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Muscular loading during simulated carpentry tasks

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Abstract

Carpenters are at high risk for work related musculoskeletal disorders due to the nature of their work tasks. The objective of this research was to quantify forearm muscular loading of eighteen novice carpenters performing two simulated carpentry tasks: deck building and picket installation. Surface EMG of select forearm muscles were collected during 15 minute task simulations. Though no differences were found between work tasks, mean and peak EMG measures were found to be signficantly greater than recommended levels for localized muscle fatigue development (15% of maximum voluntary contraction), increasing injury risk for these tasks.

Keywords
Construction, work related musculoskeletal disorder, carpenter, electromyography

1. Introduction

Construction workers historically have some of the highest incident rates for work related musculoskeletal disorders (WMSDs). WMSD risk across construction trades is not uniform [1]. Carpenters have been identified as a high risk trade within construction, with 43.5 per 10,000 full time workers having over exertion injuries [2]. This number is significantly higher than all other industries which is reported to be 32.8 per 10,000 full time workers [2]. Carpentry work is physically demanding and exposes workers to a variety of known occupational risk factors, including high force, repetition, non-neutral postures, and vibration, among others.

Frequent forceful and repetitive hand activities are some of the most frequently identified high risk activities in the construction industry, particularly for carpenters [3]. Forceful exertions in the construction industry can arise from tool usage, handling of materials, or using the body/limbs to perform work activities. Research has shown that carpenters handle loads of greater than 10kg for approximately 7% of their total working time [4]. Increased force requirements have been found, irrespective of other factors, to increase odds ratios of developing an upper extremity WMSDs [e.g., 5-8].

Romerts curve's are some of the most commonly used tools to evaluate potential injury risk from task demands. These curves display the time a person can sustain an exertion at a specified level [9]. It has been generally accepted that exertions less than 15% of maximum are "safe" and minimize injury risk, though recent research has shown that prolonged low level exertions (i.e., exertions less than 15%) also cause localized muscle fatigue [e.g., 10]. The objective of this study was to quantify muscular loading of the forearm of novice carpenters during simulations of two residential, finished carpentry tasks.

2. Methodology

2.1 Experimental Design

A repeated measures design was used to compare forearm muscle loading between two tasks (deck building and picket installation) and four forearm muscles. Exposure to tasks was counterbalanced to minimize confounding related to order of exposure.

2.2 Participants

Nineteen participants (15 males and 4 females) completed the study protocols. Participants had no experience in construction, could not have hobbies comparable to residential construction (e.g., wood working, home improvement, etc.), or have upper extremity musculoskeletal injuries. All inclusion criteria were determined via self report through a demographic questionnaire.

2.3 Work Task Simulations

Each participant completed the two tasks (deck building and picket installation) for a 15 minute period, for a total of 30 minutes of work. These tasks were selected based on discussions with a residential construction carpenter. The pace of the work was self determined. A 15 minute period was selected to minimize fatigue associated with task performance. A minimum of 10 minutes of rest was provided between each task. Prior to beginning the second work task, participants verbally rated their perceived level of fatigue using a modified Borg CR-10 Perceived Level of Exertion Scale [11]. No participant was allowed to continue until a perceived fatigue level of 1 or lower was reported to reduce any confounding influence of fatigue on task performance. Participants received an explanation of both tasks and a 5-minute familiarization period (followed by 5 minutes of rest) to become accustomed to using a nail gun. All testing was completed within a single test session lasting approximately 2 hours.

2.3.1 Deck Building

Participants were asked to install deck planks on a 10' x 10' deck frame. Participants retrieved deck boards from a stack located near the deck frame. One deck board was fitted with pre-set lags for the picket installation task. Participants were required to retrieve this board first and secure it to the outer edge of the deck frame. Participants secured each board with two nails at each end, and along each joint of the decking. A pneumatic nail gun was used for nail installation. All required materials for this task (e.g., nails, boards, eye protection, and hearing protection) were made available to the participants.

2.3.2 Picket Installation

Picket installation involved only the aspect of obtaining a picket and screwing it onto the preset lags along the edge of the deck planking (as is common in this activity). Pickets were 1¾" dowels with pre-drilled holes in the end for ease of attachment. A set of 24 pickets were available to participants. Participants manually screwed pickets onto lags until they were flush and tight. Participants that completed this task first had the deck board with the lags attached to the deck frame prior to starting. This board was then removed from the deck frame during the rest period. As with the deck building task, all required materials for this task were made available to the participants.

2.4 EMG Measurement

Surface electromyography (EMG) of the flexor carpi ulnaris (FCU), extensor carpi ulnaris (ECU), flexor carpi radialis (FCR), and brachioradialis of the dominant arm was obtained using 10-millimeter, circular Ag/AgCl pregelled bipolar disposable electrodes. Standard electrode preparatory procedures were followed and electrodes were placed according to standard practice [12]. Leads were secured to the arm with medical tape to reduce noise and minimize lead displacement. EMG signals were hardware amplified, band-pass filtered (10-500 Hz), RMS converted (110 ms time constant), and A/D converted. The amplifier gain was set such that the signals did not exceed 2-3 volts. Input impedance was measured using a standard voltmeter to ensure impedance was within acceptable levels ($<10k\Omega$).

