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Tittel: Postural load and the development of musculo-skeletal illness.

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ABSTRACT. Early in the 1970s, high rates of sick-leave due to musculo-skeletal complaints were frequently recorded among workers at Standard Telefon and Kabelfabrik's (STK's) factory in Norway. Workstations were redesigned according to ergonomics principles that allowed workers a wider choice of working postures and following their introduction in 1975, there was a marked reduction in sickness absence.

Postural load was studied in groups of female workers in well defined assembly tasks. Trapezius load was recorded by electromyography (EMG). Simultaneously, postural angles of the upper arm in the shoulder joint and flexion/extension of head/neck and back were measured by using pendulum potentiometers. A quantitative relationship was found for the group between its median value of static trapezius load and the development of musculo-skeletal sick-leave, as a function of length of employment. Further support for a relationship between musculo-skeletal injury and trapezius load was found for the same subjects who suffered less musculo-skeletal sick-leave, consistent with the reduced trapezius load when working at the redesigned work stands.

The relationship between postural load and musculo-skeletal injury was studied in comparable groups of the female workers with respect to age, working hours per day and time of employment. Psychosocial problems, spare time activities and living habits of workers did not show any significant difference across the groups.

Postural load, both in terms of the magnitude of the flexion angle of the upper arm in the shoulder joint and the distribution of the work load between flexors and extensors, appeared to influence the incidence of load-related musculo-skeletal illness in the upper part of the body.

The incidence of musculo-skeletal sick-leave in a group of workers with a median static trapezius load of about 1 to 2 % MVC (Maximum Voluntary Contraction) for most of the work day, was approximately the same as for a group of comparable female workers without continuous work load. This suggests that a static trapezius load level of about 1 % MVC is acceptable for the major part of the work day if adequate breaks in the load pattern are allowed when needed.

At the same time, a median arm flexion of 15° and a median arm abduction less than 10° indicate the amplitude of these angles for 50 % of the recording time. No details about the work-pause pattern was obtained, therefore these limits are only a rough indication of an acceptable arm position.

Stikkord: Muskel-skjelettsykdommer
Arbeidsbelastninger

Key words: Musculo-skeletal system
Working conditions
Occupational health

CONTENTS

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INTRODUCTION

Musculo-skeletal illness is a major health problem in working life in Norway and other industrialized countries.
Statistics showing the prevalence of these illnesses are not available for the whole country. However, investigations done in cooperation between the health authorities and the local industry of Porsgrunn city, have shown that illness in the musculo–skeletal system was a common cause of sick leave in the 1970's.

A survey of about 9000 workers employed in industry in this area, in the period 1967–80, showed that 17% of all sick leave was caused by musculo-skeletal illness. This accounts for about 25% of all days lost through sick leave. (Iversen, 1981). Another survey of 9000 patients treated by general practitioners in Norway showed that 20% of all patients suffered from musculo–skeletal complaints, accounting for 30% of time lost through sick leave. (Borchgrevink, 1980).

The incidence of musculo-skeletal illness is also reported to be increasing; among a work force of about 9000 in the Porsgrunn area, 40,2% of all sick leave in female workers in 1979 was due to musculo-skeletal illness compared to 28,8% in 1967 (Iversen, 1981).

A study of musculo-skeletal illness in a large metal industry in Sweden showed that of workers who had had a period of sick leave including the whole year of 1979, musculo-skeletal illness were responsible for 70,1% of all sick leaves compared with 54,6% for similar statistics in 1975. (Kvarnstrøm, 1983).

In 1974, Standard Telefon og Kabelfabrik A/S (STK) recorded a high rate of sick leave, labour turn-over and rehabilitation problems, which convinced the management and unions of the need to establish a preventive program with stated principles for organization and execution of work environmental projects at the company. (Aarås and Westgaard, 1979).

This provided us with the opportunity to carry out a quantitative study regarding the occurrence of musculo-skeletal illness among workers in work situations demanding static muscle work at STK's telephone plant in Kongsvinger.

In early 1975, several major changes were implemented to improve the design of the work places, giving the workers greater flexibility in adjustment of the work piece.
Details of the ergonomic principles applied and redesign implemented have been discussed (I, Aarås at al., 1985) and (Bjørset and Aarås, 1983).

AIMS OF THE STUDY

The general aim of the present investigation was to study the relationship between postural load for a group of workers and the development of musculo-skeletal illness related to time of employment.

The postural load was quantified by recording EMG, mainly from the descending part of m. trapezius, and postural angles in terms of flexion/extension and abduction/adduction in the shoulder joint, head and back flexion/extension.

The incidence of musculo-skeletal illness was evaluated by using the personal records of each subject concerning their sick leaves. All sick leaves of more than 3-days duration was then identified by collecting the medical diagnosis from the local health authorities. The musculo-skeletal sick leave was studied in groups of employees working at well defined tasks. These groups were formed by identifying the work duties of all workers employed at the factory from the start of the employment of the subject and then year by year to the termination of their employment or to the end of the study. The following questions formed the basis for the present study.

1. Is there a quantitative connection between the postural load and the development of musculo-skeletal illness?

2a. Does the introduction of more ergonomically designed workplaces reduce the postural load?

2b. To what extent does the reduction of postural load influence the incidence of musculo-skeletal illness?

The following strategy was used in our attempt to answer these questions;

1. The investigation of musculo-skeletal illness resulting in sick leave for groups of female workers in well-defined work situations (I, III and V).
2. The measurement of postural load for the same groups of workers by recording EMG from appropriate muscles, mainly the descending part of m. trapezius (III).
3. The recordings of postural angles in terms of flexion/ extension and abduction/adduction in the shoulder joint, head and back flexion/extension for the same groups of workers (V). Continuous measurements of postural angles were performed by constructing and evaluating the "Ergonometer", a system based on potentiometer-sensed penduli attached to upper arm, head and back (IV).
4. Relationship between postural angles of the shoulder joint and EMG recordings of the trapezius load was studied in terms of assessing the work load on the shoulder and neck regions (V).
5. The changes in postural load due to improved workplace design and the effect on the workers' health in terms of development of musculo-skeletal illnesses, resulting in sick leave. (II, III and V).

DISCUSSION OF METHODS.

The quantification of both postural load and health effects were studied in order to evaluate a cause-effect relationship between these parameters for groups of female workers. The mechanical load on the musculo-skeletal system was assessed by using electromyography and postural angle measurements. Strain on the workers was also estimated by the time from employment until the first musculo-skeletal sick leave occurred. The severity of the health effect was estimated by the parameters defined in table 1, page 7.

MEASUREMENTS OF MUSCLE LOAD BY EMG.

Recording of the electromyographic activity was performed by using surface electrodes. (II and III). The shoulder and the neck were assessed to be the most loaded body parts in these work situations because of the work being performed to a great extent above elbow height. Thus, many workers reported symptoms located in the body and tendons of the trapezius, symptoms which were confirmed during medical examination. (Aarås, 1986, unpublished). The load on m. trapezius (descending part) was selected as an indicator of the load on shoulder and neck area since this muscle is the main lifter of the shoulder girdle, and is important in the stabilization of the scapula during arm movements.
A representative work load was obtained by recording EMG over a whole work cycle for each task, sometimes including more than one hour.

The quantification of the EMG signal was based on a digital full wave rectification and integration of the signal, averaging the signal over time intervals of o.5 and 1 s. (III).

A calibration of the myoelectric signal amplitude to indicate muscle force was performed, to allow a comparison of activity levels between different muscles and between subjects on different occasions. (III). Methodological limitations of EMG technique concerning calibration procedure and recordings from work situations were considered. (Westgaard, 1987, see also Ericson and Hagberg, 1978, Jonsson, 1978 and Grieve et al., 1976).

Sources of *error* such as artifacts from loose electrode contact, bad connection to earth, movement of connecting wires and 50 Hz line voltage were avoided by continuous observation the raw EMG signal on an oscilloscope. The force developed by the muscle during work was then estimated as a percentage of maximal voluntary contraction (% MVC) by using the established force-EMG calibration curve.

A profile or quantitative analysis of the muscle load during a period of work was obtained by ranking the interval estimates (0.5 or 1 s duration) of muscle force from the recording period to produce a cumulative amplitude distribution function (Jonsson, 1982). (III).

