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Workplace upper limb disorders: A prospective study with intervention

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A prospective longitudinal study was carried out to investigate the occurrence of upper limb disorders in an electromechanical plant between 1980 and 1988. It included clinical and epidemiological studies, measurement of vibration produced by the power tools used, ergonomic assessment of the works and time and motion studies. Simultaneously during the same period remedial actions were taken through multidisciplinary interventions when the specific causal factors were known. The study shows the clinical entities of the disorder, identifies the risk factors and evaluates the results of the interventions. It assists in establishing a cause and effect relationship for the condition and demonstrates the way a preventive strategy could be developed.

BACKGROUND

Work-related upper limb disorders (ULDs) have been known from the time of Ramazzini in the 17th century. Since that period it has been described under various synonyms[1] involving many occupations[2]. The data from the recent international statistics[3] show that ULDs rank prominently among the occupational musculo-skeletal disorders. A similar trend for the prevalence of ULDs was observed in a small assembly plant during 1979. The plant occupational health statistics showed that 19 subjects (representing 40 per cent of those with musculo-skeletal conditions) were affected. Of these 18 (95 per cent) were women and a man, their mean age was 46.1 (SD, 7.4) years and 37 per cent of them had a history of using vibratory tools. This promoted the need for an exploratory study and relevant contemporary litarature was reviewed[1]. The aim was to consider all possible occupational and non-occupational factors which could be associated with this condition, assess the effects of interventions on such factors and identify the need for further investigations. The objective was to formulate appropriate control measures and to set up a strategy for the prevention of ULDs.

MATERIALS AND METHODS

Subjects

The study was carried out in a plant with a total workforce of 1110 where the main work basically consisted of assembly of small electrical and mechanical car parts. The duration of the study was limited from 1980 to 1988. During this period, apart from the natural attrition, there was no turnover of the employees until the end of 1988 when 230 new semi-skilled workers were recruited. Three departments (A, B and C), recognized as being affected by this condition, were included. All manual workers from these areas (ie, men = 274, women = 421, total = 695) were admitted to the study and their mean age was 49.1 (SD, 7.3) years.

Health surveillance

The surveillance consisted of an epidemiological study using a questionnaire, clinical examinations of the patients, job checks and calculation of the annual incidence rates for ULDs. The questionnaire included particulars for each employee; medical, gynaecological and personal histories; occupational history with the details of the frequency and duration of each task, types of tools used and the body motions involved. The subjects with any symptoms suggestive of ULD were referred to the occupational health physician (D. S. C.) for detailed interview and clinical examination. Procedure included calculation of the latent period involved between the starting point in the job and the development of the first symptom. Diagnoses were made according to the criteria described by Silverstein[4] and Cyriax[5]. For each case identified, a job check was performed to establish any possible relationship between the conditions diagnosed and the occupational activities involved. Finally at the end of each year an annual incidence rate was calculated according to the method adopted by the United States Department of Labor[6]. The last procedure was continued beyond the year 1988 so that the effectiveness of the occupational interventions could be studied with more accuracy.

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Measurement of vibration

The measurement was carried out by the Department of Applied Acoustics, University of Salford in 1985. Mainly two types of pneumatic screw drivers (Clecomatic 7RSA20 and Atlas Copco LUM14PRO185) were used. Both were 229 mm in length, weighed 0.59 kg and with diameters ranging between 32.5 and 37 mm. One was equipped with an auto shut-off and the other with the slipping clutch system but both were torque controlled with torques ranging between 0.5 and 1.8 Nm. Each driver was suspended from a spring counterbalance unit which had a variety of force settings, the mean force being 3.6 N with a range 1.0–9.0 N. The processes were identified as German screws, GKN screws, Flat screws and Nut runners. All the tools were operated on a line pressure of 80 psi.

