; scale ranges from 0 = no discomfort to 10 = extremely strong, almost maximal discomfort) that was visible continuously to participants. Cardiovascular demand was monitored continuously during the work period using a Polar heart rate monitor (Model RS800, Polar USA, Lake Success, NY, USA). Performance at the assembly task was monitored through quantification of the completed number of assemblies during each 3:50-minute work cycle.

Data Processing and Dependent Measures

Three EMG-based measures of fatigue were obtained from data collected from each muscle during each reference contraction. Specifically, a 6-second window was extracted from each 10-second sustained posture; the first 3 seconds and last second were removed to reduce transition effects. The first measure, *EMG amplitude* (Amp), was obtained from the EMG signal after full-wave rectification, low-pass filtering (Butterworth, 3-Hz cut-off, 4th-order, bidirectional), and correction for resting amplitudes. The second, *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 third, *Dimitrov spectral index* (DSI), was calculated from the raw EMG signal as in Equation (1), where *PS* is

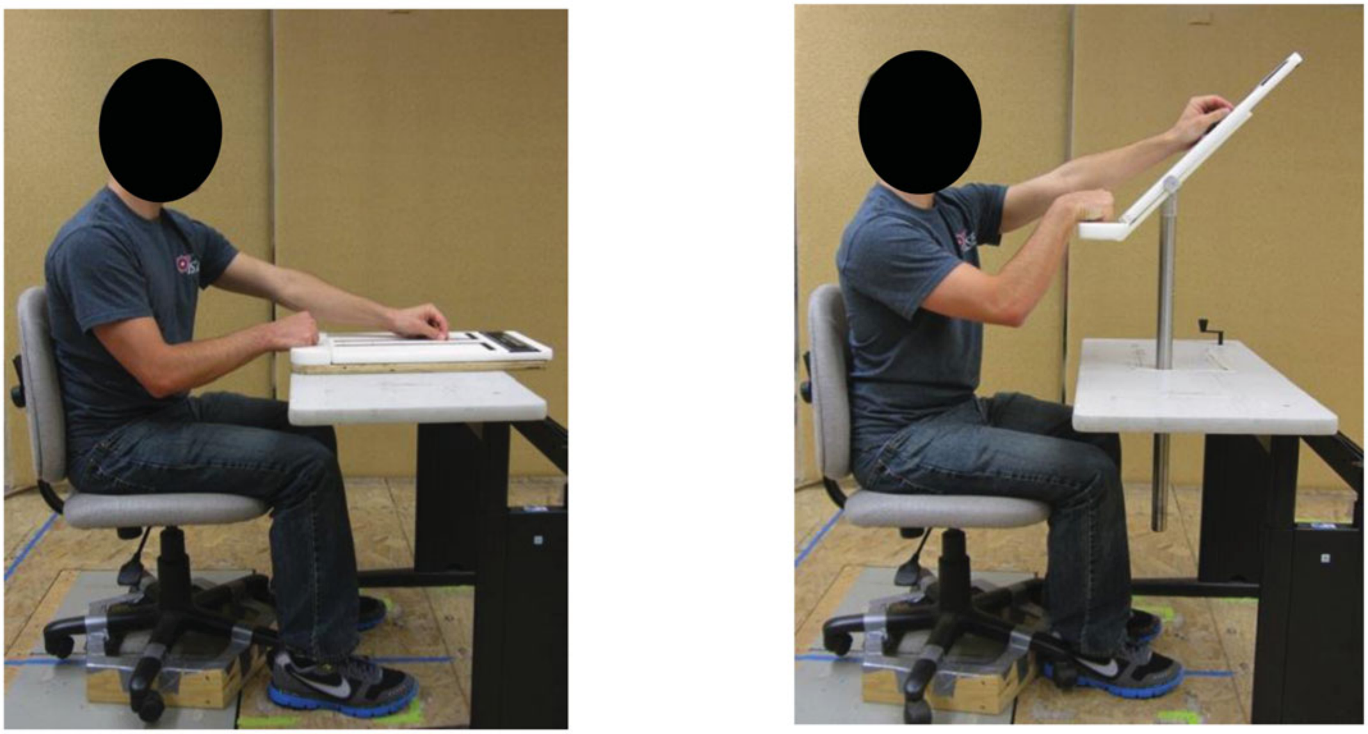

FIGURE 4 **Configurations for assembly task: waist height = lower exertion level (left), shoulder height = higher exertion level (right) (color figure available online).**

the power spectrum, $f_1 = 30$ Hz, and $f_2 = 450$ Hz (Gonzalez-Izal et al., 2010; Horton et al., 2012). For each experimental session, Amp, MnPF, and DSI were normalized to corresponding mean values determined from the baseline reference contractions. Increases in Amp and decreases in MnPF were interpreted as indicating muscle fatigue (Krogh-Lund & Jørgensen, 1991; Potvin & Bent, 1997; Nussbaum, 2001), and DSI values were expected to increase with fatigue (Dimitrov et al., 2006):

$$DSI = \frac{\int_{f_1}^{f_2} f^{-1} * PS(f)df}{\int_{f_1}^{f_2} f^{5} * PS(f)df}. \qquad (1)$$

