HUMAN FACTORS, 1989, 31(4), 413–420

Effects of Handle Angle and Work Orientation on Hammering: II. Muscle Fatigue and Subjective Ratings of Body Discomfort

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This research investigated how changes in hammer handle angle and hammering orientation affected muscle fatigue in the forearm and subjective ratings of body discomfort. Forearm muscle fatigue and discomfort ratings were not significantly affected by handle angle, but they were significantly higher in the wall hammering orientation than in the bench orientation. The research in this article and in the companion article (Part I) reveal that for novices, hammers with handles angled in the range of 20–40 deg are advantageous because (1) they reduce ulnar deviation and may possibly decrease the incidence of hand/wrist disorders, and (2) they do not significantly affect hammering performance in the bench conditions, forearm muscle fatigue, or subjective ratings of body discomfort.

INTRODUCTION

This article explores how changes in hand tool design (i.e., hammer handle angle) and task design (i.e., hammering orientation) affected internal and cognitive measures of hammering, muscle fatigue in the forearm, and subjective ratings of body discomfort. The companion paper to this study (Schoenmarklin and Marras, 1989, this issue) discusses external measures, wrist motion, and performance. Collectively the two articles represent the results of two complementary approaches to the study of hand tool and task design parameters.

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Muscle Fatigue

Muscle fatigue in the extrinsic muscles of the forearm is an important dependent measure because it is an indicator of the status of the internal components of the wrist and forearm. Study of muscle fatigue could facilitate an understanding of cumulative trauma disorders (CTDs) in the wrist, such as carpal tunnel syndrome and tenosynovitis, in the substitution patterns of muscular contractions. In awkward wrist postures the fatigue of forearm muscles could bring about substitution patterns that would require additional forearm muscles to provide force. The increased tendon forces of these additional muscles could cause an increase in the contact forces between the tendons and their adjacent structures in the wrist (carpal bones and flexor retinaculum) and could result in tendon inflammation. The inflamed tendons of the additional muscles could increase the overall risk of CTDs. In this way substitution patterns brought on by fatigue could place workers at a greater risk of injury.

Muscle fatigue can also be a measure of hand tool/hand compatibility and can be used to evaluate various hand tool designs in terms of ergonomics. An ergonomically designed hand tool should minimize the amount of fatigue in the forearm.

In this study muscle fatigue was measured by analyzing the shift in the power spectrum of the electromyographic (EMG) signal from a muscle. Chaffin (1969) found that as muscle fatigue increased, the power spectrum shifted to a low-frequency range, thereby decreasing the median frequency of the EMG signal. As illustrated in Figure 1, the median frequency is the frequency at which the area under the power density curve is divided into halves (Merletti, Biey, Biey, Prato, and Orusa, 1985). The shift to low frequencies is a direct result of the physiologic process of fatigue; see Basmajian and De Luca (1985, p. 211) for a detailed explanation.

Subjective Ratings of Body Discomfort

Subjective discomfort ratings are important in that they can indicate areas of

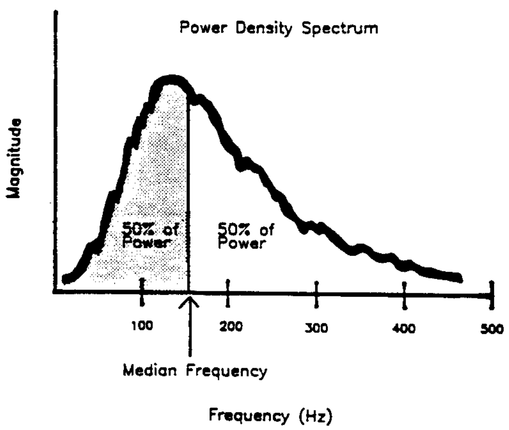

Figure 1. *The median frequency of an EMG signal.*

human-tool-task incompatibility that have not been quantified (Corlett and Bishop, 1976). These areas of human-tool-task incompatibilities can then be researched further with objective dependent variables. Subjective ratings are also important because they can provide additional information on muscle fatigue that has already been quantified by objective techniques.

METHOD

Subjects

Eight healthy, right-handed males volunteered to be subjects. All were novices at hammering.

Experimental Design

The independent variables were hammer handle angle (0, 20, and 40 deg) and hammering orientation (bench and wall). A complete description of the independent variables can be found in Schoenmarklin and Marras (1989, this issue). The dependent variables were muscle fatigue as measured by shifts in median frequency and subjective ratings of body discomfort.