An Endevco triaxial accelerometer (type 228/c) was attached to the barrel of the screw drivers by means of a jubilee clip. The output from the accelerometer was fed into three separate Bruell and Kjaer charge amplifiers (type 2635) in order that the acceleration could be measured simultaneously in three mutually perpendicular directions, ie:

X = perpendicular to the axis of the tool,
Y = tangential to the axis of the tool,
Z = radial to the axis of the tool.

The signals measured in the X and Y directions were fed into a two channel Sony PCM Fl audio processor and a portable video cassette recorder. The signals in the Z direction were recorded on a Bruel and Kjaer FM tape recorder type 7003. At the output of the recorders the signals were monitored on an oscilloscope. A continuous recording was made during the time it took for the processes being studied to be repeated on different workpieces.

The analysis of the recorded signal was performed in the laboratory using two different procedures:

1. A Bruel and Kjaer digital frequency analyser type 2131 enabled a linear average of each of the recorded signals to be obtained and the result presented in terms of RMS acceleration in one third octave bands between 8 and 2000 Hz.
2. A Bruel and Kjaer high resolution signal analyser type 2033 enabled the acceleration time history of the signals produced during the operation of the tool to be recorded.

For each individual operation the integration time was chosen so as to be long enough to include the work on one complete workpiece associated with a particular process. The mean weighted vibration value together with the standard deviation of the 10 measurements was determined for each process studied. The vibration acceleration values were then normalized to 1000 workpieces per day (considered as average daily output) and expressed as 4-h equivalent continuous values in m s^{-2}.

Ergonomic study

The study was initiated by the Ergonomic Division, the Institute of Occupational Medicine, the National Coal Board in 1986 and continued by the plant engineers trained in ergonomics using the same protocol. It consisted of video recording, photography of the tasks performed and measurement of the work stations.

The results were analysed by application of the anthropometric man model system adapted from the body link system of Dempster[7] and incorporating data on postures and range of joint movements from a variety of sources[8,9]. The body dimensions were selected from 5th to 95th percentile female population which covered 90 per cent of the female and 40 per cent of the male operating population.

Time and motion study

The procedure followed was in accordance with the Methods-Time Measurement (MTM) System as modified by Barnes[10]. In each department three high risk activities were sampled for measuring the task elements and the cycle times were calculated in seconds.

Interventions

A multidisciplinary method was adopted. The actions taken were general and specific, the latter being targeted to counteract the abnormalities observed from the various investigations performed. Basicaly there were four types of interventions.

Educational. The supervisors and the engineers received presentations on clinical manifestations and the known risk factors of ULDs and how they could be avoided. An advice leaflet was produced to inform all existing and potential employees of the methods of early recognition and reporting of these disorders and advising them of the safe working practices. In addition, a basic course on applied ergonomics was arranged for the plant engineers, safety representatives and the occupational health and safety personnel.

Occupational health. Following the establishment of early diagnosis and job check a medical restriction system was implemented so that the affected individuals could be prevented from further exposure to any risk factor. Subjects with abnormal clinical findings were reviewed periodically and, where indicated, referred to their general practitioners for further investigations and medical or surgical intervention.

Engineering. An engineering task force was formed and the maintenance schedule was regulated. For all short-term problems prompt corrective actions were implemented. The solutions to the long-term defects were effected initially by designing prototypes to be replaced subsequently by definitive changes.

Organizational. A steering committee was set up involving the management, engineering and occupational health functions. Its aim was to carry out effective planning and implementation of the procedures, ensure appropriate facilities for rehabilitations and to monitor the progress.

Statistical method

The analyses were carried out by using a logistic regression model[11]. The purpose was to associate concomitant variables (covariates) with the probability of occurrence of ULDs.

RESULTS

Clinical study

Analysis was based on the results of the study carried out between 1980 and 1988 and are shown in *Table 1*. In total 88 cases of ULDs were detected, 27 (30.68 per cent) of which had secondary lesions in other parts of the body. One of the 88 primary cases acquired the condition before joining the plant. Most of the subjects developed the disorders in the dominant hand (right handed = 60, left handed = 17), right side showing the higher prevalence of the symptoms.