Heart rate was analyzed using percentage of HR reserve (%HRR), which was calculated using Equation (2), where $HR_{average}$ is the mean HR across the four 15-minute work periods, $HR_{\max} = 220 - \text{age}$ (Fox & Haskell, 1970; Strath, 2000), and HR_{rest} was determined using a 6-minute rest period in a supine posture; the last minute of this trial was averaged to determine HR_{rest} (Jouven et al., 2001). Higher %HRR values were considered to represent increased cardiovascular demand (Garet et al., 2005) and to indirectly represent increased physical workload (Kuijer et al., 1999):

$$\%HRR = \left(\frac{HR_{mean} - HR_{rest}}{HR_{\max} - HR_{rest}}\right) * 100. \qquad (2)$$

EMG was available from the reference contractions and resulted in the following dependent measures from each of the muscles tested: mean EMG Amp, MnPF, and DSI. Further dependent measures were mean and peak RPDs from each body part, %HRR, and mean and minimum number of assemblies; both performance and heart rate data were available continuously during the work period. All dependent measures were calculated across the available data from a given condition (i.e., 60 minutes of repetitive lifting or four reference contractions). Mean values were used to represent the accumulation of fatigue (or the effects of fatigue); since each condition had the same duration, the integral of a measure over the work period is equivalent to the product of the mean of the measure and the duration. Mean values were chosen, as they represent the overall cumulative effects of fatigue during the 1-hour period.

Statistical Analysis

Separate mixed-factor analyses of variance (ANOVAs) were performed to assess the effects of condition (six levels) and gender on each of the dependent measures. Presentation order of the six conditions was included as a blocking variable. When there was a significant main effect of condition, post-hoc contrasts were used for several planned comparisons. In the following, "L" denotes the lower exertion task, "H" denotes the higher exertion task, and each letter represents one 15-minute period. Specific comparisons were made: (1) between no-rotation versus all-rotation conditions (LLLL versus all rotation conditions and HHHH versus all rotation conditions), (2) between the two no-rotation conditions (LLLL versus HHHH), (3) between rotating every 15 versus 30 minutes (rotation frequency), and (4) between Start L versus Start H (starting task). Significant interactions with gender were explored using simple effects analyses. Summary statistics are presented as means (*SD*). All statistical analyses were performed using JMP 9.0 (SAS Institute Inc., Cary, NC, USA), and significance was concluded when $p < 0.05$. Parametric model assumptions were verified. In cases where sphericity violations were found (using Mauchly's Test), p values are reported using the Huynh–Feldt procedure.

RESULTS

There were significant main effects of condition on many dependent measures, including some EMG measures, all mean and peak RPDs, and both mean and minimum performance measures. From the EMG data, there was a significant main effect of condition on AD MnPF ($p = 0.0024$); AD MnPF was higher for LLLL (0.99(0.04)) compared to the rotation conditions (0.96(0.05); $p = 0.046$) and lower for HHHH (0.93(0.06)) compared to the rotation conditions ($p = 0.021$). There was also a significant interaction effect of gender and condition on AD MnPF ($p = 0.0095$). For males, LLLL was less fatiguing than the rotation conditions ($p = 0.054$) and HHHH ($p = 0.055$), though these differences only approached significance; for females, both LLLL and the rotation conditions were less fatiguing than HHHH ($p = 0.0046$ and 0.0065, respectively; Fig. 5). Further, there were significant effects of rotation frequency for both genders; however, the direction of the effect was inconsistent. For males, MnPF was lower for Rotate 30, though this only approached significance ($p = 0.098$), while for females, MnPF was higher for Rotate 30 ($p = 0.0012$) compared to Rotate 15 (Fig. 6).

There was also a significant interactive effect of gender and condition for MD DSI ($p = 0.016$). For males, LLLL and the rotation conditions had lower DSI than HHHH ($p = 0.050$ and 0.12, respectively), while for females, no significant differences were found for the rotation versus no-rotation conditions (Fig. 7). Further,

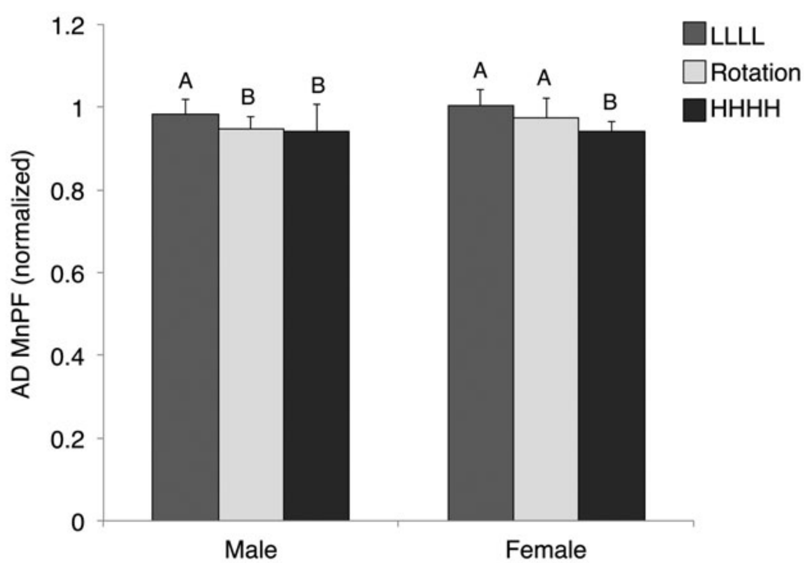

FIGURE 5 Gender differences in the effects of rotation versus no-rotation on AD MnPF. Within each gender, values not having the same letter are significantly different. Error bars indicate *SD*s.