Apparatus

EMG apparatus. The EMG apparatus and system are shown in Figure 2. Miniature silver-silver chloride surface electrodes (Baby Beckman type) were glued to the forearm flexor muscles. At the muscle site surface electrodes were connected to a miniature preamplifier, which was connected to the EMG system. EMG signals were monitored by an analog-to-digital converter and were stored on an IBM AT. The raw EMG data were collected at 1024 Hz and were analyzed by Fast Fourier Transform (FFT) software, which computed the median frequency of the raw EMG signal.

Test exertion. A hand dynamometer was used to record hand grip strength, as illus-

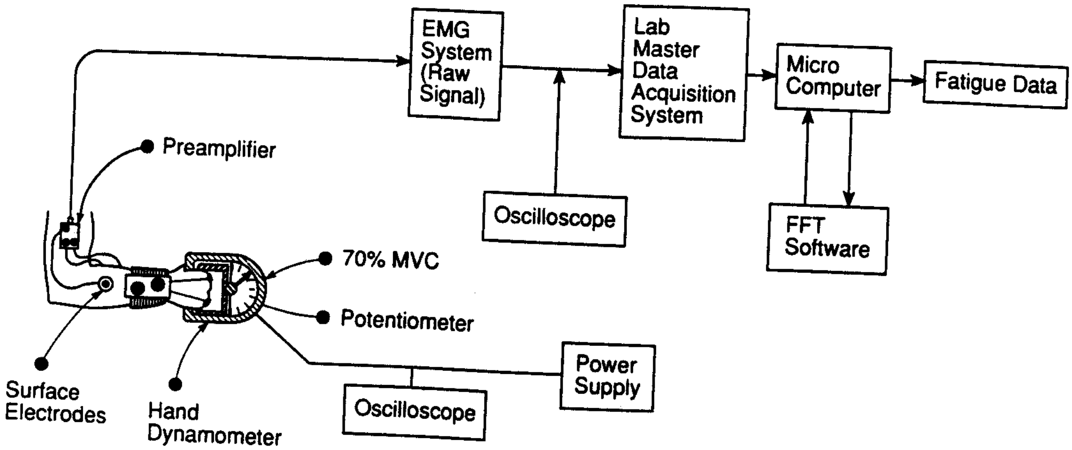

Figure 2. *Apparatus used to measure muscle fatigue data.*

trated in Figure 2. Grip strength was displayed on an oscilloscope by a voltage trace so the subject could monitor his exertion level. Temporary marks were placed on the oscilloscope's display which indicated the absolute level of each subject's 70% maximum voluntary contraction (MVC) of grip strength.

Procedure

The skin was prepared for electrode placement, two surface electrodes were glued to the flexor carpi radialis on the medial side of the forearm, and one ground electrode was placed on the dorsal side of the forearm.

Before the experimental hammering sessions began, the median frequencies of the EMG signals were determined while the subject exerted a sustained 70% MVC of grip strength. Based on a pilot study, 70% MVC was found to be a force level that subjects could exert after a 3-min hammering session. While monitoring his grip strength on the oscilloscope, the subject exerted a sustained 70% MVC exertion until fatigue (defined as the point when the subject could no longer maintain a 70% MVC level) was experienced. The median frequency was computed every 4 s during the sustained contraction.

Immediately after each 3-min hammering session, the subject exerted a brief 70% MVC contraction for 8 s, which was the time required for two estimates of median frequency. In addition, the subject rated the comfort/discomfort of various body segments that are illustrated in Figure 3 on an ordinal scale from 1 to 9 representing extremes of comfort and discomfort, respectively.

Data Treatment

The purpose of the sustained 70% MVC contraction before hammering was to derive a median frequency graph for each subject, as shown in Figure 4. Petrofsky and Lind (1980) found that the median frequency of the extrinsic flexor muscles decreased linearly with time throughout the duration of a fatiguing isometric contraction during constant tension.

An average of the two estimates of median frequency after each hammering session was used to calculate the percentage of fatigue, defined by Equation 1