In the remaining 11 (12.5 per cent) cases the condition was bilateral and a job check showed that these operators required to use both hands equally. Clinically the ULDs diagnosed were supraspinatous tendinitis (35), lateral (19) and medial (2) epicondylitis, carpal tunnel syndrome (19), de-Quervain's syndrome (9), trigger thumbs and fingers (4). The mean latent intervals (i.e., duration between starting a specific job and the onset of symptoms) for developing the disorders in different parts of the upper extremity varied from 7.3 (SD, 3.3) and 10.1 (SD, 4.2) years with the median as 9 years. Approximately 54 per cent of those affected needed surgical intervention, 33 (37.5 per cent) by hydrocortisone injections and 15 (17 per cent) by operations. A follow-up showed that 45 (51.1 per cent) of the ULD cases were not able to continue with their existing job and required medical restrictions. The rehabilitation of these patients was greatly influenced by three main elements in the tasks. The majority of them were able to return to repetitive work but 50 per cent were unable to do so if the task also involved force and only 4 per cent could tolerate a further exposure to vibration. This intolerance to vibration (especially shock type) was observed even 4 years after a surgical intervention (eg, carpal tunnel decompression). In fact, periodic review showed that in most of the cases disorders developed into chronic conditions.

Epidemiological study

Both the occupational and non-occupational factors were considered. *Figure 1* summarizes the relevant non-occupational factors. It shows that occurrence of ULDs is significantly more common in women (85.2 per cent) than in men (14.8 per cent). Although the subjects with ULDs were slightly older there was no statistically significant difference in age between the affected (mean age, 49.3 years; SD, 6.8) and the unaffected groups (mean age, 49.0 years; SD, 7.9). Among other non-occupational factors those with the

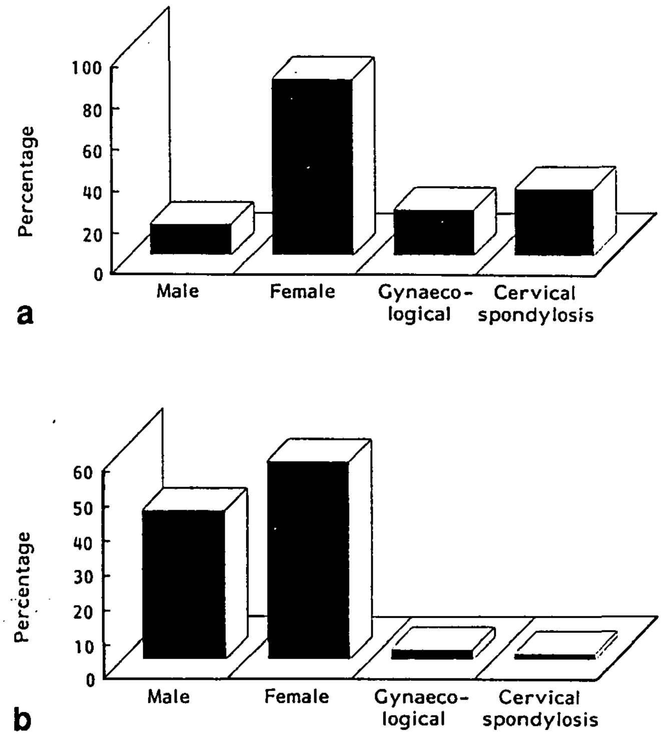

Figure 1. Non-occupational factors and upper limb disorders. **a** With ULDS, n = 88; mean age 49.3 (SD, 6.8) years. **b** Without ULDS, n = 607; mean age 49.0 (SD, 7.9) years.