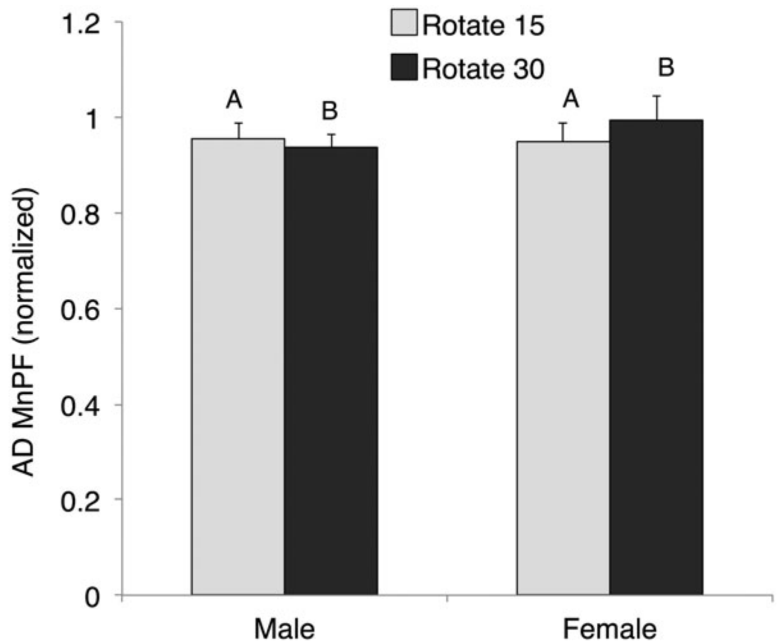

FIGURE 6 **Gender differences in the effects of rotation frequency on AD MnPF. Within each gender, values not having the same letter are significantly different. Error bars indicate *SD*s.**

there were effects of starting task for both genders. For males, Start L resulted in higher DSI ($p = 0.049$), while the opposite occurred for females, for which Start L resulted in lower DSI than Start H ($p = 0.0056$; Fig. 8). No significant effects were found for the EMG data for the TR or PD or for the EMG Amp data from any muscle.

There were main effects of condition on mean and peak RPDs from all body parts, which overall showed that LLLL was less fatiguing than the rotation conditions, HHHH was more fatiguing than the rotation conditions, and LLLL was less fatiguing than HHHH (Table 1), though not all post-hoc comparisons were significant. However, these effects were not observed in

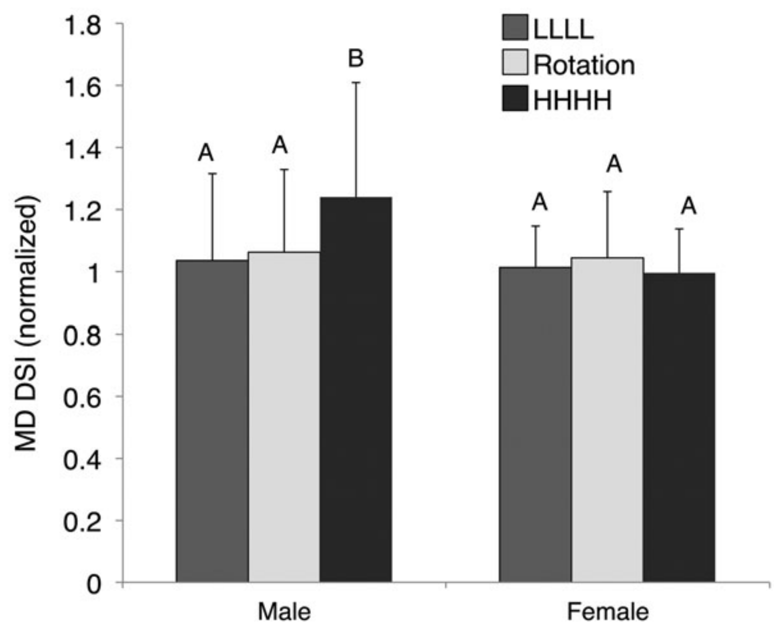

FIGURE 7 **Gender differences in the effects of rotation versus no-rotation on MD DSI. Within each gender, values not having the same letter are significantly different. Error bars indicate *SD*s.**