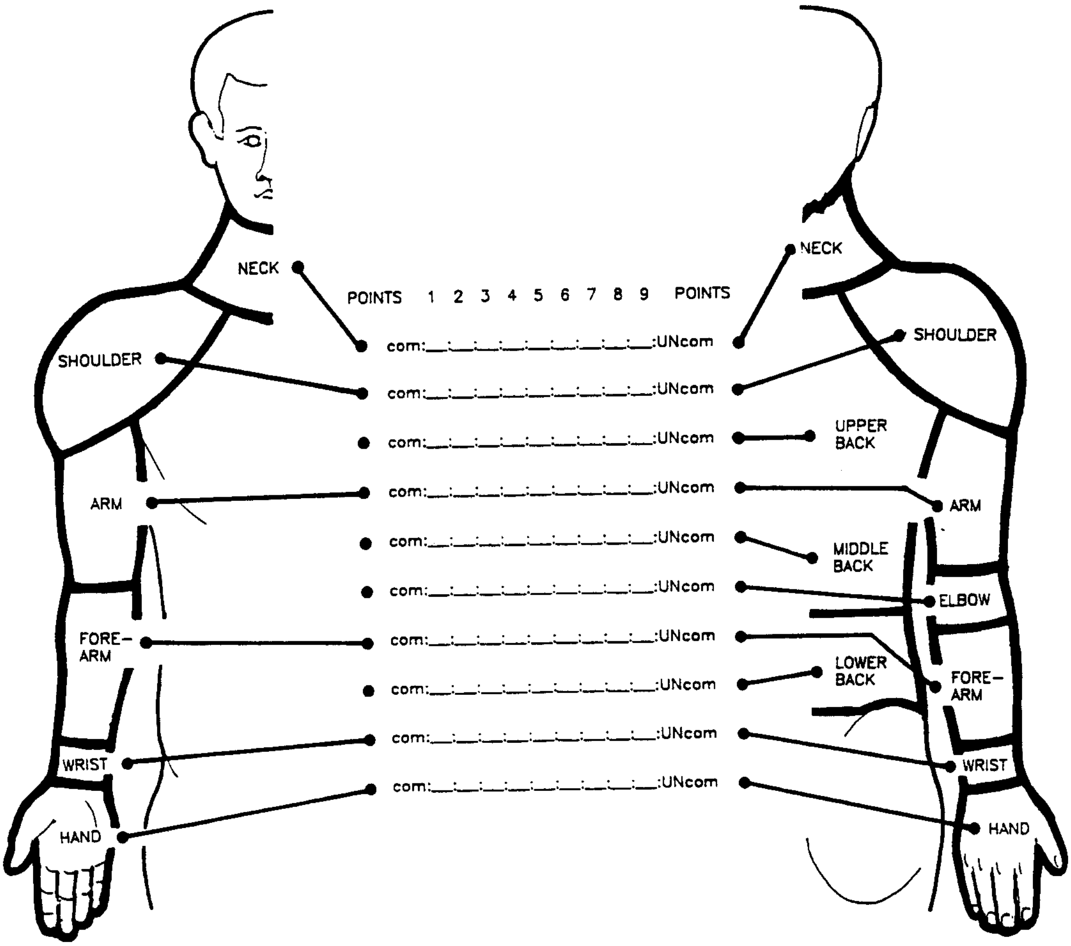

Figure 3. *Body segments that each subject rated for comfort/discomfort after each hammering session. Ratings of 1 and 9 represent levels of extreme comfort and discomfort, respectively.*

Percentage of fatigue =

$$\frac{|MF(\text{session}) - MF(\text{beginning})|}{MF(\text{beginning}) - MF(\text{end})} \quad (1)$$

where *MF* (beginning) = median frequency at start of sustained 70% MVC (before hammering sessions), *MF* (end) = median frequency at end of sustained 70% MVC, and *MF* (session) = average median frequency of brief 70% MVC after each hammering session.

Statistical Analysis

Using SAS Institute, Inc., software, we analyzed the fatigue data with an analysis of variance technique. A significance level of 0.10 was selected for the fatigue data.

The subjective data were analyzed with a nonparametric test, the Kruskal-Wallis one-way ANOVA. The effects of angle and orientation were analyzed separately.

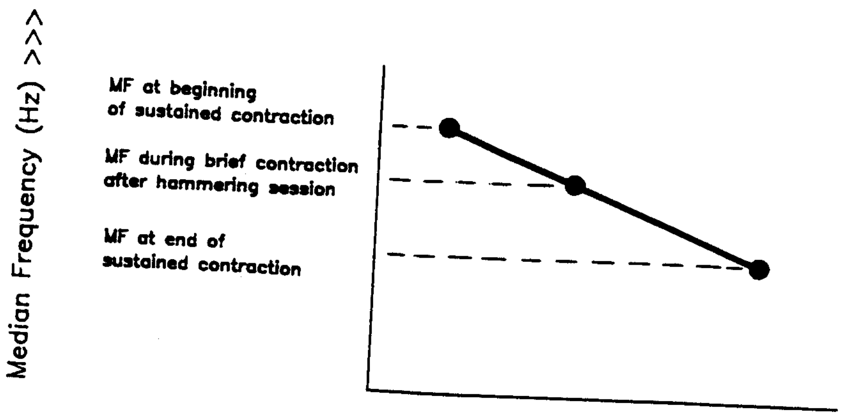

Figure 4. *Linear decrease of median frequency (MF) of the forearm flexor muscles during a sustained handgrip contraction of constant force. During a sustained contraction until fatigue, the MF decreases approximately 24% from beginning to end of contraction (Petrofsky and Lind, 1980).*