Table 1. Details of the upper limb disorders by anatomical sites

	Shoulder	*Elbow*	*Wrist*	*Hand/finger*	*Total no.*	*%*
Primary lesions	35	21	19	13	88*	
Secondary lesions	14	4	9	0	27	30.68
Right-sided	23	14	13	10	60	68.18
Left-sided	7	6	1	3	17	19.31
Bilateral	5	1	5	0	11	12.50
Hydrocortisone injected	14	13	3	3	33	37.50
Operation	0	1	10(3)†	4(1)†	15	17.04
Change of job	17	14	10	4	45	51.13
Latent period (SD)	8.7(4.2)	10.1(4.2)	7.5(3.3)	8.2(3.9)	8.7(4.0)	

* One subject developed ULD before joining the plant.
† Figures within the parentheses denote the number of subjects who were able to return to work with vibration.

disorders showed higher prevalence of gynaecological abnormalities (19 = 22 per cent with the history of hysterectomy and oophorectomy) and cervical spondylosis (29 = 32.9 per cent). In comparison, among those without ULDs 18 (3 per cent) had a history of gynaecological operations and 10 (1.6 per cent) of cervical spondylosis. *Figure 2* shows the percentage of ULDs by department (department A being predominantly affected) and the associated occupational factors. Although all three departments consisted basically of assembly works, there are some obvious functional differences between them. The main occupational factors identified through epidemiological search are repetitiveness, use of force, exposure to vibration and variation in types of grips used. Amongst all these repetitiveness is the feature most common to all the departments affected. Departments A and B are very similar in the nature of their work, except that in department A tasks involve more exposure to vibration and force. In contrast the majority of the tasks in department C are much lighter (no use of force and exposure to vibration) and least repetitive. A further

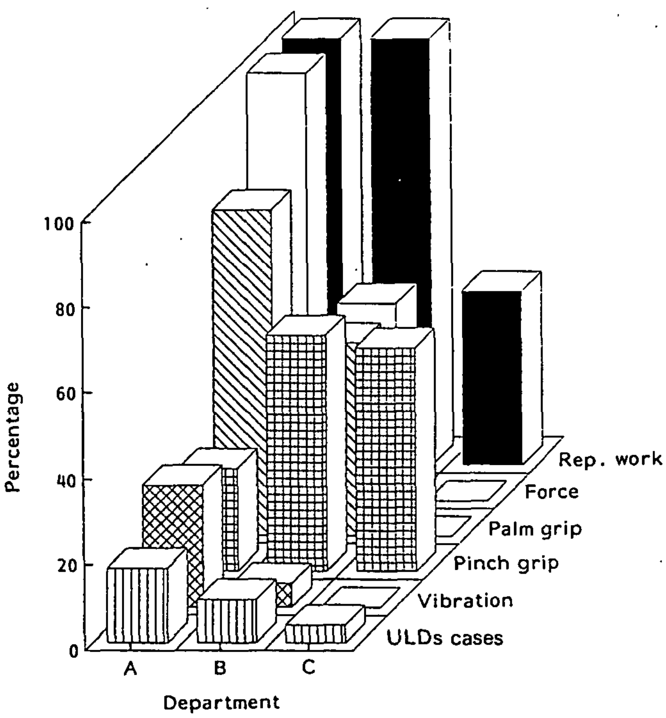

Figure 2. ULDs by department and occupational factors.

Table 2. Incidence of upper limb disorders by department and sex

		Dept A	*Dept B*	*Dept C*	*Total*
Male:	no.	6(73)	2(53)	4(148)	12 (274)
	%	8.2	3.8	2.7	4.3
Female:	no.	62(321)	9(56)	4(44)	75 (421)
	%	19.3	16.0	9.0	17.8
Total:	no.	68(394)	11(109)	8(192)	87*(695)
	%	17.2	10.0	4.1	12.5

* One case out of 88 was excluded from analysis as he developed ULDs before joining the plant.
Figures in parentheses indicate the total number of employees in each department.