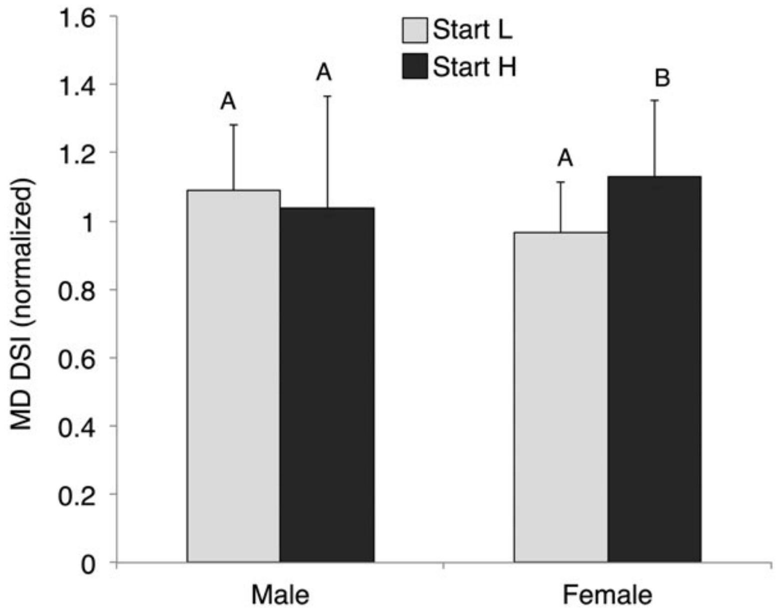

FIGURE 8 **Gender differences in the effects of starting task on MD DSI. Within each gender, values not having the same letter are significantly different. Error bars indicate *SD*s.**

the %HRR, for which there was not a significant effect of condition. There were also main effects of condition on both mean and minimum performance values, which showed better performance for LLLL compared to both the rotation conditions and HHHH (Table 1). Further, there was an effect on mean performance that approached significance, showing worse performance for HHHH compared to the rotation conditions ($p = 0.11$). There were no significant effects of rotation frequency or starting task for any of these measures.

Several main effects of gender were present in this study, suggesting that males were more fatigued than females. From the EMG data, there was an effect of gender that approached significance for AD MnPF ($p = 0.066$), and which was lower for males (0.94(0.047)) compared to females (0.98(0.056)). However, gender differences were only significant for a few of the contrast

TABLE 1 **Summary of the main effects of condition on RPDs and performance**

Measure	LLLL	HHHH	Rotation	Condition	LLLL versus rotation	HHHH versus rotation	LLLL versus HHHH
RPDs							
Mean							
Shoulder	1.59(1.23)	3.85(1.61)	2.22(1.07)	<0.0001*	0.0133*	<0.0001*	<0.0001*
Upper arm	1.40(1.15)	2.69(1.90)	1.68(0.93)	0.0051*	0.15	<0.0001*	<0.0001*
Upper back	1.92(1.12)	2.86(1.53)	1.99(1.10)	0.0077*	0.74	0.0001*	0.0007*
Peak							
Shoulder	2.35(1.62)	5.53(1.91)	4.00(1.60)	<0.0001*	<0.0001*	0.0002*	<0.0001*
Upper arm	2.13(1.63)	4.13(2.38)	3.24(1.59)	0.0002*	0.0005*	0.0049*	<0.0001*
Upper back	3.04(1.68)	4.30(2.07)	3.59(1.71)	0.024*	0.07	0.020*	0.0014*
Heart rate							
%HRR	12.3(9.02)	14.4(11.0)	14.7(8.70)	0.14	—	—	—
Performance							
Mean	42.5(5.79)	39.3(5.34)	40.5(6.93)	0.017*	0.0068*	0.11	0.0009*
Minimum	39.1(5.99)	35.4(5.76)	36.4(7.55)	0.016*	0.0025*	0.28	0.0014*

Corresponding mean (SD) values are shown for distinct conditions along with results from post-hoc comparisons. Significant effects are indicated by the symbol *.

levels of interest: Rotate 30 ($p = 0.0003$), and Start H ($p = 0.021$), and approached significance for Start L ($p = 0.11$). There were also effects of gender that approached significance for both mean and peak RPDs from the shoulder ($p = 0.056$ and 0.061, respectively), with higher ratings from males than females. Respective values for mean ratings were 2.9(1.2) and 1.9(1.3) and for peak ratings were 4.7(1.5) and 3.3(1.9).

DISCUSSION

In this study, we investigated the effects of rotation on localized muscle fatigue and performance, specifically the effects of rotation frequency and starting task, during repetitive assembly tasks at two exertion levels. Several measures indicated that rotating between the tasks resulted in less fatigue and improved performance compared to only performing the higher intensity task and increased fatigue and reduced performance compared to only performing the lower intensity task. This agrees with expected results and with prior research on rotation (Kuijer et al., 2004; Raina & Dickerson, 2009; Horton et al., 2012, 2013). Further, these results confirm that the two task conditions were distinct in terms of their physical workload.

Rotation frequency and starting task influenced a few of the EMG measures, but the direction of these effects was inconsistent between genders, and these effects were not supported by any other measures. Though it was hypothesized that less frequent rotation (i.e., 30 minutes versus 15 minutes) would increase overall fatigue, this effect was not present in this study's results. It is likely that the low-intensity loading periods did not allow for recovery from the higher intensity task, which does not follow the expectations that the low-intensity loads would serve as active recovery periods and reduce fatigue accumulation (Bond et al., 1991; Bogdanis et al., 1996; Sairyo et al., 2003). Similar results were found in earlier studies, which also showed no effects of rotation frequency on fatigue (Horton et al., 2012, 2013). Of note, a contemporary ergonomic tool, namely the occupational repetitive action index (OCRA), implicitly assumes an effect of rotation frequency in that rotation sequences containing longer duration tasks are given higher risk values (Occhipinti & Colombini, 2005).