MECHANICAL WORK LOAD MEASURED BY POSTURAL ANGLES.

Measurements of body movements were performed by using a specially developed equipment, the "Ergonometer", which continuously recorded angular displacement of the movements, flexion/extension and abduction/adduction in the shoulder joint as well as flexion/extension of the head and back in the sagittal plane (IV).

The "Ergonometer" or angle transducer consists of a pendulum potentiometer. The measuring performance of this equipment was tested in a laboratory study and found acceptable for oscillatory movements at moderately slow angular velocity (less than 20 degrees per second). Electromechanical assembly work comprised movements with angular plateaus of some duration and the Ergonometer output approximated the real deflection for these movements (Fig. 6 of IV). In addition to this calibration setup, video recordings were performed to assess the accuracy of the method in terms of flexion in the shoulder joint. These recordings indicated that on average the "Ergonometer" underestimated slightly the angle of the real movements.

Postural angles were measured in terms of deviations from a reference body position. This was defined as a standing position with balanced, neutral upright head and trunk posture, relaxed shoulders and both arms hanging relaxed along the body. Zero head angle was defined according to a horizontal sight line fixation.

The reproducibility of this position when readapting the reference posture was tested and found to vary only by a few degrees (IV).

The calibration procedure, where the postural angles were set to zero degrees, was carried out before the vocational recording period and checked after this recording.

The quantitative analysis of postural angles was carried out by ranking the interval estimates during the recording period to produce a cumulative amplitude distribution function similar to a method frequently used for quantification of EMG recordings (Jonsson, 1982).(III and IV). An acceptable validity of postural angle measurements require a close correlation between such measurements and the load on the musculo-skeletal system, if we wish to use postural angles alone as an indicator of postural work load.

Shoulder load has been calculated in terms of flexion/abduction moments of the shoulder joint by using biomechanical models (Ashton-Miller, 1986). His studies has shown that holding the arm in a static position in front of the body is a stressfull cause of shoulder loading and that the dynamic shoulder moment rarely rises above the static shoulder moment. However, a weight in the hand dramatically increased shoulder muscle loading (Personal communication). Shoulder muscle load has also been studied in relation to postural angles of the shoulder joint by using electromyography (Sigholm et al., 1984 and Hagberg, 1981a and b). (V). A significant positive correlation was similarly found when median flexion/extension in the shoulder joint was compared with median trapezius load for 6 subjects who performed wiring work at the 8B system. (Fig. 10 of V).

Limitations of postural angle method for assessing the shoulder load are discussed in (V) and also by Ashton-Miller, (1986), Sigholm et al., (1984) and Chaffin, (1973).

Mechanical load on the *neck* has a close relationship with the forward flexion of the neck (Kumar and Scaife, 1979). Neck muscle activity levels required to equilibrate the head in the range from a well balanced position to extreme flexion positions of the cervical spine has been found to be very low (Harms-Ringdahl, 1985). Passive muscle and ligament forces were calculated biomechanically to be almost sufficient to balance the forward turning moment of a fully flexed head at C_7-Th_1 (Dul et al., 1982).

Therefore, estimating the total mechanical load on the neck by measuring the flexion in the sagittal plane, may be a better method than by measuring the neck muscles' activity such as trapezius load, which does not appear to follow this mechanical load pattern (Harms-Ringdahl, 1985).

Mechanical load on the *lumbar spine* due to forward flexion of the trunk in the sagittal plane depends primarily on the size of the flexion angle according to biomechanical calculations (Kumar and Scaife, 1979). Andersson et al. (1977, 1978) by measuring the disk pressure at the third lumbar disk, showed that the load on the lumbar spine increased approximately linearly with increasing flexion in the sagittal plane up to a forward flexion of 50°. The muscle activity of erector spinae measured at the third lumbar level also showed a linear increase with increasing forward flexion angle.

Parameters such as hand-held weights or other external loads (Schultz and Andersson, 1981 and Schultz et al., 1982, 1983), use of arm rest and lumbar support (Andersson, 1978 and Nachemson, 1964) and acceleration of the trunk (Leskinen, 1983 and Son et al., 1986) influence the load on the lumbar spine but are not quantified by measuring the trunk flexion. However, if the work pattern and movements are assumed to be similar including use of tools before and after ergonomic improvements, a reduction in forward flexion should mean reduced mechanical load on the lumbar spine.

ESTIMATION OF RISK OF INJURY

Load related musculo-skeletal illness is likely to have a multifactorial aetiology, and search for aetiological factors often requires information concerning events that occurred many years in the past. Questionnaires or interviews alone, were not considered satisfactory since interview methods clearly resulted in underreporting of clinically evaluated conditions (Sanders, 1962).

However, questionnaires and interviews provide additional information concerning the level and duration of pain, especially when such health consequences has not yet led to a period of sick leave.

It was decided to use musculo-skeletal sick leave for quantification of injury, since such statistics give reliable information concerning both the development of musculo-skeletal sick leave and the variation of such sick leave as a function of time.

Musculo-skeletal sick leave is a well-defined parameter signifying that the patient has experienced an episode of pain of sufficient intensity and duration to visit a doctor. Following clinical examination, the doctor has reached the conclusion that the patient was unable to work. This is the underlying basis for the statistical analysis.

Musculo-skeletal sick leave is also well-defined in terms of consequences for the company. In particulary it is possible to indicate the financial cost of such sick leave (Spilling, Aarås and Eitrheim, 1985).

In the quantification of musculo-skeletal injury only load–related musculo-skeletal illnesses such as tendinitis, myalgia, myotendinitis, lumbago and sciatica were selected. This because overload on muscles, tendons or supporting tissue, is considered to be a major factor in the aetiology of these illnessses.

No distinction was made whether such overload had been caused by conditions at work, activities unrelated to work, or other factors, since activities outside work, or leisure activities, may contribute to the development of injuries at the work place.

Various types of arthritis, Bechterews disease and various specific diseases producing weakness of muscles were excluded from the analysis since these conditions are not related to mechanical work load. Long duration and recurrence of the load–related musculo-skeletal illnesses together with the medical history, make it often possible to differentiate between these illnesses and other non-muscular illnesses with referred pain to neck and shoulder region (Bateman, 1978).

Pain is the main symptom of musculo-skeletal illness and the main cause to see a doctor. Therefore, by classifying all load related musculo-skeletal illnesses into one group, the potential error in not getting the diagnosis into the right group is small.

The health effects at group level were quantified according to the parameters listed in table 1.

Duration of employment was taken into account, since time of employment is time of exposure to the load, and it is a reasonable assumption that the risk of contracting an injury at any time during employment increases with duration of exposure to load.

The probability of not recording a musculo-skeletal sick leave before a given time was calculated for the group of workers employed in the old work situation and for those who were recruited after the ergonomic redesign at different times after employment by using survival statistics. Such calculations consider the time from employment to the first musculo-skeletal sick leave and the total time of employment (III).

TABLE 1.

Definition	Explanation
1. Development of musculo-skeletal sick leave according to a defined period of employment.	The number of workers with one or more recorded musculo-skeletal sick leave as a fraction of total workers at risk within this defined period of employment.
2. Median duration of musculo-skeletal sick leaves per man-labour years.	The median is defined as the observation having as many musculo-skeletal sick leaves per man-labour years above as below.
95% conf. interval of musculo-skeletal sick leaves per man-labour years.	95% confidence interval of this parameter is defined as an interval wich covers the parameter with a probability of 95%.
3. Duration of sick leave	Total duration (days) of each episode of musculo-skeletal sick leave.
4. Ratio of musculo-skeletal diagnosis	Total number of musculo-skeletal diagnosis as a percent of man–labour years.
5. Ratio of workers ill with musculo-skeletal sick leave	Number of workers with musculo-skeletal sick leave as a fraction of total workers employed.
6. Musculo-skeletal sick leave (%).	The duration of musculo-skeletal sick leave (days) in percent of total time of employment (possible working time (I and II) or calendar days (III and V)).
7. Turn-over	Number of workers terminating their employment in percent of average number of people employed.

SUBJECT POPULATION

Confounding factors were controlled for by selecting only female workers employed full time (8 hours per day) when comparison of musculo-skeletal sick leave was done between the groups. Mean age at recruitment and mean time of employment are given below for each work system.