Table 3. Upper limb disorders and exposure to vibration

		Dept A	*Dept B*	*Total*
Exposed to vibration	no.	44(112)	3(6)	47(118)
	%	39.3	50.0	39.8
Not exposed to vibration	no.	18(209)	6(50)	24(259)
	%	8.6	12.0	9.2

Figures in parentheses indicate the total number of employees involved; employees in dept C were not exposed to vibration.

analysis showed that the use of vibratory tools was confined exclusively to women. Consequently *Tables 2* and *3* were devised to assess the effects of sex and vibration separately on the incidence of ULDs. The data in both of these *Tables* were analysed by using an 'additive model'. From these it is clear that the coefficients for both the factors were much greater than their standard errors, indicating that these data are showing the real effects. However, the coefficient for the effect of exposure to vibration (2.04) was somewhat larger than that (1.18) obtained for the sex effect (the detailed statistical analyses have been submitted to the editor). This indicates that there are separate effects for sex and for vibration in the tasks but these two cannot be isolated.

Vibration levels

All the initial results showed that the vibration was always least in the Z directions and therefore the data related to this direction were excluded from the subsequent analysis.

The values obtained from the measurements in the X directions ranged from 0.7 to 2.4 $m\,s^{-2}$ and in Y directions from 1.7 to 3.6 $m\,s^{-2}$. In addition to the magnitude of vibration the waveforms associated with the operation of the screwdrivers were also observed. In many of them there were clear similarities. Typically there is a short length of signal associated with the commencement of the process followed by a longer period during the actual driving of the screw (*Fig. 3*). Subsequently the signal levels increased as the clutch started to slip when the driver reached its set torque. Occasionally, the waveforms would deviate from this normal pattern (*Fig. 4*). This was especially observed when the operator had difficulties in driving a screw or nut home and the clutch would appear to slip for a

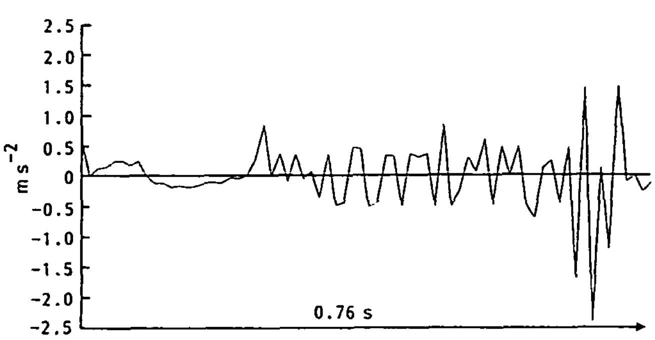

Figure 3. Vibration level one pulse X direction using German screw.

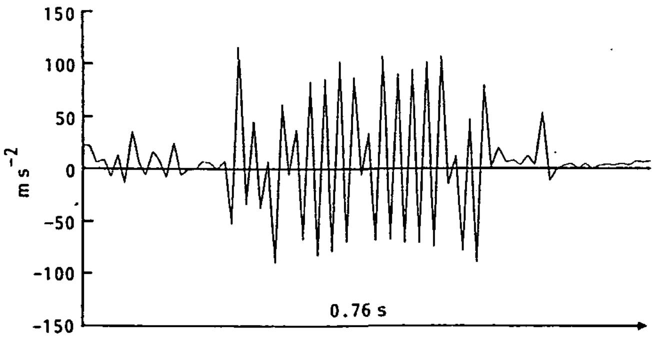

Figure 4. Vibration level one pulse Y direction using flat screws.

longer period of time. This clearly gave rise to significantly increased signal levels. On each of these occasions the operators involved experienced a severe shock-type sensation with pain radiating proximally from the hand to shoulder. In some cases this effect would last for several weeks unless the operator was completely restricted from further exposure to vibration.

Ergonomic study

In general three types of ergonomic problems were observed.

Seating. Poor seating positions associated with badly designed workstations were observed in all three departments. This was mainly due to the fact that in many areas a cross member and a support rail were in the way of the operator's leg and the height of the footrests was low.

Reach. Difficulties in reach were experienced in many operations. The causal factor seemed to be due to an interaction between the small size of some of the female operators, too wide a work surface, badly designed trays of displays and the conveyor belt being positioned beyond the satisfactory reach envelops of the operators.

