

MUSCULOSKELETAL STRESSES DURING LIGHT ASSEMBLY

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ABSTRACT

This study of workers on a rotating electronic assembly line examined musculoskeletal stresses in the upper limbs. Rotation has often been suggested as a means of controlling musculoskeletal loads. Of particular interest therefore were the differences between jobs within the rotation sequence. Also of interest was the between worker differences. The musculoskeletal stresses on the right arm and shoulder were evaluated using electromyography (EMG) of the forearm and shoulder (trapezius) musculature, and postural analysis of the wrist. Six female workers were monitored as they rotated through four different workstations under normal production conditions. As expected, sizable differences between workers were found but the relative musculoskeletal stresses of the four tasks showed consistency.

INTRODUCTION

Assembly workers have been found to suffer from a number of musculoskeletal health problems, particularly in the wrist, arm, neck and shoulders e.g., Kourinka and Koskinen (1979), Kilbom *et al.* (1986), Aaras and Westgaard (1987).

Job rotation is often used to compensate for stressful work of short cycle time. Hagberg (1986) suggests that slightly different tasks may lead to changes in loading and lead to a decrease in the rate of fatigue. Jonsson, (1988) however showed that for assembly of telephones, the load on the trapezius muscle showed only small differences between tasks whereas assembling and inspecting printed circuit boards did show differences in loading. The effectiveness of rotation therefore depends, in part, on the difference in musculoskeletal loads between tasks, taking into account not only shoulder loads but also those on the forearm and hand.

In epidemiological investigations it is tempting to quantify exposure to musculoskeletal stress using only a few workers. Cristensen (1986) has shown large differences between subjects using EMG whilst Kilbom and colleagues (1986) have shown that there are large postural variations between workers, even when they perform exactly the same task.

This paper reports the upper limb musculoskeletal stresses on rotating assembly workers on a light electronic assembly line, particularly the between worker differences and the differences between jobs within the rotation sequence.

METHODOLOGY

The tasks investigated here were line paced assembly operations (cycle time of 20-28 seconds), on small (weights of less than 500gm) electromechanical products. To relieve the physiological and psychological monotony, job rotation every two hours had been practised

routinely. With the exception of fully adjustable chairs, the workstations were not adjustable. The complete line comprised of approximately ten distinct operations. For the purpose of this study these were clustered into four groups on the basis of the dominant activities. Table 1 describes the four tasks selected, one from each group.

TABLE 1.

The Four Representative Tasks.

TASK#	ATTRIBUTES
17	Standing. Grasp part from shelf, clamp and place in machine. Remove second part from box and place onto first part. Press two buttons on machine with fingers. Place complete part on conveyor using a tweezer like tool.
18	Sitting. Take part from the right laterally placed conveyor and place in front. Take second part and place on the first. Place in machine and press two palm buttons for 7 seconds. Replace on conveyor.
19	Sitting. Take part from forward located conveyor onto workbench. Place three other parts into first. Place four screws into holes. Drive screws with inline, balanced air screwdriver. Replace part on conveyor.
20	Sitting or Standing. Take part from conveyor. Place second part onto first. Inspect and use knife to trim flash if necessary. Place in one of two test fixtures. Press button to initialise test and then observe results. Replace part on conveyor.

Data on musculoskeletal stresses were collected using the video and EMG system described by Wells *et al.*, (1988). The system allowed the recording of quantitative estimates of the hand, wrist and shoulder loads during manipulative tasks. Four types

of information were recorded: a standard video image of the activity, electromyographic activity of musculature (EMG) and the kinematics of the fingers and of the wrist. Despite the availability of the other information, the video image remains an important resource for interpretation. Kinematic data on hand motion were obtained via a lightweight instrumented glove (VPL Research) which transduced finger flexion/extension. The data were stored on a portable microcomputer. A non-restrictive goniometer (Penny and Giles) was used to transduce wrist flexion/extension and ab/adduction. The linear envelope EMG and wrist angle data (10 channels, bandwidth 0-20Hz) were collected on a battery powered signal processing unit worn as a waist pack. The EMG and wrist transducer data were then encoded and transmitted in multiplexed form to one stereo sound channel of the video camcorder via an infra-red fibre optic link. The other sound channel contained timing pulses to synchronise the finger kinematics to the rest of the data. Upon playback of the video cassette all the above information could be retrieved, synchronized to the video image. Data on muscle activity(force), posture and repetition were recovered in machine readable form after analog to digital conversion at 60Hz.