Regarding starting task, it was hypothesized that starting with the low-intensity load would serve as an active warm-up period and reduce fatigue compared to starting with the high-intensity task. However, the results did not support such an effect. Existing work on task order has shown mixed results. Some studies have shown an order effect such that higher exertion ratings are given when starting a sequence with a more (versus a less) demanding task (Raina & Dickerson, 2009; Horton et al., 2012). In addition, warm-up exercises can improve performance and increase endurance time (Bishop, 2003). However, other research on rotation has indicated no effect of task order on either fatigue or performance (Keir et al., 2011; Horton et al., 2013). Further, the OCRA index assumes no effect of task order. For comparative purposes, Table 2 shows a ranking of the conditions from the present results (based on RPD ratings, Table 1) and from application of the OCRA index to the conditions (following methods in Occhipinti & Columbini, 2005). This comparison suggests that the OCRA approach may be overestimating the influence of task order, though future evidence is clearly needed to address this issue.

TABLE 2 Ranked conditions according to current results (RPDs) and OCRA index (Occhipinti & Columbini, 2005)

	RPDs	OCRA
LLLL	1	1
LHLH	3.5	2.5
HLHL	3.5	2.5
LLHH	3.5	4.5
HHLL	3.5	4.5
HHHH	6	6

Notes. A lower rank indicates lower risk; ranks of tied conditions are shown as the mean of the tied positions.

Several measures differed between genders, which indicated that males were more fatigued than females, a common finding in studies of upper extremity tasks performed at comparable levels of effort relative to capacity (e.g., Hicks, 2001; Nussbaum et al., 2001; Avin et al., 2010; Horton et al., 2012). Here, the mean effort level (i.e., lifting arms to perform task) for males was approximately 11% MVC (relative to shoulder flexion MVCs) and was approximately 13% MVC for females. However, gender differences were not consistent between muscles or measures tested, suggesting that the gender differences in fatigue development were not substantial.

The results of this study did not indicate any effects of task condition on heart rate. Heart rate was likely affected by individual performance on the task, since increased work pace can lead to increased metabolic demands (Garg et al., 1978), which in turn leads to an increase in heart rate (Kroemer et al., 1997). Although a lower heart rate was expected for the less demanding task, there was also higher performance for this task, which could have countered the effects of the lower physical demands on heart rate. Further, although some effects of rotation versus no rotation were seen in the EMG collected from the AD and MD, EMG measures were largely non-significant. A possible reason for this is that EMG data was only available during low-level reference contractions, which were on average ∼12% MVC (relative to shoulder flexion MVCs). EMG measures may not be sensitive to fatigue at exertion levels below 30% MVC (Oberg, 1994; Sood et al., 2007; Yassierli & Nussbaum, 2008; Movahed et al., 2011), possibly due to rotation of motor units or changes in firing rates (Westgaard & de Luca, 1999; Kamo, 2002). Further, although postures were controlled during each reference contraction, slight changes in posture may have been made that affected muscle activation levels and masked subtle changes occurring due to fatigue (De Luca, 1997).

Several additional limitations of this study should be noted. The work involved simulated assembly tasks performed in a controlled laboratory setting. Although this type of task broadly occurs in many occupations (i.e., upper extremity tasks requiring fine motor control), the tasks used here may not be representative of actual occupational work. Performance on the task in this study can be influenced largely by motivation (Buddenberg & Davis, 2000), and participant motivation here likely was lower than that of actual workers. Further, the task was similar to “bench” assembly, in which there is internal versus external control of pacing; the lack of controlled pacing of the task could have introduced a confounding effect due to differences in the amount of movement with differing performance. However, the static loading of the task (i.e., prolonged upper extremity elevation) was likely most relevant to fatigue development here, and differences in performance across conditions, though significant, were relatively minor (Table 1).

In addition, several constraints were placed on the study to facilitate implementation in a laboratory setting, and that may affect the generalizability of results to actual work environments. A small sample of healthy young adults was used, and it is likely that older workers would respond differently to the fatiguing tasks (Kent-Braun et al., 2002; Merletti et al., 2002; Deschenes, 2004; Yassierli et al., 2007; Avin & Frey Law, 2011). Further, the study may have been underpowered due to the small sample size and could therefore not detect what may be relatively small effect sizes due to rotation frequency and starting task. A compressed time period of 1 hour was used, and thus, the level of fatigue induced may not be representative of that experienced during a longer, more realistic, work shift. Only acute effects of fatigue were examined, within a 1-hour work period, though more cumulative effects, over longer periods or across days, may contribute to WMSD risk. In addition, only relatively simplistic rotation schedules were investigated (i.e., rotating only once or twice per shift).