Work system	Periode of time	No. of workers	Mean age at recruitment	Mean time of employment
8B	1967 – 1974	221	22.1	2.2
Cableform making	1967 – 1974	25	30.9	3.1
Minimat	1970 – 1974	24	24.2	2.1
10C	1975 – 1983	29	24.9	4.3
11B	1974 – 1983	32	24.4	3.6

STATISTICS

(Paper I, II, III and V).

Non-parametric statistical analysis were used for calculations of differences between work systems, concerning duration of individual episodes of musculo-skeletal sick leave (I), number of such episodes and difference in days lost through such sick leave. Difference between total days lost due to musculo-skeletal sick leave was also compared prior and after the ergonomic adaptation by using the theory of double Bernoulli sequencies (II).

Wilcoxon signed midrank test was used for comparing musculo–skeletal sick leave per man-labour years within and between groups. The median with 95% confidence interval of such sick leave for groups, were constructed by the Bernoulli-Wilcoxon procedure. Static muscle loads were compared within the same systems by using the same method. Kaplan and Meier's method (1958) was used to analyse the probability of not getting a musculo-skeletal sick leave according to time of employment.

Gehan test (1965) was applied for analyses of differences in developing of musculo-skeletal sick leaves between groups (III).

Pearson correlation analysis was used to evaluate the relationship between flexion in the shoulder joint and the load on m. trapezius (V).

SUMMARY OF THE RESULTS

The relationship between postural load and the development of musculo-skeletal sick leave.

Such relationships were studied for groups of female workers who manufactured parts for telephone exchanges. The work operations are described in detail for each work system both before and after the ergonomics redesign of the work places in 1975. (I)

Postural load clearly influenced the development of musculo–skeletal sick leave. The static load on the descending part of m. trapezius is given as a median value with range for different work systems on the vertical axis and the time required to maintain this load as a percent of total work time on the horizontal axis, figure 1 A.

The median value of static trapezius load was similar for groups of workers employed at the 8B, cableform making and the Minimat systems in the old work situation, 4.3 to 5.5% MVC, regardless of sitting or standing work positions (Table 1 of III). For the redesigned systems 10C and 11B, the workers showed a much lower median static muscle load for the predominant standing work position, 1 to 1.3% MVC, compared with those workers employed at the 8 B, cableform making and Minimat systems in the old situation.

More than 75% and 50% respectively of the work at the 11B and 10C systems was performed in a standing position (III), which created less load on the shoulder compared with a seated posture.

The wiring work required a median static trapezius load when sitting compared with standing position at the 10C (3.8 vs 1)% MVC and 11B (4.1 vs. 1.3)% MVC respectively. (Table 3 of III).

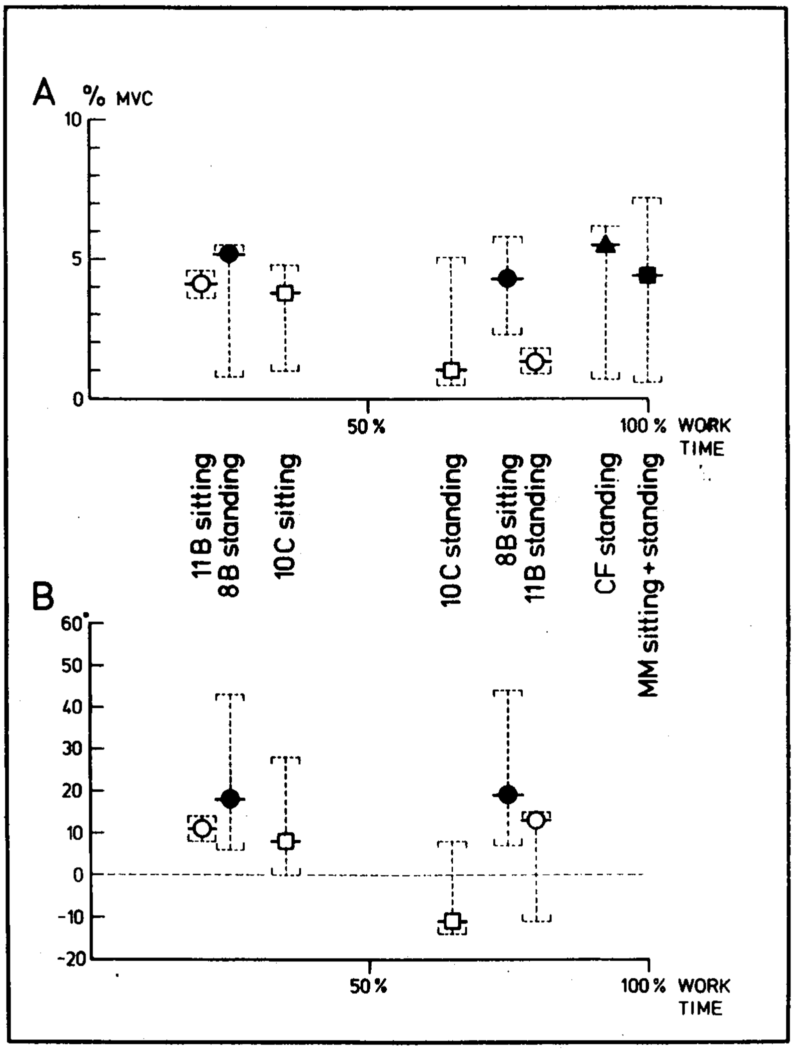

Figure 1. The load on m. trapezius is given as median static value and range for different work systems and the time required to maintain this load as a percent of total work time . (A). Corresponding values are given for median flexion/extension in the shoulder joint (B).

However, the individual variations of the load on m. trapezius were considerable, as shown by the range of values for all systems except for work at the 11B system. The skewed distribution of the values indicates that some individuals performed the work with a very small or large muscle load compared with the rest of the group.

The median and peak loads on the m. trapezius were low for all systems and did not normally exceed 11 and 22% MVC, respectively.

The mechanical work load on the shoulder was also assessed by measuring flexion/extension and abduction/adduction in the shoulder joint as well as head flexion. The movement of the upper arm in the sagittal plane was much more dominant than abduction/ adduction in the shoulder joint. The median values for these angles were small and similar in terms of deflexion of the angles from the reference position for all systems. (Fig. 3B, 6B and 8B of V).

Thus, when considering the shoulder loading in terms of the postural angles in the shoulder joint, the difference between the 8B system and the 10C/11B systems was particularly in the values of flexion and extension. The range of the median flexion/ extension as well as the median values for the group of workers at the 8B, 10C and 11B systems is shown on the vertical axis in figure 1 B. The time required to maintain these angles as a percent of total work time is indicated on the horizontal axis. The arm flexion showed considerable interindividual variability for workers at the original 8B situation (Fig. 3 A of V). Comparing the same task in a sitting position, three subjects recorded much higher median flexion angles (26° to 44°) than three other subjects (7° to 12°).

The arm flexion remained largely unchanged for the subjects, when comparing sitting and standing work position. Workers at the 8B system showed no significantly difference in the values of median flexion compared with workers at the 10C/11B systems.

However, workers at the 10C/11B systems had less upper arm flexion compared with those who worked with high flexion angle at the original 8B system (Fig. 6 A, 8 A vs. 3 A of V). The median angle of flexion varied between -14° and 8° for 10C and -11° and 15° for the 11B system respectively.

The static, median and peak angles indicate clearly a different pattern of movement of the upper arm in the sagittal plane for most workers at the 10C/11B systems vs. the 8B system. For the latter system, the workers showed only flexion in the shoulder regardless of the working position, while most workers at the 10C/11B systems performed wiring with both flexion and extension of the arm.

The external load in the hand will increase the trapezius load for same postural angle of the arm. The wrapping gun was about 0,5 kg heavier for workers in the original work situation at the 8B system compared with the 10C/11B systems where workers used a wrapping gun of about 0.3 kg. The requirement for precision of the movements was the same for the three systems.

The two independent methods to assess shoulder lood, showed a significant positive correlation between the simultaneously recorded measurements of median flexion/ extension in the shoulder joint and the median load on m. trapezius for the 8B system. The Pearson correlation coefficient was $r = 0,65$, $p < 0.01$. However, there was no longer any correlation between arm flexion and trapezius EMG if all these results from different work systems were included.