Postures. Postural analyses showed that normal ergonomic criteria were exceeded in the following postures and joint movements.

(a) Pronation of wrists was excessive in more than 40 per cent of works mainly due to the worksurface being horizontal.
(b) Increased elbow flexion was observed in approximately 13 per cent of the operations, especially when the task heights were above the elbow level. Most of these tasks were associated with an excessive static work load.
(c) In more than 30 per cent of the operations internal rotation of arms and elevation of shoulder girdle conjoined with a static work load were increased.
(d) Excessive neck flexion due to the tasks being too close to the operator's body was observed in 75 per cent of the operations.
(e) Works involving manual screwdrivers and spanners caused increased ulnar deviation of wrists due to the bad design of the tools.
(f) Some units such as speedometers and small packages were gripped by the finger tips around the perimeter of the display at its greatest diameter and therefore with the worst possible mechanical disadvantage.
(g) In some sub-assembly works involving application of clips or insertion of small bulbs into the sockets, excessive movement of the terminal phalanges of the thumb or finger with force was necessary.

In addition some operations such as circuit bending required repeated application of forceful pinch grip.

Job check showed that there was a close association between the type of awkward postures or movements and the anatomical site of the ULDs. Supraspinatous tendinitis was associated with increased elevation of the shoulder especially when using power tools and epicondylitis with the flexion and rotation of the elbow. This was particularly observed when static load or forceful pinch grip was involved. Incidence of carpal tunnel syndrome was associated with the use of vibratory tools and where there was local pressure on the base of the palm, de-Quervain's syndrome with excessive ulnar deviation and trigger thumb or finger with the increased movement and local pressure on the terminal phalanges.

Job analysis

The results of the job analysis by the time and motion studies are shown in *Figure 5*. It is clear from this that all the high risk jobs are repetitive and in many of them each workshift involved more than 25 000 hand motions.

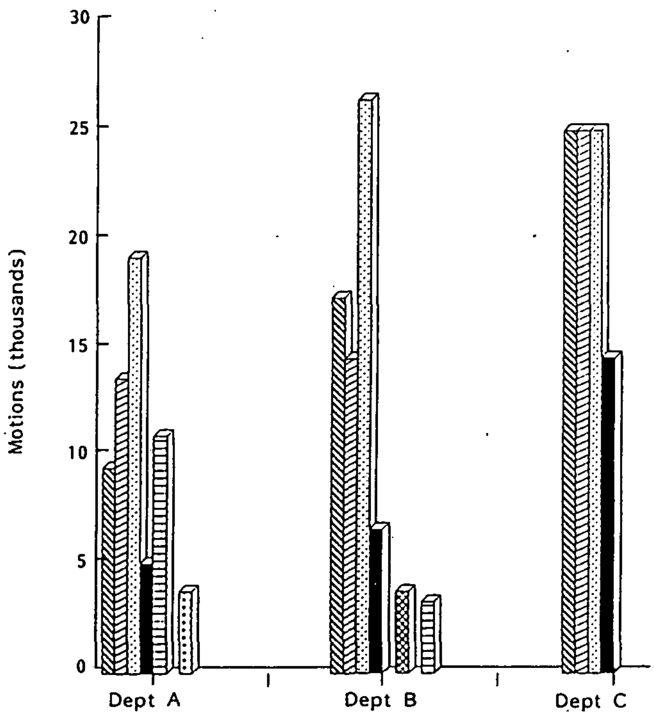

Figure 5. Upper limb disorders: time and motion studies, Departments A and B worked 7 h 20 min per shift and Department C, 6 h 52 min per shift. ▧, reach hand empty; ▨, grasp; ▤, move hand fully; ■, wrist turn (various); ▤, apply pressure; ▩, foot motion; ▦, body twist; ▤, move with 8 kg pull.