In summary, the current results indicate that, as expected, rotation under the task conditions studied here reduced/increased fatigue compared to only performing the higher/lower intensity task. However, for this specific task and exertion levels, there did not appear to be any benefits toward increased rotation frequency, nor were there any benefits of starting with a lower exertion task. Further, neither parameter affected task performance. Overall, these findings suggest relatively small effects of rotation frequency or starting task. It is possible that effects were present but not detected due to their small effect sizes or due to the constrained nature of the task. Further, the current results may not be generalizable to rotation schedules with more than two tasks and/or longer work durations. Therefore, further work is needed to assess these effects under more realistic situations, for example, with longer duration tasks and using a larger, more diverse sample of tasks and participants.

CONFLICT OF INTEREST

The authors declare no conflict of interest. Dr. Woldstad served as Editor for this paper during the review process.

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REFERENCES

Allison, G. T., & Henry, S. M. (2002). The influence of fatigue on trunk muscle responses to sudden arm movements, a pilot study. *Clinical Biomechanics*, *17*(5), 414–417.

Allwood, J. M., & Lee, W. L. (2004). The impact of job rotation on problem solving skills. *International Journal of Production Research*, *42*, 865–881.

Anderson, J., & Budnick, P. (2009). *2008 Safety index: Ergonomics related injuries top disabling injury costs*. Retrieved February 27, 2012, from *Ergoweb*: http://www.ergoweb.com/news/detail.cfm?id=2315.

Aptel, M., Cail, F., Gerling, A., & Louis, O. (2008). Proposal of parameters to implement a workstation rotation system to protect against MSDs. *International Journal of Industrial Ergonomics*, *38*(11–12), 900–909.

Avin, K. G., & Frey Law, L. A. (2011). Age-related differences in muscle fatigue vary by contraction type: A meta-analysis. *Physical Therapy*, *91*(8), 1153.

Avin, K. G., Naughton, M. R., Ford, B. W., Moore, H. E., Monitto-Webber, M. N., . . . Law, L. A. (2010). Sex differences in fatigue resistance are muscle group dependent. *Medicine and Science in Sports and Exercise*, *42*(10), 1943–1950.

Azizi, N., Zolfaghari, S., & Liang, M. (2010). Modeling job rotation in manufacturing systems: The study of employee's boredom and skill variations. *International Journal of Production Economics*, *123*(1), 69–85.

Bishop, D. (2003). Warm up I: potential mechanisms and the effects of passive warm up on exercise performance. *Sports Medicine*, *33*(6), 439–454.

Bogdanis, G. C., Nevill, M. E., Lakomy, H. K. A., Graham, C. M., & Louis, G. (1996). Effects of active recovery on power output during repeated maximal sprint cycling. *European Journal of Applied Physiology*, *74*, 461–469.

Bond, V., Adams, R. G., Tearney, R. J., Gresham, K., & Ruff, W. (1991). Effects of active and passive recovery on lactate remove and subsequent isokinetic muscle function. *The Journal of Sports Medicine and Physical Fitness*, *31*(3), 357–361.

Borg, G. (1990). Physhophysical scaling with applications in physical work and the perception of exertion. *Scandanavian Journal of Work, Environment, and Health*, *16*, 55–58.

Buddenberg, L. A., & Davis, C. (2000). Test–retest reliability of the Purdue Pegboard Test. *The American Journal of Occupational Therapy*, *54*(5), 555–558.

Bureau of Labor Statistics (BLS). (2011). *Nonfatal occupational injuries and illnesses requiring days away from work, 2010*. Washington, DC.

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, *13*, 135–163.

Deschenes, M. R. (2004). Effects of aging on muscle fibre type and size. *Sports Medicine, 34*, 809–824.

Diego-Mas, J. A., Asensio-Cuesta, S., Sanchez-Romero, M. A., & Artacho-Ramirez, M. A. (2009). A multi-criteria genetic algorithm for the generation of job rotation schedules. *International Journal of Industrial Ergonomics*, *39*(1), 23–33.

Dimitrov, G. V., Arabadzheiv, T. I., Mileva, K. N., Bowtell, J. L., Crichton, N., & Dimitrova, N. A. (2006). Muscle fatigue during dynamic contractions assessed by new spectral indices. *Medicine and Science in Sports and Exercise*, *38*(11), 1971–1979.

Dugan, S. A., & Frontera, W. R. (2000). Muscle fatigue and muscle injury. *Physical Medicine and Rehabilitation Clinics of North America*, *11*(2), 385–403.

Fox, S. M., & Haskell, W. L. (1970). *The exercise stress test: needs for standardization*. New York: Academic Press.

Frazer, M., Norman, R., Wells, R., & Neumann, P. (2003). The effects of job rotation on the risk of reporting low back pain. *Ergonomics*, *46*(9), 904.

Garet, M., Boudet, G., Montaurier, C., Vermorel, M., Coudert, J., & Chamoux, A. (2005). Estimating relative physical workload using heart rate monitoring: a validation by whole-body indirect calorimetry. *European Journal of Applied Physiology*, *94*(1), 46–53.

Garg, A., Chaffin, D. B., & Herrin, G. D. (1978). Prediction of metabolic rates for manual materials handling jobs. *American Industrial Hygiene Association Journal*, *39*(8), 661–674.

Gonzalez-Izal, M., Malanda, A., Navarro-Amèzqueta, I., Gorostiaga, E. M., Mallor, F., Ibañez, J., and Izquierdo, M. (2010). EMG spectral indices and muscle power fatigue during dynamic contractions. *Journal of Electromyography and Kinesiology*, *20*(2), 233–240.