The head flexion influenced the trapezius load much less than arm position (Fig. 9 D, A and B).

The workers at the 10C and 11B systems had greater head flexion compared with the 8B system. The measurements showed a variation of the median flexion of 39° to 58° for 10C, 15° to 48° for 11B and 9° to 31° for 8B respectively. (Fig. 6C, 8C and 4A of V).

The load on the lumbar spine was assessed by postural angle measurements, which showed that the back flexion was greater for workers at the 10C and 11B systems compared with those who were employed at the 8B system for the predominant work position. The median angles varied between 13° to 24° for the 10C, 2° to 47° for 11B and 0° to 12° for the 8B system respectively. (Fig. 6D, 8D and 4B of V).

Studing a postural load/musculo-skeletal sick leave relationship requires identification of the medical diagnoses for all sick leave. This was obtain for 99 percent of all sick leave. Workers at the original work places at the Minimat, cableform making and the 8B systems (1967–1974) had a statistically significant higher incidence of musculo-skeletal sick leave compared with workers at the redesigned 10C/11B systems (1975–1983) with time of employment between 0–2 and 2–5 years ($p<0.01$). Figure 2 (Fig. 3 of III).

For workers employed more than 5 years, a statistically significant difference was found between workers at the 8B systems vs. workers at the 10C/11B systems ($p = 0.05$). The different development of musculo-skeletal sick leave was not due to differences in age at the time of employment at the different systems, the mean age at recruitment was 24.9 years (10C) 24.4 years (11B) and 22.1 years at the 8B system.

The reason for including all musculo-skeletal sick leave is that loads of the upper part of the body also influence the load level of the lumbar spine in addition to the load created by flexion of the low back. (See Methods).

However, our load measurements assessed more specifically the shoulder load, and local muscle strain was considered to influence mostly the shoulder and neck regions. Therefore, the development of musculo-skeletal sick leave is considered separately for these body areas. Figure 3. (Fig. 5 of III). Workers at the 10C and 11B systems are considered to be a homogeneous group as the EMG recordings showed nearly identical trapezius load at the two systems and the development of musculo-skeletal sick leave was very similar. The workers at the 8B system was significantly different from those employed at the 10C/11B systems concerning the development of musculo-skeletal sick leave, when comparing the time of employment between two and five years, $p < 0.05$. The difference between workers employed for other time intervals did not show any significant difference, partly due to few workers in these groups.

In addition to the above results, there was a statistically significant difference in sick leave due to musculo-skeletal illness when comparing the original 8B system with the 11B and 10C systems.

1. in percent of possible calendar days, 5.1% (8B) vs. 1.6% (11B) and 1.0% (10C), $p < 0.05$,
2. in number of sickness absences in percent of man-labour years (24.5%) vs. (12.1%) and (8.1%), $p < 0.05$.
3. in mean duration of individual episodes of sick leave. The mean duration of sick leaves at the 10C and 11B systems was 46.1 and 47.2 days, both significantly lower than for the original 8B system, 72.8 days, $p < 0.01$. (Table 3 of I and table 4 of III).

The comparison between workers at the original 8B, cableform making and Minimat systems and the redesigned 11B/10C systems, involves different work periods. Even when the comparison was done in the same period of time (1975–1983) between workers at the 10C and 11B systems and those who were employed at the Minimat system, there was a significant difference of duration of musculo-skeletal sick leave per man-labour years, $p < 0.03$. (Table 4 of III).

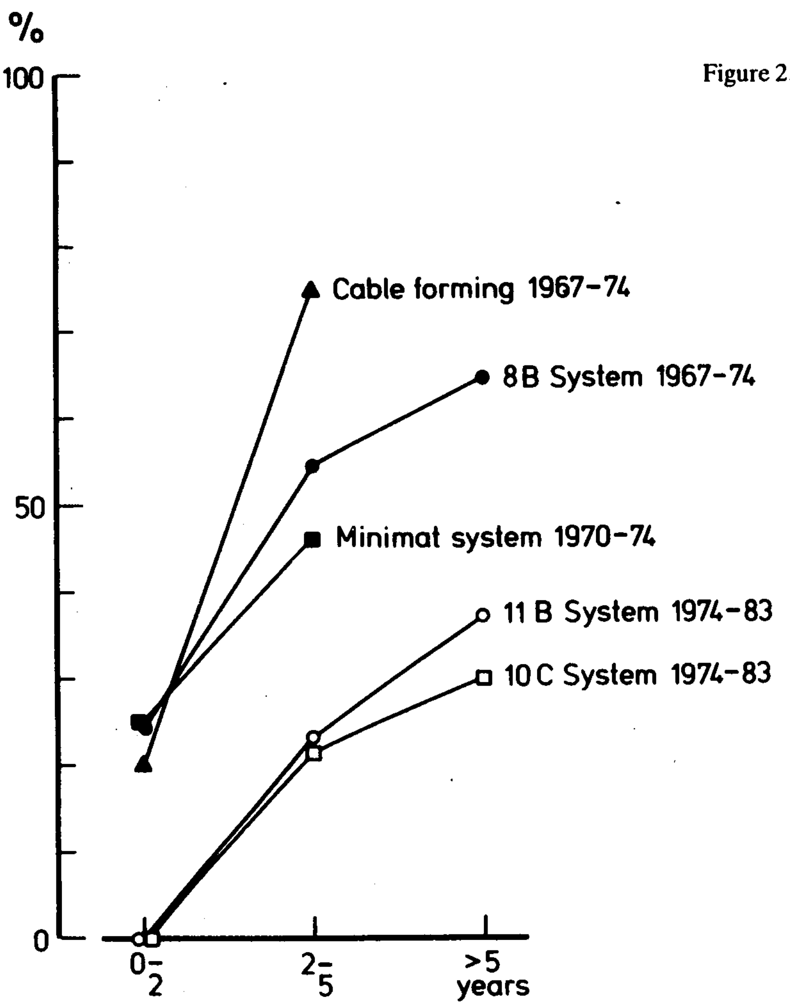

Figure 2. Percentage of female workers with one ore more recorded musculo–skeletal sick leaves as a function of time of employment. Five groups of workers are shown: The 8B system, employed between 1967 and 1974 (filled circles); the Cable making system 1967–74 (filled triangles; the Minimat system 1967–74 (filled squares); the 11B system 1974–83 (open circles) and the 10C system 1974–83 (open squares). Number of subjects in each "time of employment" group (less than 2 years, 2–5 years, more than 5 years): 126, 73, 20 (8B); 10, 12 (Cable making); 12, 13 (Minimat); 9, 13, 8 (11B); 5, 14, 10 (10C).