RESULTS

Fatigue

As shown in Table 1, the hammer handle angle effect and angle-orientation interaction were not significant at the 0.10 level of significance. The percentages of fatigue across all hammer handle angles were closely spaced, ranging from 40.1% for the straight hammer to 45.1% for the 40-deg hammer.

The orientation effect was significant. The wall conditions resulted in a 46.2% decrease in median frequency, 8.5% more than the 37.7% decrease in median frequency in the bench conditions.

Typically subjects display high individual differences in EMG studies. Figure 5 illustrates the percentage decrease in median frequency for all eight subjects as a function of hammering orientation. The percentage decreases differed dramatically, ranging from approximately 10% to 95%.

Subjective Ratings of Body Segment Comfort/Discomfort

Table 2 shows the results of the Kruskal-Wallis nonparametric analysis of body seg-

TABLE 1

Levels of Significance from ANOVA of Percentage of Muscle Fatigue

Dependent Variable	*Independent Variables*		
	Orientation	*Angle*	*Orientation × Angle*
Percentage of fatigue	$p = 0.0757$*	$p = 0.5397$	$p = 0.9242$

* Significant at 0.10 level.

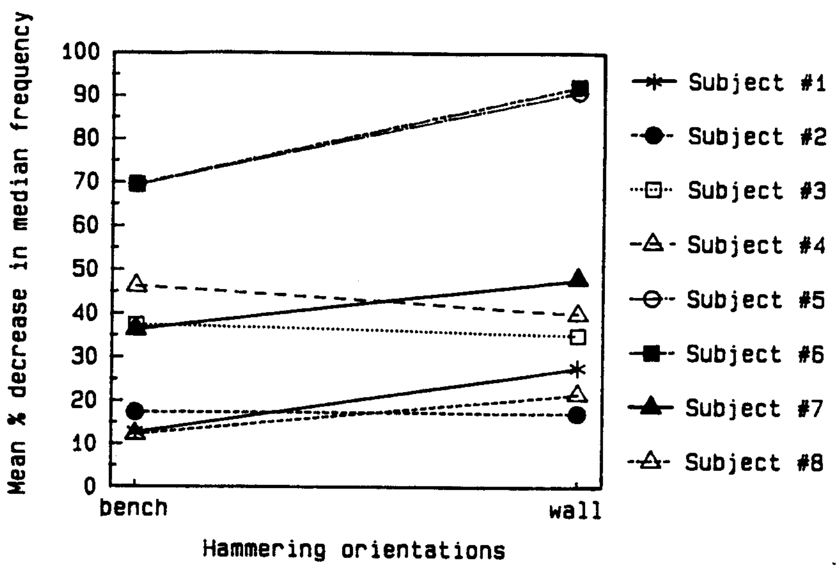

Figure 5. *Mean percentage decrease in median frequency of forearm flexor muscles in bench and wall orientations for all eight subjects.*

ment discomfort data. None of the body segments revealed a significant hammer handle angle effect, but several segments in the arm, upper torso, and neck regions revealed a significant orientation effect. Figure 6 illustrates the subjective discomfort ratings for each body segment as a function of hammering orientation. For each body segment that had a significant orientation effect, the bench orientation was judged more comfortable.

DISCUSSION

Muscle Fatigue

The median frequency parameter was selected as the fatigue measure in this experiment because it has been shown to be an objective estimator of fatigue (Stulen and De Luca, 1981). However, another parameter, the amplitude of the EMG signal, is sometimes used to estimate fatigue. The amplitude of the EMG signal has been shown to increase during fatiguing isometric contractions at constant tensions (Lippold, Redfearn, and Vuco, 1960; Petrofsky, Glaser, and Phillips, 1982). However, EMG amplitude is not as reliable as the median frequency in estimating fatigue (NIOSH, 1989).

The difference in forearm muscle fatigue between the two hammering orientations can be explained by the physical nature of the orientations. In the wall orientation, the hand must grip the hammer handle to support the hammer weight in addition to absorbing the net reaction force at impact, whereas in the bench orientation the handle can be gripped more loosely because of the decreased likelihood of dropping the hammer. The increased forearm muscle fatigue in the wall orientation could increase the number of repetitions required to complete a hammering task, which would expose the worker to a greater risk of upper-limb CTD injury.