Gorelick, M., Brown, J. M. M., & Groeller, H. (2003). Short-duration fatigue alters neuromuscular coordination of trunk musculature: implications for injury. *Applied Ergonomics*, *34*(4), 317–325.

Granata, K. P., & Gottipati, P. (2008). Fatigue influences the dynamic stability of the torso. *Ergonomics*, *51*(8), 1258–1271.

Henderson, C. J. (1992). Ergonomic job rotation in poultry processing. *Advances in Industrial Ergonomics and Safety IV*, 443–450.

Hicks, A. L. (2001). Sex differences in human skeletal muscle fatigue. *Exercise and Sport Sciences Reviews*, *29*(3), 109.

Hinnen, U., Laubli, T., Guggenbuhl, U., & Krueger, H. (1992). Design of check-out systems including laser scanners for work posture. *Scandanavian Journal of Work, Environment, and Health*, *18*, 186–194.

Horton, L. M., Nussbaum, M. A., & Agnew, M. J. (2012). Effects of rotation frequency and task order on localised muscle fatigue and performance during repetitive static shoulder exertions. *Ergonomics*, *55*(10), 1205–1217.

Horton, L. M., Nussbaum, M. A., & Agnew, M. J. (2013). Rotation during lifting tasks: Effect of rotation frequency and task order on localized muscle fatigue and performance. (Under review.)

Jonsson, B. (1988). Electromyographic studies of job rotation. *Scandanavian Journal of Work, Environment, and Health*, *14*, 108–109.

Jorgensen, M., Davis, K., Kotowski, S., Aedla, P., & Dunning, K. (2005). Characteristics of job rotation in the Midwest US manufacturing sector. *Ergonomics*, *48*(15), 1721–1733.

Jouven, X., Zureik, M., Desnos, M., Guérot, C., & Ducimetière, P. (2001). Resting heart rate as a predictive risk factor for sudden death in middle-aged men. *Cardiovascular Research*, *50*(2), 373–378.

Kamo, M. (2002). Discharge behavior of motor units in knee extensors during the initial stage of constant-force isometric contraction at low force level. *European Journal of Applied Physiology*, *86*(5), 375–381.

Keir, P. J., Sanei, K., & Holmes, M. W. R. (2011). Task rotation effects on upper extremity and back muscle activity. *Applied Ergonomics*, *42*(6), 814–819.

Kent-Braun, J. A., Ng, A. V., Doyle, J. W., & Towse, T. F. (2002). Human skeletal muscle responses vary with age and gender during fatigue due to incremental isometric exercise. *Journal of Applied Physiology*, *93*(5), 1813–1823.

Kher, H. V., Malhotra, M. K., Philipoom, P. R., & Fry, T. D. (1999). Modeling simultaneous worker learning and forgetting in dual resource constrained systems. *European Journal of Operational Research*, *115*(1), 158–172.

Kroemer, K. H. E., Kroemer, H. J., & Kroemer-Elbert, K. E. (1997). *Engineering physiology: Bases of human factors/ergonomics* (3rd ed.). Hoboken, NJ: John Wiley & Sons.

Krogh-Lund, C., & Jørgensen, K. (1991). Changes in conduction velocity, median frequency, and root mean square-amplitude of the electromyogram during 25% maximal voluntary contraction of the triceps brachii muscle, to limit of endurance. *European Journal of Applied Physiology and Occupational Physiology*, *63*(1), 60–69.

Kuijer, P. P. F. M., de Vries, W. H. K., van der Beek, A. J., van Dieën, J. H., Visser, B., & Frings-Dresen, M. H. W. (2004). Effect of job rotation on work demands, workload, and recovery of refuse truck drivers and collectors. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *46*, 437–448.

Kuijer, P. P. F. M., van der Beek, A. J., van Dieën, J. H., Visser, B., & Frings-Dresen, M. H. W. (2005). Effect of job rotation on need for recovery, musculoskeletal complaints, and sick leave due to musculoskeletal complaints: A prospective study among refuse collectors. *American Journal of Industrial Medicine*, *47*(5), 394–402.

Kuijer, P. P. F. M., Visser, B., & Kemper, H. C. G. (1999). Job rotation as a factor in reducing physical workload at a refuse collecting department. *Ergonomics*, *42*(9), 1167–1178.

Mathiassen, S. E. (2006). Diversity and variation in biomechanical exposure: What is it, and why would we like to know? *Applied Ergonomics*, *37*(4), 419–427.

Merletti, R., Farina, D., Gazzoni, M., & Schieroni, M. P. (2002). Effect of age on muscle functions investigated with surface electromyography. *Muscle & Nerve*, *25*(1), 65–76.

Möller, T., Mathiassen, S. E., Franzon, H., & Kihlberg, S. (2004). Job enlargement and mechanical exposure variability in cyclic assembly work. *Ergonomics*, *47*(1), 19–40.

Movahed, M., Ohashi, J.-Y., Kurustien, N., Izumi, H., & Kumashiro, M. (2011). Fatigue sensation, electromyographical and hemodynamic changes of low back muscles during repeated static contraction. *European Journal of Applied Physiology*, *111*(3), 459–467.