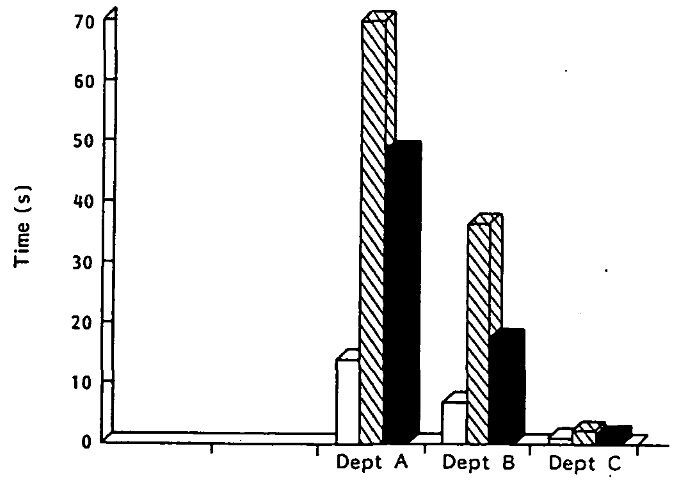

Figure 6. Floor to floor cycle times by department in high risk jobs.

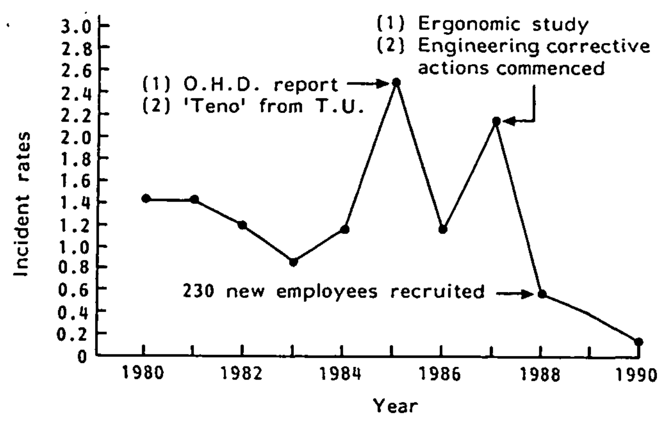

Figure 7. Incident rates for upper limb disorders 1980–1990.

Figure 6 confirms that the shortest cycle time measured in all three areas affected is less than 30 s indicating that those jobs should be regarded as highly repetitive. This is especially observed in department C where the high risk jobs have the shortest possible cycle time yet the others are not particularly repetitive. In addition *Figure 5* shows that the jobs in departments A and B are complex and consist of multiple components and involve application of force or pressure.

Interventions

Engineering modifications to counteract the ergonomic and other task problems resulted in the following changes.

Repetition. Although it was not possible to reduce the cycle time in some tasks, the effects of repetition were minimized by allowing more regular rest pauses and job rotation, providing more man power and introducing automation.

Seating. Seating positions were improved by providing new workstations or modifying existing stations by removing cross members and vertical supports and adjusting height of the footrests.

Reach. Difficulties in reach to the conveyor belt were counteracted by narrowing the worksurface and rotating the display trays and bringing them forward.

Vibration effect. Discomfort due to vibration was largely eliminated from the process changes by replacing the majority of the power tool operations with automated ultrasound welding. For the remaining power tools the operation was made easier by attaching a plastic sleeve guard with a collar (as designed by McKenzie and his colleagues[12]) to the tool which would provide a downward pressure and thereby reduce the transverse grip.

Shoulder movements. Elevation of shoulder girdle was minimized by either recessing the display supports into the worksurface or by replacing the operating levers which were too high with foot pedals and palm buttons.

Static work load. Static work load was reduced by modifying the workstations and providing padded arm supports.

Pressure on the palm. Pressure on the base of the palm from the ball handles was eliminated by changing them into T-bars which would slide easily with minimal torque.

Pinch grip. Forceful pinch grips and ulnar deviation of the wrist were reduced by tooling the operations which used to be done manually.

Cervical spine. Symptoms related to cervical spines were improved by repositioning the tasks away from the edge of the work surface and adjusting the task heights.