Subjective Ratings of Body Discomfort

The higher subjective discomfort in the wall conditions is supported by actual fa-

TABLE 2

Levels of Significance of Body Segment Comfort/Discomfort Using the Kruskal-Wallis One-Way ANOVA (Nonparametric)

Dependent Variables	Abbreviation	Independent Variables: Orientation	Angle
Neck	Neck	p = 0.0017**	p = 0.5979
Shoulder	Shdr	p = 0.0019**	p = 0.4723
Upper back	Ubck	p = 0.0172*	p = 0.9373
Arm	Arm	p = 0.0076**	p = 0.3381
Middle back	Mbck	p = 0.0090**	p = 0.9366
Elbow	Elbw	p = 0.1592	p = 0.3060
Forearm	Farm	p = 0.0261*	p = 0.1024
Lower back	Lbck	p = 0.0850	p = 0.9236
Wrist	Wrst	p = 0.0855	p = 0.0803
Hand	Hand	p = 0.5119	p = 0.1543

* Significant at 0.05 level; **significant at 0.01 level.
The orientation and angle independent variables were evaluated separately.

tigue data and the literature. Considering the early fatigue of the supraspinatus, upper trapezius, and biceps brachii muscles when the arm is elevated (Hagberg, 1981), it is understandable that subjects rated the shoulder, upper back, middle back, and upper arms as more uncomfortable in the wall orientation.

The subjective ratings of discomfort in the wall orientation indicate an inadequacy of match between the worker and task (based on the principles of Corlett and Bishop, 1976) and point out a design parameter that should be considered in the workplace design of carpentry and woodworking jobs. Hammering in the postures that require arm elevation could cause degenerative tendinitis in the

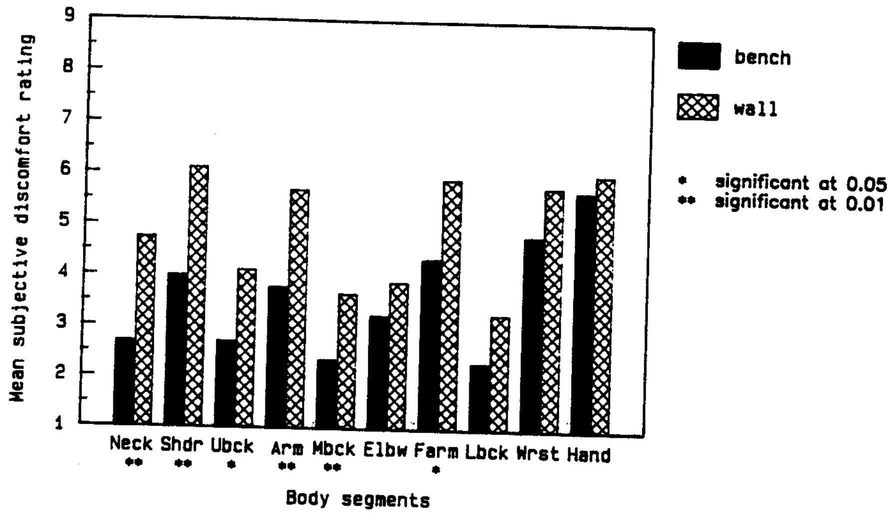

Figure 6. *Mean subjective ratings of comfort/discomfort of body segments as a function of hammering orientation. See Table 2 for abbreviations and Figure 3 for locations of body segments. Ratings of 1 and 9 represent extreme comfort and discomfort, respectively.*

biceps and supraspinatus (Chaffin and Andersson, 1984).

CONCLUSION

This research shows that muscle fatigue data as measured by EMG median frequency and subjective ratings of body discomfort can provide valuable information in the ergonomic evaluation of hand tools and workplace design. Fatigue of the forearm flexor muscles provides information on the hand and hand tool interface. Hammer handle angle did not significantly affect forearm muscle fatigue, but wall hammering did result in significantly higher muscle fatigue than did bench hammering.

Subjective ratings of body discomfort were consistent with *objective* fatigue data. Hammer handle angle did not significantly affect body segment discomfort ratings, but the subjective ratings of discomfort in the upper torso, neck, and arm indicated increased discomfort in wall hammering. The discomfort ratings and the increased muscle fatigue in the wall orientation point out an inadequacy between the worker and task. The elevated arm posture in wall hammering could possibly cause CTDs in the shoulder.

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