Muscle activity of the workers was monitored bilaterally using surface electrodes over the trapezius(below the angle of the neck), the forearm flexors (midpoint of a line between medial epicondyle and radial styloid) and forearm extensors(over the extensor muscle mass just distal to the lateral epicondyle). The signal was full wave rectified and low pass filtered at 6 Hz. The kinematics of the right wrist and fingers were also determined as previously described.

Six female workers on the assembly line were selected as subjects in this study from those who volunteered. All had at least one years experience on the job. Subject calibration involved eliciting maximal contractions from the forearm and shoulder musculature as well as calibrating the wrist and finger transducers. The relationship between EMG and grip force was established using nine (3x3) sustained contractions against grip and pinch dynamometers. The wrist posture was varied (natural, flexed, and extended) in each of power grasp, one and two finger pinch; Li *et al.*, (1989).

After subject preparation and calibration each worker was monitored for at least ten minutes per workstation as they rotated through the four representative workstations. They worked at their regular places at the line pace during a regular shift. None of the workers considered the equipment hindered them in the performance of their jobs.

The linear envelope EMG data were normalized to an MVC and analyzed over several cycles to produce the Amplitude Probability Distribution Function(APDF). The motion of

the wrist was also calculated for the right side. A histogram of wrist angle was created, divided according to the recommendations of Drury(1987). Comparisons of musculoskeletal stresses between workers and jobs within the rotation sequence were then made.

RESULTS AND DISCUSSION

Figure 1. illustrates the EMG and wrist kinematics for one subject performing one of the four jobs.

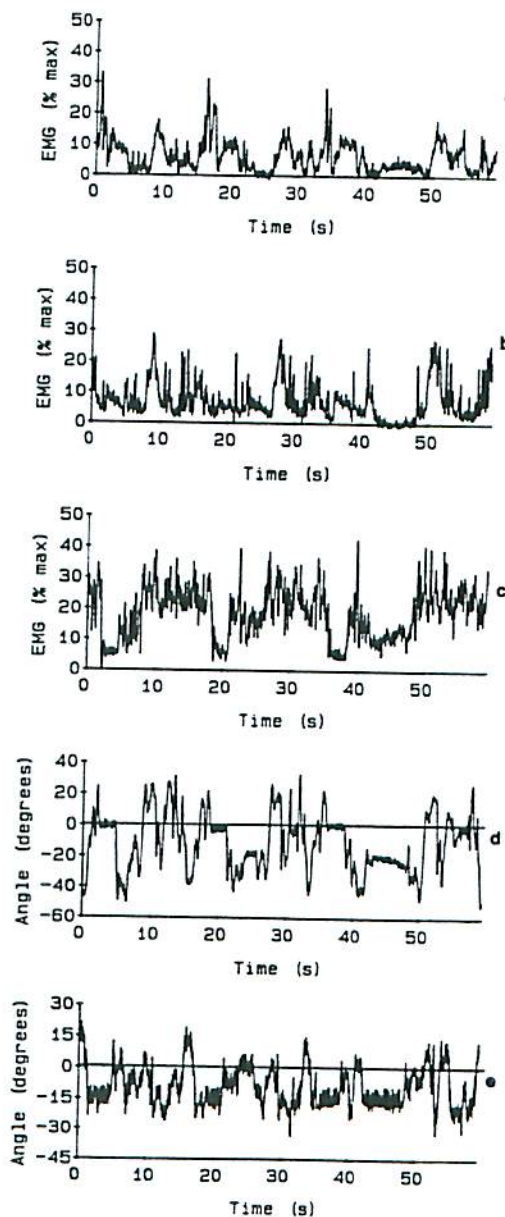


Figure 1. EMG and Wrist Kinematics of One Subject Performing Task 18. a) right flexor, b) right extensor, c) right trapezius, d) right wrist flexion(+ve) and extension and e) radial(+ve) and ulnar deviation

Figures 2. and 3. depict the muscle loads as determined by the APDF of the EMG in the right trapezius and flexors across subjects and jobs. Table 2. summarizes these results for the static(0.1), median(0.5), and peak(0.9) levels.