After stabilization of the electrodes (15 minutes), resting and maximum voluntary contractions (MVCs) were obtained. Resting RMS EMG measurements were recorded at 256 Hz for 6 seconds with the participant's hands resting along their sides. MVCs were obtained by having participants hold a wooden dowel, ¾ inch in diameter in the two hands and twist the hands in opposing directions. A minimum of three trials were performed following a 5 second ramp-up, ramp-down procedure. A one minute rest period was provided between exertions. Additional MVC trials were run only if the maximum was obtained for any muscle on the third trial. Participants Peak RMS EMG signals were identified for each trial using Noraxon's MyoResearch XP Master Edition software (Noraxon, Scottsdale, Arizona), and the maximum value taken as the MVC for that muscle for normalization of task EMG.

Task RMS EMG was sampled at 256 Hz for the entire test session using a Myosystem 1400A system (Noraxon, Scottsdale, Arizona), and subsequently smoothed (5 Hz low pass filter) and stored. This smoothed data was used to estimate normalized force levels. Peak and mean RMS values were calculated for the entire test session. The first and last 10 seconds of the experimental condition were removed to reduce start up and task completion effects. Processed data was expressed in terms of percent MVC.

2.5 Procedure

Participants were provided with a verbal and written description of the research, its objectives, and completed informed consent documents approved by the Mississippi State University IRB prior to any experimentation. Demographic questionnaires were completed and inclusion determined. All participants received training on Borg Scale use, fitted with the data collection equipment, familiarized with the task, and following the stabilization period for EMG, resting and MVC assessments were taken. Participants completed the experimental test session and were monetarily compensated for their time.

2.6 Data Analysis

A repeated measures ANOVA was used to determine the effect of task and muscle on normalized task mean and peak EMG readings. Tukey's HSD tests were run where appropriate. All data analysis was performed using SAS 9.1.3 and results were considered significant at alpha = 0.05.

3. Results

Descriptive statistics for forearm muscular loading are provided in Table 1. As can be seen in the table, most muscles had mean loading levels at or above the 15% of MVC limit for minimizing localized muscle fatigue. Peak activity levels were approximately 60% or greater. Repeated measures ANOVA and Tukey HSD results indicate that only % Peak MVC differed across muscles with the FCR having significantly higher activity than the other muscles (Table 2). No interaction effects were found.

Table 1. Descriptive statistics of forearm loading by task and muscle. Values are mean (standard deviation)

Task	Muscle	% Mean	% Peak
Deck Building	Brachioradialis	14.46 (16.64)	70.31 (49.41)
	ECU	14.87 (10.27)	69.09 (42.11)
	FCR	22.46 (27.24)	139.69 (137.62)
	FCU	17.19 (18.76)	87.01 (70.68)
Picket Installation	Brachioradialis	11.00 (8.90)	58.79 (46.50)
	ECU	16.52 (13.40)	85.55 (69.26)
	FCR	20.11 (23.01)	138.96 (159.43)
	FCU	10.47 (9.04)	66.74 (44.93)

Table 2. Repeated measures ANOVA results. Values are p-values.

Factor	DF	% Mean	% Peak
Task	1	0.3139	0.7800
Muscle	3	0.1176	**0.0013**
Task by Muscle	3	0.7446	0.8224

Bold value indicates significant finding

4. Discussion

The objective of this study was to quantify muscular loading of the forearm during simulated finished carpentry tasks. Results of this study show that loading was not affected by task, though some differences across muscles were found. Muscular loading levels were found to exceed 15% of maximum for most muscles, with peak values in excess of 60% of maximum. The lack of differences between tasks was unexpected. The deck building task was expected to elicit higher muscle activity levels due to the use of a nail gun (static loading from holding the nail gun as well as increased activity during nail gun activation). Also, the transport of boards from a "supply location" and arrangement on the deck frame were expected to elicit higher activity levels. It is likely that the lack of a significant finding is due to rest periods built into the deck building task (e.g., setting down the gun, moving unloaded). Because these activities would be frequent (roughly every board), it can be estimated that approximately 50% of the task was performed without muscular loading on the forearm muscles. The picket installation task, on the other hand likely elicited muscle activity for a greater proportion of the task (during the screwing down of the pickets) though this level may have been at a lower level. This study only investigated gross measures of muscle activity.

Research has shown that other measures (EMG gaps, percent of time spent above various levels of activity, etc.) may more accurately represent the muscular loading of individuals during task performance. Further analysis of this data will incorporate these more descriptive values.

Another potential reason for a lack of difference between tasks and muscles is the muscles under investigation. Other muscles of the upper extremity (e.g., the shoulder, cervical spine, and upper back) may have higher activity levels due to the role in maintaining posture and during transport of materials (boards and pickets). Though those muscles were not the focus of this paper, analysis of muscle activity levels for those muscles is currently underway.

Further, individual differences may also be of interest (e.g., gender, body size, etc.) as these have been associated with various WMSDs. This study did not investigate these differences, as the focus of this paper, was task effects. Future analysis of this data should include these factors as potential covariates.

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