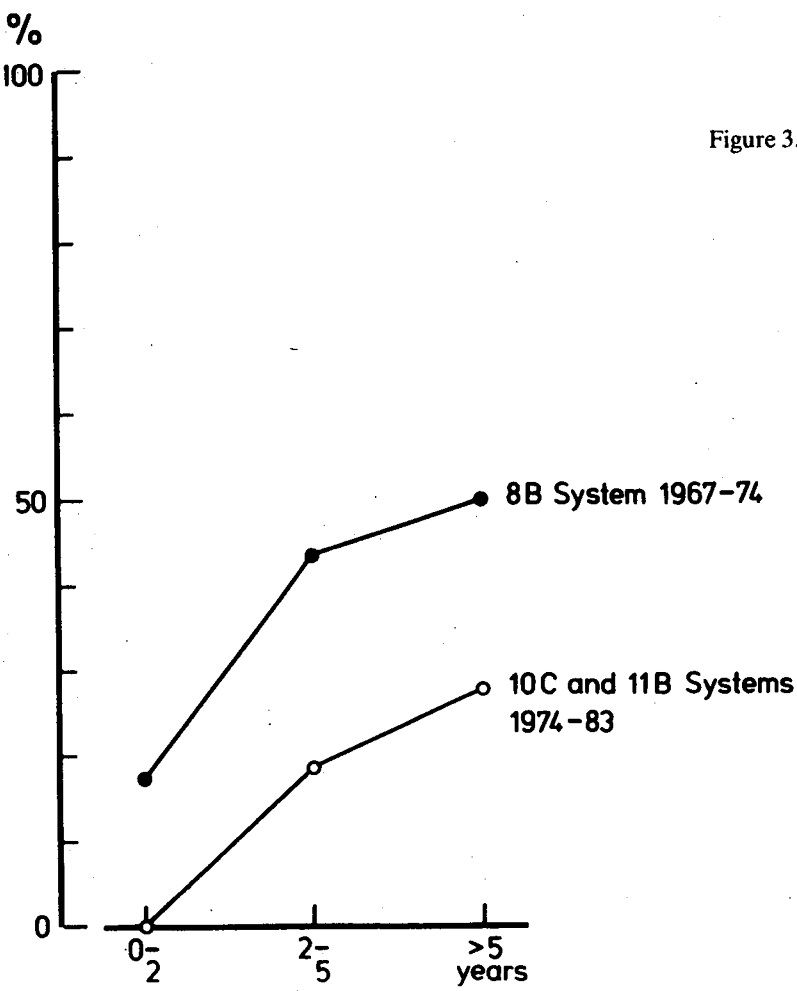

Figure 3. Percentage of female workers with one or more recorded musculo–skeletal sick leaves located to the shoulder and neck region as a function of time of employment. Two groups of workers are shown: the 8B system 1967–74 (filled circles) and the combined 10C/11B systems (open circles). Number of subjects in each group is given in the figure legend of Fig.2.

The time of employment was similar for the three groups of workers. Median values varying between 3.1 and 3.9 years, no statistically significant differences.

The median value of static trapezius load was also higher for workers at the Minimat system compared with those who were employed at the 10C/11B systems. (Table 1 and 3 of III).

The development of musculo-skeletal illness in the low back in a period less than 2 years, 2–5 years and more than 5 years was for the 8B (5%, 10%, 5%) and for 10C/11B (0%, 4%, 0%) respectively. This rate is much lower than the development of such illness in the upper part of the body. (Fig. 3 of III). There was no statistically significant difference between the incidence of musculo-skeletal sick leave in low back for the three systems.

Psychosocial problems and activities outside work may have influenced the development of musculo-skeletal illness for the individual and at group level. However, a coarse quantification of some important psychosocial factors, spare-time activities and living habits of the workers, showed no statistically significant difference for these factors between the groups in 1984. (Aarås, 1986, unpublished).

Other situational variables such as the foremen and the factory hall were also the same during the period of investigation (1967–1983).

EFFECT OF ATTEMPTS TO IMPROVE WORKING POSTURE

The work situation during the years 1967 to 1974 was very strenuous as indicated by the very short time periode from employment until the workers got their first musculo-skeletal sick leave. Particularly for workers at the 8B system, the first episode of such sick leave was most frequent within the first year of employment and this tendency was similar for different age groups (Fig. 16 A and figure 17 of I).

In contrast, women with general office work (our control group), showed no clear grouping of time to first musculo-skeletal sick leave, and certainly no tendency for such sick leave to happen within the first two years after employment (Fig. 16 C of I). The development of musculo-skeletal sick leave was also much higher for workers at the 8B system compared with the control group, (Fig. 15 C of I). In fact, the musculo-skeletal sick leave of different age groups of workers at the 8B system was much higher than all long term sick leave for similar age groups of female workers with administrative and clerical work in the Norwegian telecommunications administration, and of domestic assistance in the same organization. (Fig. 14 of I).

The effect of the ergonomics redesign was, for workers at the 8B system, a considerable reduction in median static trapezius load from the old to the new work situation, both with sitting (4.3 vs. 1.9% MVC) and standing (5.2 vs 1.2% MVC) posture. (Table 1 of III).

When comparing eight subjects who did the same work task in the old and the new work situations, the median static load with range was reduced from 4.3% MVC (0.8–5.8% MVC) to 1.4% MVC (0.5–5% MVC), $p < 0.01$. (Table 2 of III).

The mechanical shoulder load assessed by measuring flexion/extension in the shoulder joint showed no significant difference in flexion angles between workers in the original and redesigned situation at the 8B system, when comparing the lower half of the frame. (Fig. 3A of V). However, workers with high values of flexion in the orginal work situation recorded a considerable reduction of these angles at the adjustable work places. Workers at the adjustable work stand usually preferred to perform all wiring in a seated position, and recorded similar flexion angles at the upper half of the frame as in the standing position at the unadjustable work place. With the redesigned work stand, there was a tendency to record lower flexion angles in standing compared with sitting.

The abduction/adduction was small compared with flexion/extension and there was almost no difference between the old and the new work situation, considering both sitting and standing work position, (fig. 3 B of V).

When comparing the differential effects of the ergonomics redesign on trapezius load and flexion angles, it should be noted that the load in the hand was reduced from 0.85 Kg to almost zero by counterbalancing the wrapping gun at the redesigned 8B system. In addition, arm rest were available in the redesigned work situation.

At the cableform making, the trapezius load showed no significant difference when comparing the same work task in the old and the new work situation. (Table 2 of III). However, at the time of the ergonomics redesign, the main work at cableform making was switched from producing small forms which required relatively high static load, 5.5 (0.7–6.2)% MVC, to larger forms which was a less demanding task, 0.8 (0.5–4.2)% MVC, independently of the redesign of the work places. (Table 1 of III).

At the Minimat system, the number of EMG recordings were limited due to the closure of the system at the time the measurements were performed. The range of static muscle load was considerable and precludes drawing general conclusions. (Table 1 of III).

The new work places for the 10C/11B systems were designed on the basis of the same ergonomics principles as used when redesigning the work places of the old systems. Load measurements from the earliest versions of the 10C work place indicated a static trapezius load of 6 to 10% MVC both with sitting and standing postures. Thus, even for these new systems, the ergonomics redesign has been suggested as important in reducing the work load, particularly on the shoulder and neck region.

Musculo-skeletal sick leave, at the 8B system, was reduced from 5.1% in the period 1967 to 1974 to 4.6% following the ergonomics redesign in 1975. The number of sick leaves due to musculo-skeletal diagnosis in percentage of man-labour years was reduced by a third (16.5% vs. 24.5%, $p < 0.05$) signifying that such complaints have become less frequent but of longer duration. This was mainly due to a single sick leave with a duration of more than a year, accounting for 1.2% of total sick leave after 1975. Excluding this chance occurrence of a very long sick leave, musculo-skeletal sick leave in the years 1975–81 was 3.3%, which is clearly lower than the musculo-skeletal sick leave before the ergonomics redesign.

This result was supported by comparing workers employed both in the original and the redesigned work situation for at least one year in order to have a sufficient observation period to assess the effect of the work load on the health of the workers. The same subjects were compared to eliminate interindividual differences in general health condition and in ability to tolerate prolonged muscle load. To assess changes in the health condition, only subjects with at least one recorded musculo-skeletal sick leave were included in the comparison.

Such sick leaves were reduced (as a median duration per man-labour years with 95% conf. interval) from 22.9 days (4.4–50.8) in the old situation to 1.8 days (0–34.4) in the new one, a difference which is statistically significant, ($p < 0.02$) (Table 5 of III).

This reduction was obtained in spite of longer time of employment and higher mean age of the workers in the period after the redesign of the workplaces. The total work time for the group before and after redesign were not significantly different.

Cableform making showed also a statistically significant reduction in musculo-skeletal sick leave as a percentage of possible work days, 4.7% vs. 1.6%, and the number of such sick leaves as a fraction of man-labour years was also reduced from 30.6% to 14.3% when comparing the period before and after the ergonomics redesign.

The effect of the ergonomics redesign as such was also assessed by comparing all workers employed on the old systems before the redesign with workers recruited after 1974 and employed only on the redesigned systems. The latter group of workers had a much higher probability of not getting a musculo–skeletal sick leave at any time during the first two years of employment than workers at the old systems. After 2 years of employment, the difference was highly significant, ($p < < 0.01$).

This result was not due to differences in age (mean age 24.9 and 23.2 years for workers at the redesigned and original systems) or in proportion of male workers in the group (17 vs. 21%), (Fig. 4 of III).

There was also a statistically significant reduction of average musculo-skeletal sick leave calculated as a function of production *time* in the years 1975–1982 (3.1%) compared with (5.3%) in the period 1967 to 1974, $p < 0.01$ (Table 2 of II). This comparison concerns all production workers in the two periods of time. This reduction was in part due to the low rate of development of such sick leave at the 10C/11B systems (Table 4 of III).