Muramatsu, M., Miyazaki, H., & Ishii, K. (1987). A successful application of job enlargement/enrichment at Toyota. *IIE Transactions*, *19*(4), 451–459.

Nussbaum, M. (2001). Static and dynamic myoelectric measures of shoulder muscle fatigue during intermittent dynamic exertions of low to moderate intensity. *European Journal of Applied Physiology*, *85*(3), 299–309.

Nussbaum, M. A., Clark, L. L., Lanza, M. A., & Rice, K. M. (2001). Fatigue and endurance limits during intermittent overhead work. *AIHA Journal*, *62*, 446–456.

Oberg, T. (1994). Subjective and objective evaluation of shoulder muscle fatigue. *Ergonomics*, *37*(8), 1323–1333.

Occhipinti, E., & Colombini, D. (2005). The occupational repetitive action (OCRA) methods: OCRA index and OCRA checklist. In N. Stanton, K. Brookhuis, A. Hedge, E. Salas, & H. W. Hendrick (Eds.), *Handbook of human factors and ergonomics methods* (pp. 1–14). Boca Raton, FL: CRC Press.

Perotto, A. O. (1994). *Anatomical guide for the electromyographer* (3rd ed.). Springfield, IL: Charles C. Thomas.

Potvin, J. R., & Bent, L. R. (1997). A validation of techniques using surface EMG signals from dynamic contractions to quantify muscle fatigue during repetitive tasks. *Journal of Electromyography and Kinesiology*, *7*(2), 131–139.

Raina, S. M., & Dickerson, C. R. (2009). The influence of job rotation and task order on muscle fatigue: A deltoid example. *Work*, *34*, 205–213.

Rissen, D., Melin, B., Sandsjos, L., Dohns, I., & Lundberg, U. (2002). Psychophysiological stress reactions, trapezius muscle activity, and neck and shoulder pain among female cashiers before and after introduction of job rotation. *Work & Stress*, *16*(2), 127–137.

Sairyo, K., Iwanaga, K., Yoshida, N., Mishiro, T., Terai, T., Sasa, T., & Ikata, T. (2003). Effects of active recovery under a decreasing work laod following intense muscular exercise on intramuscular energy metabolism. *International Journal of Sports Medicine*, *24*, 179–182.

Simão, R., Farinatti, P. T. V., Polito, M. D., Maior, A. S., & Fleck, S. J. (2005). Influence of exercise order on the number of repetitions performed and perceived exertion during resistance exercises. *Journal of Strength and Conditioning Research*, *19*(1), 152–156.

Sood, D., Nussbaum, M. A., & Hager, K. (2007). Fatigue during prolonged intermittent overhead work: Reliability of measures and effects of working height. *Ergonomics*, *50*(4), 497–513.

Spreuwenberg, L. P. B., Kraemer, W. J., Spiering, B. A., Volek, J. S., Hatfield, D. L., Silvestre, R., . . . Fleck, S. J. (2006). Influence of exercise order in a resistance-training exercise session. *Journal of Strength and Conditioning Research*, *20*(1), 141–144.

Strath, S. J. (2000). Evaluation of heart rate as a method for assessing moderate intensity physical activity. *Medicine and Science in Sports and Exercise*, *32*(9), S465–S470.

Tharmmaphornphilas, W., & Norman, B. A. (2004). A quantitative method for determining proper job rotation intervals. *Annals of Operations Research*, *128*(1), 251–266.

Tiffin, J., & Asher, E. J. (1948). The Purdue Pegboard: Norms and studies of reliability and validity. *Journal of Applied Psychology*, *32*(3), 234–247.

Weist, R., Eils, E., & Rosenbaum, D. (2004). The influence of muscle fatigue on electromyogram and plantar pressure patterns as an explanation for the incidence of metatarsal stress fractures. *The American Journal of Sports Medicine*, *32*(8), 1893–1898.

Wells, R., McFall, K., & Dickerson, C. R. (2010). Task selection for increased mechanical exposure variation: Relevance to job rotation. *Ergonomics*, *53*(3), 314–323.

Wells, R., Moore, A., & Ranney, D. (1989). Musculoskeletal stressses during light assembly. *Conference of the Human Factors Association of Canada*, Toronto, Ontario, November 26–29.

Westgaard, R. H., & de Luca, C. J. (1999). Motor unit substitution in long-duration contractions of the human trapezius muscle. *Journal of Neurophysiology*, *82*(1), 501–504.

Winkel, J., & Westgaard, R. (1992). Occupational and individual risk factors for shoulder-neck complaints: Part II—The scientific basis (literature review) for the guide. *International Journal of Industrial Ergonomics*, *10*(1–2), 85–104.

Yassierli, & Nussbaum, M. A. (2008). Utility of traditional and alternative EMG-based measures of fatigue during low-moderate level isometric efforts. *Journal of Electromyography and Kinesiology*, *18*(1), 44–53.

Yassierli, Nussbaum, M. A., Iridiastadi, H., & Wojcik, L. A. (2007). The influence of age on isometric endurance and fatigue is muscle dependent: A study of shoulder abduction and torso extension. *Ergonomics*, *50*(1), 26–45.