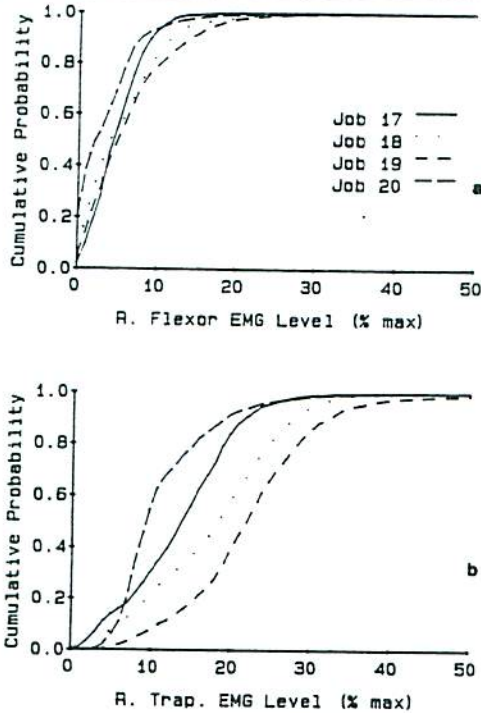


Figure 2. APDF of the Right Trapezius and Flexors for One Subject Across the Four Tasks. Same subject as Figure 1. a) flexors and b) trapezius.

As regards the right shoulder loading, the static loads (0.1 APDF level), exceeded the 2-5% level recommended by Jonsson (1982). This was not true of the left shoulder except for Job 19. Similar results were found for the 10-14% median (0.5 APDF level) contraction levels recommended by Jonsson. The loads were similar to those found by Cristensen(1986) who recorded static loads of 7.8% and 4.8% MVC for those with and without shoulder pain and discomfort respectively. It was also our observation that subjects who complained of shoulder pain appeared to have higher contraction levels. This could be due to performing the task differently or to a lower MVC normalisation contraction. A longitudinal study would be required to separate cause and effect.

The load levels obtained from the APDF have also been found useful for showing relative overall loading in the forearm flexor musculature due task force and posture requirements (Moore, 1988). The summary of results shows that all APDF load factors for the flexors and the extensors were the highest for Job 19. This corresponds with reported exertions on this job.

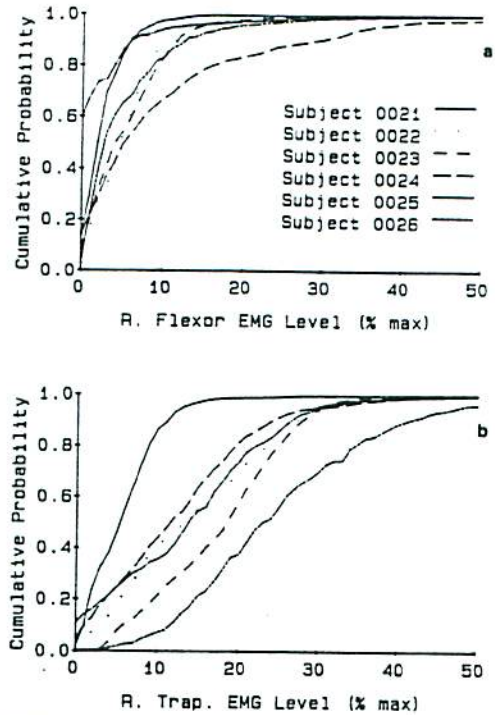


Figure 3. APDF of the Right Trapezius and Flexors for All Subjects Performing One Task. Same task as Figure 1. a) flexors and b) trapezius.

TABLE 2.

Summary of APDF results averaged across subjects (means/standard deviations, n=6)

Job/ Muscle	17	18	19	20
Flexor				
0.1	0.7/.8	0.1/.2	0.8/.6	0.1/.2
0.5	3.4/2.9	3.1/1.9	5.7/4.9	2.8/2.3
0.9	8.7/4.9	12.8/8.5	16.9/11.4	11.1/6.7
Extensor				
0.1	1.4/1.1	0.7/.9	3.0/2.3	0.4/2.3
0.5	5.6/2.5	5.2/2.8	8.9/3.8	4.4/4.1
0.9	13.4/2.5	14.2/3.1	20.1/6.7	16.8/5.3
Trapezius				
0.1	3.2/2.7	4.8/3.9	10.9/6.0	5.6/3.3
0.5	11.0/6.0	15.8/6.1	20.1/8.7	13.6/7.4
0.9	21.1/8.3	27.7/9.8	30.6/13.0	26.7/1.2