The very sharp interruption of the increasing incidence of musculo-skeletal sick leave, coinciding with the introduction of the ergonomics redesign, provide additional very compelling evidence for a sudden improvement of the health situation for workers in STK's Kongsvinger plant (Fig. 3 of II). The reduction in musculo-skeletal sick leave was not due to reduced productivity which had on average been higher during the years following the ergonomics redesign than the years preceding these (Fig. 6 of II).

The effect of the redesign of the workplaces was also assessed by interviews and questionnaires. Interviews concerning feelings of discomfort and pain while working were carried out in the autumn of 1978. Workers employed at least one year in the old situation at the 8B and cableform making indicated a higher level of pain in various parts of the body in the old work situation, compared with the pain level experienced in 1978. (Fig. 5 of II). The workers at the old 8B situation were in 1978 in part employed at the 10C and 11B system when interviewed, but they had all had some experience with the 8B system after the ergonomics redesign.

The location of complaints on the basis of interviews was in good agreement with the body location of the musculo-skeletal diagnosis and the likely location of the muscle load (Fig. 19 of I and Fig. 13 A and B of I).

Another series of interviews in 1984 supported the fact that pain intensity and duration was still a serious problem for about every eighth worker in the redesigned situation. (Aarås, 1986, unpublished). A considerable amount of clinical symtoms and signs of load-related musculo-skeletal illnesses were still found among the workers during the summer of 1984 (Aarås, 1986, unpublished).

The workers' own views on the reasons for the reduction in musculo-skeletal sick leave clearly indicated that the redesign of the work places together with the introduction of a fixed pay structure were of considerable significance. (Table 4 of II). Another indication of improved environmental work conditions was a statistically significant reduction of turn-over from 30.1% (1967–1974) to 7.6% of total man-labour years (i.e. average number of workers) in the period (1975–1982) ($p < 0.001$). (Table 5 of II).

DISCUSSION

The aim of this investigation was to study the relationship between the postural load and the development of musculo-skeletal illness. Such a relationship between the incidence of musculo–skeletal illness and static trapezius load has been confirmed for groups of female workers. Figure 1A and 2.

However, the great variation in static trapezius load and the 95% conf. interval of duration of musculo-skeletal sick leave per man-labour years within each group, indicate clearly that such a relationship is only valid when considering the median value for the group. (Table 4 and 5 of III).
The median value is rather insensitive for extreme values and was chosen as a measure of central tendency for the skewed distribution of these data.

The large difference in work load within the group doing the same task may be due to differences in speed of movements by the subjects, differences in work technique and psychological factors. Speed influences muscle tension unrelated to body posture, but muscle contractions may also appear as an unconscious reaction to a stressful stimulus from a mental problem (Westgaard and Bjørklund, 1986).

The great range of development times for musculo-skeletal sick leave for those developing such illnesses within the group, may be due to individual differences in general health condition and ability to tolerate prolonged muscle load, as well as individual differences in muscle load.

Shoulder load was assessed by two independent methods, which showed a statistically significant correlation between simultaneously recorded measurements of median flexion/extension in the shoulder joint and the median load on m. trapezius for standardized movements such as wiring at the 8B system. (Fig. 10 of V).

However, such correlation weakens and may disappear when load on m. trapezius is increased due to loads in the hand or a combination of shoulder lift in addition to the trapezius load created by forward flexion of the upper arm.

Therefore, the two estimators of shoulder load did not substitute for each other without considering parameters which influence shoulder loading, but not quantified by arm position. Important parameters in this study are the weight of the wrapping gun and arm rests for elevated arms.

The work load assessed by trapezius load was much lower for the predominant work position for workers at the 10C/11B systems compared with those who were employed at the old 8B system. Figure 1 A. The difference in mechanical shoulder load in terms of flexion/extension of the shoulder joint is less clear. Half of the workers at the 8B system recorded much higher values of flexion compared to the others. This difference was not related to stature of workers. Different work technique is a reasonable explanation of the variation of postural angles. Considering the predominant work position, there was no significant difference in flexion/extension for workers at the 8B system compared with workers at the 10C/11B systems. (Fig. 3A, 6A and 8A of V). However, workers at the latter systems had lower flexion/extension compared with at least those who recorded high values of flexion at the 8B system. In addition, most workers at the 10C/11B system reduced the period of activity of the flexors and extensors of the shoulder joint by distributing the work load between the two muscle groups, while workers at the 8B system performed the wiring with only flexion in the shoulder joint. A further analysis of the periods of activity and the pauses between the load will be carried out at some future date. The shoulder load was also influenced by a lighter hand tool. The weight of the wrapping gun was 0.5 kg lower with a correspondingly lower load on the trapezius when comparing the workers at the 10C/11B systems with those who worked at the 8B system.

The importance of hand load on the upper trapezius load is documented by Sigholm et al., (1984), showing that 1 kg. hand load increased the trapezius load about 15% for flexion and abduction movements in the shoulder joint. This increased value was calculated on the basis of increasing of rms values of the amplitude from electromyographic recordings.

Thus, according to the load related parameters discussed above, the loading of the substructures of the shoulder joint has been less for workers at the redesigned 10C/11B systems compared to the original work situation at the 8B system.

Most workers at the 10C/11B systems showed higher trapezius load in the sitting vs. standing position. This indicates the importance of being able to change between the two postures in order to reduce the work load on the upper part of the body.

There was a clear evidence of less musculo-skeletal sick leave for workers at the 10C/11B systems compared with workers at the original 8B system. Workers at the latter system had a statistically significant higher incidence of musculo-skeletal sick leave for those employed full time (8 hours per day) for a period of time more than five years. Figure 2. (Fig. 3 of III).

The same was true for development of musculo-skeletal sick leave in the upper part of the body when considering the period of employment between two and five years ($p < 0.05$). Figure 3. (Fig. 5 of III).

There was also a statistically significant difference between workers at the old 8B system and the adapted 10C/11B systems when comparing the number of musculo-skeletal diagnoses, musculo-skeletal sick leave (%) and the mean of the total episodes of the sick leave. (Table 3 of I and table 4 of III).

The hypothesis postulating a relationship between the level of postural load and the incidence of musculo-skeletal illnesses, also assumes a reduction in the occurence of musculo-skeletal illnesses following reduction of postural load. The ergonomics redesign in 1975 significantly reduced the trapezius load for workers at the 8B system, particularly for standing work by making the work stand adjustable and by reducing the hand load by counterbalancing the wiring gun and reducing its weight by 0.5 kg. (Table 1 and 2 of III).

In contrast, flexion in the shoulder joint showed no significant difference as a median group value, for workers performing wiring at the orginal and redesigned work stand at the lower half of the frame. (Fig. 3A of V). However, those workers with high values seemed to reduce these angles by adjusting the work frame. This was in contrast to workers with low flexion in the original situation who recorded almost unchanged angles at the adjustable work place. This is in agreement with experience from working life, where workers adjust the work area only when feeling fatigue and discomfort due to strenuous posture. In this study, the subjects have been allowed to perform their own adjustments and chose their own posture, as they would do during a normal working day. The purpose of this study was not to perform carefully controlled adjustment of the same work stand, which might have given different result.

The differential effects of the ergonomics redesign on trapezius load and flexion angles may be explained by the reduction of the shoulder loading due to support of the forearms and the reduction of the weight of the hand tool to almost zero. This reduction of shoulder loading was independent of the load created by flexion of the upper arm in the shoulder joint. The result emphasizes the need for quantification of external loads as well as support to body posture, if postural load is to be quantified in terms of postural angles.

Most workers prefer to remain seated for all wiring work at the redesigned work places in spite of higher values of flexion angles when working at the upper half compared with the lower half of the frame. (Fig. 3 of V). Working in the seated position offers advantages, such as improved precision and stability in addition to increased mobility of the legs and feet. (Grandjean, 1980), less energy expenditure and muscle load on the legs over the standing position. However, the possibility of standing up and accordingly reduce the shoulder load may have been important for at least those who felt discomfort or pain.