Although no reference has been made, most of these modifications are illustrated in the Health and Safety Executive booklet on work related upper limb disorders[13], where Appendix 3 in its entirety has been taken from this study.

Consequent to these changes, the subjective symptoms from ULDs showed dramatic improvement. In addition, early reporting of the symptoms helped to make prompt diagnosis of the conditions. This promoted speedy recovery from early medical or surgical interventions and adequate rehabilitation. More importantly, as illustrated in *Figure 7* the incidence rates for new cases fell from 2.1 in 1987 (when major engineering modifications were commenced) to approximately 0.1 in 1990.

DISCUSSION

This study uncovers many facets of a disease which is so widespread yet so badly understood by many.

It is clear from this study that ULD is not a single clinical entity but a diversified syndrome. Pathologically, as the results show, it may be due to direct involvement of the nerve, blood vessels, muscles and tendons of the upper extremity or secondary to changes in cervical spines.

The causal factors seem to be many but from the evidence obtained, they can be divided into general and local causes. Both clinical and special investigations show that among the general causes, repetitive movements, vibration and female sex seem to have significant influence on the occurrence of ULDs.

The effect of repetition is well documented[14–17]. Hammer[18] in his study concluded that human tendons will not tolerate more than 1500–2000 manipulations per hour. According to Armstrong and colleagues[19] highly repetitive jobs are defined as those with a cycle time of less than 30 s or when more than 50 per cent of the cycle time is involved in performing the same motion pattern. The results show that most of these criteria are often exceeded in the present study.

Similarly vibration is known to cause chronic nerve and tendon disorders[20–22], especially when combined with ergonomic factors. Exposure to vibration can exhibit a tonic vibration reflex (TVR)[23] in the form of increasing involuntary contractions. Frequent episodes of such contractions from the use of the power tools can therefore cause fatigue progressing to soft tissue disorders in the upper extremity. However, as the study showed, the power tools were used mostly by the female operators and it was not possible to isolate whether the female sex or vibration is the more significant causative factor. Nevertheless, the statistical analyses suggest that both sex and vibration are significant. Some studies[24–25] support this finding suggesting that women are at higher risk than men for ULDs. It has been suggested[26] that women may be exposed to higher stresses because the average dimensions of the female hands are less than those of the male and others[27] have used physiological considerations. Association of high age group of the women affected and the prevalence of the gynaecological abnormalities, further suggest that ULD could be related to hormonal changes which are common during the menopause. Cannon *et al.*[28] have made similar observations in their study, but the underlying mechanism is not clear.

In addition to these general factors it seems that the local factors such as awkward postures, excessive movement of joints or mechanical trauma are responsible for the actual manifestations of the disorders. It has also been shown from the study that most of these were associated with increased static work load and both of them jointly contributed in localizing the symptoms. A literature search confirms that these findings are in line with those of the previous studies[29–35]. However, none of these factors individually may cause the symptoms. Throughout the study observations highlight that in most cases it is the association of excessive, unaccustomed or sudden application of force which is responsible for the actual onset of the symptoms. Previous studies[16,36] have recognised this as a critical factor. It could be that the general factors initiate the pathogenesis of the disease, the local factors determine the anatomical site of the lesions but the actual onset of the symptoms is triggered off mainly by force. Whatever is the integral mechanism involved, the results of the positive interventions and especially the decreased incidence rates prove that the cause and effect relationship, shown in this study, is real.

In spite of all this, some questions still remain unanswered as to what is the real cause for the women exhibiting such a high prevalence of ULDs, how vibration may influence the disease, what is the cause for the chronicity of the disorders and what is the actual magnitude of the force which is supposedly responsible for the onset of the symptoms. For these and many others, further research would be required. In conclusion it can be said that the study has succeeded in showing clearly the common clinical manifestations of the disease and objectively assessing the risk factors. In addition, it can claim to make a modest contribution to the prevention of the disease by outlining several practical procedures. These strategies, if not for the complete removal, will certainly assist in reducing the incidence of upper limb disorders significantly.

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