While variation in absolute levels between subjects was high, this variation is reduced when using a ranking approach within subjects. The high variations between subjects could be due to differences in muscle capability, difficulties in obtaining a true maximum due to several factors including existing pain, and differences in technique. While it is likely that all 3 explanations come in to play, there is evidence of variation of technique. Comparing subjects 0024 and 0026 for Job 19 (Table 3) one can see the trade off occurring between trapezius and flexors between the two subjects. This again

emphasizes the need to use individual data in any study relating job factors to health outcomes.

TABLE 3.

Comparison of right flexor and trapezius factors across two subjects (#4 and #6) for Job 19. Levels are in % maximum EMG and Ranking is the position of the respective level compared to the other jobs for that subject (1 means the value is the highest).

Muscle	Factor	Level		Ranking	
		#4	#6	#4	#6
Flexors	static	1.6	0.6	1	1
	median	15.0	3.3	1	2
	peak	40.1	12.1	1	3
Trapezius	static	7.9	20.9	1	1
	median	13.9	33.1	3	1
	peak	23.3	51.1	3	1

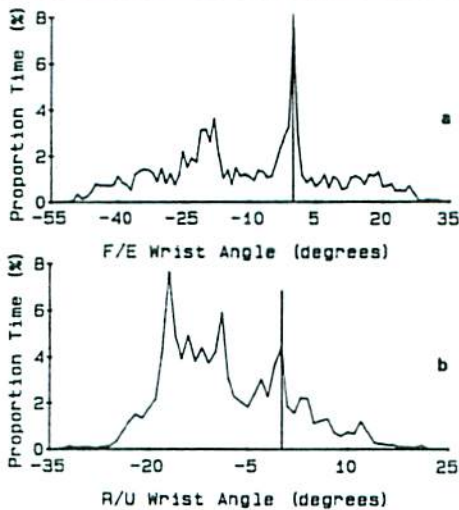


Figure 4. Histogram of Right Wrist Kinematics for One Subject Performing One Task. Vertical axis indicates the proportion of time spent at 1 degree intervals. Vertical line represents 0 degrees. Same task and subject as Figure 1: a) flexion(+ve) /extension and b) radial /ulnar(-ve) deviation.

Drury(1987) set up the zones shown in Table 4. by dividing the range of motion into four progressively less desirable regions each side of neutral. The zones bordering neutral (0 degrees) were assumed non-damaging. The results seen in Figure 4. show a large proportion of time in an apparently undesirable degree of extension (>25 degrees). This is misleading as a position of moderate extension (25 degrees) and slight ulnar deviation (5-10 degrees) has long been known as the position of function, e.g. Boyes(1964), especially when grasping. Furthermore, the neutral position is stressful for the flexors during grasping operations, Moore (1988).

TABLE 4.

Proportion of time spent in various postures. Averaged across subjects (N=6).

Job/ Position (degrees)	17	18	19	20
Extend				
>50	1.4	0.4	4.3	1.8
50-25	32.8	22.9	25.4	37.9
25-10	30.7	24.8	23.6	27.7
10-0	17.1	21.0	26.0	17.4
Flex				
0-9	7.4	12.6	11.6	6.5
9-23	5.8	11.3	6.3	6.1
23-45	4.0	0.2	2.4	1.6
>45	0.7	0.7	0.2	1.0
Ulnar				
>24	18.4	9.5	22.2	15.8
24-12	15.0	17.1	19.2	18.0
12-5	21.9	18.4	15.6	16.0
5-0	14.7	17.5	11.4	20.0
Radial				
0-3	5.6	6.5	4.9	7.0
3-7	6.5	9.3	6.8	8.5
7-14	7.1	9.1	9.0	8.8
>14	10.8	12.8	9.9	6.7

Unfortunately, optimal positioning of the wrist during manipulation is not well defined for different tasks as it appears that tasks which require straight finger positions are better served by neutral wrist positions whilst those which involve grasping require a moderately extended wrist.