In parallel with the reduced postural load when working at the redesigned work stands, the workers' health was improved in terms of reduced musculo-skeletal sick leave for the 8B system when considering the same subjects. (Table 5 of III).

Further support for the hypothesis was found in the study of workers at cableform making. The postural load was significantly reduced by changing from small to large cableforms for many of the workers at this system (Table 1 of III), even though the redesign of the work places did not reduce the trapezius load (Table 2 of III). In keeping with the reduction in load, a significant reduction of musculo-skeletal sick leave followed the change of the work task for many workers. (Table 3 of II).

The work stands of the 10C and 11B systems were designed according to ergonomics principles almost from the start of manufacturing of these systems. Both the trapezius load and the developing of musculo-skeletal sick leave were lower for workers employed at these systems compared with the orginal situation at the 8B system. (Table 3 of III and Table 4 of III).

The head and neck flexion seemed to have less influence on the load on m. trapezius and the development of musculo-skeletal sick leave related to time of employment when compared with flexion in the shoulder joint. Workers at the 10C system had considerable median flexion of the head with variation between 39° and 58° and for the neck 19° and 39° respectively for the predominant standing work position. (Fig. 6 C of V). The measurement of postural angles of the shoulder joint indicated a low shoulder load. However, the development of musculo-skeletal sick leave according to time of employment was low in the shoulder/neck area for workers at this system. Figure 3. This indicates that the tolerable level of neck flexion in the sagittal plane may be higher than 15°, as recommended by Chaffin, (1973).

These results are in agreement with studies by HarmsRingdahl (1985) showing that the flexion in the shoulder joint had much higher influence on the load on m. trapezius than did head flexion.

The basis for the postural load/musculo-skeletal injury relationship found in this investigation is supported from many other studies which have shown a relationship between a stressful position at work and functional disturbances or pain in various parts of the muscular-skeletal system, Chaffin (1973), Kourinka et al., (1979), Luopajärvi et al., (1979), Bjelle et al., (1979 and 1981), Hünting et al.,(1980), Maeda et al., (1980), Andersson, (1980) and Stubbs (1981).

Bjelle et al., (1981) found that workers who suffered from soft tissue rheumatism had a significantly longer duration and higher frequency of abduction or forward flexion in the right and left shoulder at work compared with their controls. The workers' preference for reducing the flexion in the shoulder joint is also presented in studies by Chaffin, (1973) and Hagberg, (1981 a). These studies concluded that sustained, elevated arm work, especially if supporting a load, must be minimized to avoid shoulder muscle fatigue and associated tendinitis illness. Further support for a quantitative relationship between level of postural load, and the health consequences of such load, is evident from other projects at the Institute of Work Physiology (Westgaard et al., 1986).

Low-back pain was responsible for a relatively small part of the musculo-skeletal sick leave for workers at the 10C/11B systems. The median flexion of the back was for workers at the 10C system 18° and for the 11B system 15° respectively. (Fig. 6D and 8D of V). These results are in agreement with Jørgensen (1970) who proposed that most men and women should be able to maintain a stooped posture of 20° during the day.

The importance of reducing the postural load by using work places designed according to ergonomic principles is supported by further analysis of muskulo-skeletal sick leave, interviews concerning the pain level experienced by the workers during work and the turn-over of the employees.

A significant reduction of the probability of getting musculo-skeletal related sick leave at any time during the first two years of employment, was observed for workers only employed at the redesigned work places, compared with those who worked at the original work stands. (Fig. 4 of III and Table 2 of II).

A higher level of pain was indicated by workers with experience of work in the original situation compared with the level of pain in 1978 (Fig. 5 of II). This difference of pain level might have been even greater due to underreporting of clinical symptoms in the past (Sanders, 1962).

The workers assessed the redesign of the work places together with the introduction of a fixed pay structure to be of considerable significance for the reduction of musculo-skeletal sick leave (Table 4 of II). Introduction of a fixed pay structure one year and a half after the ergonomics redesign might have been beneficial, presumably because the workers were more able to relax in their work situation. However, the reduced muskolo–skeletal sick leave was not due to less effort at work (Fig. 6 of II).

A prerequiste for the evalution of a postural load/ musculo–skeletal sick leave relationship, is that confounding factors are spread equally across the groups of workers under study.

The aetiology of the load-related musculo-skeletal illness is considered to be multifactorial. Psychosocial problems and activities outside work, spare-time activities and living habits of the workers did not show any significant difference across the groups (1984). At that time, many workers were still employed on the same work tasks (systems) as previous years. (Aarås, 1986, unpublished).

Confounding factors such as age, sex and working hours per day were controlled. All groups consisted of females who worked about 8 hours a day. Time of employment for these groups was taken into account as the fraction of workers with musculo–skeletal sick leave was calculated as a function of time of employment.

The age distribution of the groups was also similar, with a mean age at recruitment of 22.1 years (8B) which was 2.8 years less than the mean age for the 10C/11B systems. At cableform making the mean age of the workers was 7.7 years older than those who worked at the 8B system. The development of musculo-skeletal sick leave was somewhat higher for workers at cableform making compared to workers at the 8B system, considering the period of employment between two to five years, but the difference was not statistically significant (Fig. 3 of III). The median static trapezius load was also slightly higher for workers at the cableform making vs. the 8B system.

Selection of workers for tasks which suit them best did not seem to be of significance as a confounder of modifying the work load between the groups. The recruitment was always made according to the need for workers at each system. Most of the recruitments included new untrained employees. However, when the old system 8B was reduced from 1977, many employees had to be transferred to the new systems 10C/11B. These workers had already been exposed to high level of postural load and many had suffered musculo-skeletal complaints. This might have reduced their tolerance to further muscle strain and contributed to increased sick leave at the redesigned systems.

In conclusion, the confounding factors discussed above, probably influenced each work group quite similar in terms of development of musculo-skeletal illnesses, making the groups comparable concerning the relevant variable, postural load.

However, psychological aspects in the work with introducing the redesigned workplaces might have influenced attitudes of management to accept breaks for workers with symptoms of postural load.

Such psychological factors might have been evaluation and testing of ergonomically designed work stands together with education of workers and plant officials regarding the relationship between work load and development of musculo–skeletal sick leave.

However, in another study ergonomics redesign without a simultaneous reduction of the postural load, was not of major significance for the development of musculo-skeletal sick leave. This was supported by a tendency to an increasing rate of such illnesses in the period two to three years after the redesign of the work places (Westgaard et al., 1986).

A significant reduction in turn-over may be due to reduced discomfort and pain when comparing the period before and after the redesign (Table 5 of II). However, turn-over is influenced by several factors unrelated to the environmental work condition at the plant. The turn-over rate in the redesigned work situation in this study was far below the rate (between 60% to 70%) for a similar age group of female workers performing electro-mechanical assembly work in another plant during the period 1976–1979 (Westgaard et al., 1985). In this latter plant, workers were assessed to have a static trapezius load a few percent MVC higher compared to workers in the original situations in this investigation, Figure 1. Other factors were similar for the two plants, such as possibilities for obtaining alternative employment in the area and wages in the present work compared with the average wage rate in the district.

It appears difficult to suggest limits for safe level of work load. The workers at the 10C/11B systems, had a median static trapezius load of about 1 to 2% MVC for most of the work day. The work load assessed by the median flexion/extension in the shoulder joint was less than 15° and the abduction/ adduction was mostly less than 10°.

The development of musculo-skeletal sick leave due to shoulder injuries according to time of employment approximated the incidence of musculo-skeletal illness, regardless of body location, for a group of female workers without continuous work load (Fig. 5 of III and Fig. 15 C of I).

These data, suggest that shorter periods with relatively high load while sitting are tolerated for workers at the 10C/11B systems, and that the over-all work load for these systems is beginning to approximate a reasonable demand on individual muscles.

However, pain intensity and duration were still a problem for workers at the 10C/11B systems (1984) and many were found to have clinical symptoms and signs of load-related musculo-skeletal illnesses (Aarås, 1986, unpublished).

A suggested threshold level for acceptable mechanical load on the shoulder should consider both intensity and duration of such load, as well as duration of necessary pauses between periods with prolonged mechanical load. Working hours per day also influence the total work load.