One of the purposes of the study was to investigate the relative stresses of the different types of task within the rotation sequence. In terms of muscle loads, task 19 ranked first for all three muscle loadings, exceeding existing recommendations for static and median loading for the trapezius. The relative musculoskeletal stresses determined here agree with the experience of the workers who also reported task 19 to be most stressful. In fact workers did not rotate from one "screwrunning" job to another similar task without a term on one of the other tasks.

The analysis has shown the usefulness of obtaining continuous measures of EMG and posture while a person performs their task and using time distribution factors as a method of ranking job loads. Further studies are needed to better define non injurious levels for the flexor and extensor musculature. The need to look at individual response was highlighted by the between subject comparisons.

This analysis has concentrated on the EMG and wrist kinematics separately. Further analysis combining these measures to better predict musculoskeletal loading, as described by Wells *et al.*, (1989), is currently underway.

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REFERENCES

- Aaras, A. and Westgaard, R.H. (1987). Further studies of postural load and musculo-skeletal injuries of workers at an electro-mechanical assembly plant. Applied Ergonomics, 18, 3, 211-219.
- Boyes, J.H. (1964). Bunnell's Surgery of the Hand. J.B.Lippincott Co., Philadelphia, 4th Edition.
- Cristensen, H. (1986). Muscle activity and fatigue in the shoulder muscles of assembly-plant employees. Scandinavian Journal of Work, Environment and Health, 12, 582-587.
- Drury, C.G. (1987). A biomechanical evaluation of the repetitive motion injury potential of industrial jobs. Seminars in Occupational Medicine, 2, 1, 41-49.
- Hagberg, M. (1986). Optimizing occupational muscular stress of the neck and shoulder. In N. Corlett, J. Wilson and I. Manenica (Eds), The Ergonomics of Working Postures (pp.109-114), Taylor and Francis, London.
- Jonsson, B. (1982). Measurement and evaluation of local muscular strain in the shoulder during constrained work. Journal of Human Ergology, 11, 73-88.
- Jonsson, B. (1988). The static component in muscle work. European Journal of Applied Physiology, 57, 305-310.
- Kilbom, A., Persson, J. and Jonsson, B.G. (1986). Disorders of the cervicobrachial region among female workers in the electronics industry. International Journal of Industrial Ergonomics, 1, 37-47.
- Kourinka, I. and Koshkinen, P. (1979). Occupational Rheumatic Diseases and Upper Limb strain in Manual Jobs in a Light Mechanical Industry, Scandinavian Journal of Work, Environment and Health (Suppl 3), 39-47.
- Li, Y., Wells, R.P., Ranney, D. and Moore, A. (1989). Prediction of the pinch and grasp force exerted by the hand using surface and fine wire electromyography. In Proceedings of the XII Congress of the International Society of Biomechanics, Los Angeles, June 26-30.
- Moore A.E. (1988). A System to Predict Internal Load Factors Related to the Development of Cumulative Trauma Disorders of the Carpal Tunnel and Extrinsic Flexor Musculature during Grasping, MSc Thesis, Department of Kinesiology, University of Waterloo, Waterloo, Ontario.
- Wells, R.P., Moore A.E. and Ranney, D. (1989). Evaluation of hand intensive tasks using biomechanical load factors. In N. Corlett, J. Wilson and I. Manenica (Eds). Work Design in Practice. Taylor and Francis, London, (In Press).
- Wells, R., Moore, A.E. and Ranney, D. (1988). Development of a system for recording occupational hand and wrist movement. In Proceedings of the 21st Annual Conference of the Human Factors Association of Canada, Edmonton, Canada, Sept 13-16.

Stresses musculosquelettiques durant l'assemblage léger

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RÉSUMÉ

Cette étude a examiné les stressés musculosquelettiques des membres supérieurs, soutenus par les travailleurs d'une chaîne d'assemblage électronique avec rotations. La rotation des travailleurs a souvent été suggérée comme un moyen efficace de contrôler les charges sur l'appareil musculosquelettique. Il est donc intéressant de comparer les différences entre les postes de travail de la séquence de rotation. Il est intéressant aussi de comparer les différences entre travailleurs. Les stressés musculosquelettiques de l'épaule et du bras droit furent évalués en utilisant l'électromyographie (EMG) de la musculature de l'avant bras et de l'épaule (trapeze). Six travailleuses alternant entre quatre différentes stations de travail, durant des conditions de production normale, furent examinées.