The results from this prodject suggest that a static load level of about 1% MVC is acceptable for the major part of the work day if adequate breaks in the load pattern are allowed when needed. However, the same level of load is too high if it has to be maintained for working days exceeding 8 hours (Westgaard et al., 1986).

The significance of long working hours per day on the incidence of musculo-skeletal sick leave was investigated for service workers at North Sea oil platforms (Westgaard et al., 1986). This group had a median static trapezius load of 1% MVC, but had very long working hours (12 hours each day for 14 days). The development of musculo-skeletal sick leave for these workers was in fact higher compared with workers at the 10C/11B systems.

Even the work pattern, in terms of changing the median load during a working day compared with the over-all median value for this period, may influence the incidence of musculo-skeletal sick leave. Very high static trapezius load for workers at the original 8B system for at least 25% of the work time, might have been important for the high incidence og musculo-skeletal sick leave for workers at this system. (Fig. 1A of III).

The suggested level for maintained static muscle work of 2 to 5% MVC (Jonsson, 1982) is too high according to the results from this study.

This discrepancy may be explained by the long-term effects associated with the long exposure times used in the present investigation which is different from the studies by Jonsson of muscular endurance during constrained static and dynamic work.

A median arm flexion of 15° and a median arm abduction of less than 10° are beginning to approximate an acceptable arm position for continuous work task, when the external load is low. These values are much lower than limits for these angles proposed elsewhere (Chaffin and Andersson, 1984).

Thus, a threshold level for acceptable work load needs consideration of all the above discussed parameters influencing the work load.

However, acceptable work load should be related to health criteria such as acceptable limits for development of musculo-skeletal illness among a group of workers. Factors influencing the incidence of such illness such as working hours per day, total time of employment, age and sex within the group must all be taken into account.

GENERAL CONCLUSIONS.

This project has included an analysis of the muscular injuries at specific work situations and the work load for these tasks. It is concluded that:

For groups of female workers, a quantitative relationship has been established between the postural load in terms of median value across the group of static trapezius load, and the development of musculo-skeletal sick leave related to the time of employment.

By assessing the postural load of the shoulder by measuring the flexion/extension in the shoulder joint, there was indication that this load was influenced by:

* the magnitude of postural angles themselves.
* the distribution of the work load between the subgroups of muscles such as flexors and extensors, giving correspondingly reduced period of activity for each group

Redesigning the work places according to ergonomic principles reduced the postural load in terms of static trapezius load, particularly when standing for workers at the 8B system. When work load of the original and redesigned 8B system was assessed by postural angles, a considerable reduction in arm flexion was observed for those workers having high values of these angles at the original situation. Workers at the 10C/11B system had low trapezius load during the period of study, due to the introduction of ergonomically designed work places from the start of manufacture of these systems.

Reduction of the postural load was associated in time with a significantly reduction in musculo-skeletal sick leave per man–labour years for the same subjects at the 8B system. The incidence of musculo-skeletal sick leave, as a function of time of employment was lower for workers at the 10C/11B systems relative to workers at the original 8B system.

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Postural muscle strain as a causal factor in the development of musculo-skeletal illnesses

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Musculo-skeletal complaints account for 30% of time loss through sick leave. A study was made at a small manufacturing plant in Norway among workers subjected to static muscle load, with particular reference to the relationship between such illness and muscle strain due to working conditions. The paper covers old working standards and ergonomic improvements made in 1975. The results show an increase in musculo-skeletal illness with increased length of employment and increased age.

Keywords: Musculo-skeletal system, working conditions, occupational health

Introduction

Complaints originating in the musculo-skeletal system are one of the most common categories of illnesses in Norway today. A survey of 9000 patients, treated by general practitioners, showed that 20% of all patients suffered from a musculo-skeletal complaint, accounting for 30% of time lost through sick leave (Borchgrevink *et al*, 1980). It has been estimated that the cost of each day of production lost through sick leave is in the order of £100 to the company and the community at large (the value of lost production and sickness benefits), amounting to approximately £1 million per 1000 workers each year for this particular category of illnesses. Thus, both the economic and medical implications of musculo-skeletal illnesses are serious, and apparently of increasing importance relative to other illnesses.

It is likely that many of these complaints are caused or enhanced by excessive muscular load due to the need to adopt awkward postures at work. The main symptom of musculo-skeletal disorder is pain, and a correlation between posture and signs or symptoms of such disorders has been demonstrated (Luopajärvi *et al*, 1979; Maeda *et al*, 1980, Bjelle *et al*, 1981). The situation at a small manufacturing plant in Norway has allowed us to carry out a quantitative study regarding the occurrence of musculo-skeletal illnesses (i e, sick leaves with a relevant medical diagnosis) among workers in work situations demanding static muscle work, and in particular the relationship between such illnesses and muscle strain due to working conditions.

In the early 1970s the workers at Standard Telefon and Kabelfabrik's plant in Kongsvinger, Norway, frequently registered musculo-skeletal complaints, and the factory had at the same time a high rate of sick leave. The sick leave was therefore attributed to musculo-skeletal illness and new work places were designed, which allowed the workers more flexibility in adopting a suitable work posture. Arm rests on the chairs supported elevated arms, and thereby reduced muscular load on the shoulders and arms. The design of the work places made it possible to alternate between a sitting and standing posture. The new work places were introduced early in 1975, and a significant reduction of sick leave followed.

This paper describes the old work situations at the plant and the ergonomic adaptations made in 1975. The occurrence of documented incidences of sick leave due to musculo-skeletal illness in the old work situations is analysed and compared with similar data from other, less strenuous work situations. Another paper (Westgaard and Aarås, 1984) considers evidence to determine whether the ergonomic adaptations of the workplace have had any effect in improving the health of the workers. Preliminary reports from this study have been published (Aarås and Westgaard, 1979; Westgaard and Aarås, 1982).

Methods

Epidemiology

The work duties of all workers employed at the factory since the start in 1967 were identified, and all sick leaves of more than 3-days duration when a doctor's certificate is required (usually made out by general practitioners in the area), were registered. The medical diagnoses were then collected at the local health authorities, by special permission

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granted by the Department of Health and Social Security. The sick leaves were classified according to the type of diagnosis, and times away from work were calculated for musculo-skeletal illnesses and all other illnesses combined, in percent of possible time at work.

The most frequent musculo-skeletal diagnoses were myalgia, dorsalgia, brachialgia, tendinitis, lumbago and ischialgia. Rheumatic illnesses (arthritis), although of musculo-skeletal origin, were included among 'other illnesses' since muscle strain is not a primary cause of this illness.

Interviews concerning feelings of discomfort and pain while working

All workers employed in the autumn of 1979 were questioned about the intensity and location of pain on different parts of the body. A distinction was made between pain experienced in a 'past' situation (this was not related to a specific time period, but if ailments of variable intensity had been experienced, the *worst* chronic pain intensity was indicated) and the 'present' situation (a subjective evaluation of average pain intensity in the last year). Pain intensity was graded according to a scale of six steps. It was attempted to differentiate between somatic pain in muscles and tendons and other sources of pain, like migraine. A question of whether any change in pain intensity could be associated with a specific time period or any particular event was included at the end of the interview.

Only information relating to the situation before the ergonomic adaptations is included in this paper. Comparative results describing discomfort in the 'past' and 'present' situation are presented in a following paper (Westgaard and Aarås, 1984).

The factory

General

STK's factory in Kongsvinger was established in 1967 to produce parts for telephone exchanges. An average of 36 men and women were employed in production work at the factory in 1968, increasing to 137 in 1971 and reducing to 103 in 1974 (Table 1). During the last few years the factory has had a work force of about 100 (Westgaard and Aarås, 1984). From 1967 to January 1975 a total of 251 women and 69 men were employed in production work. Most of the men were employed in the production of cable forms (see below). During the time the factory has been in existence, a product development has taken place. The production was first based on the telephone exchange system 8B, followed by the internal communication system Minimat. Until 1974, cable making and the 8B system accounted for more than 90% of all production work, in 1974, 87%. In 1974 to 1976 the 8B system was to a large extent replaced by the 10C and 11B systems. The 8B system was discontinued in 1980. Twenty to thirty workers have been producing cable forms (cable making) each year from 1967 until January 1975.

The production workers had a piecework pay system until May 1976, when a fixed pay system with a collective productivity agreement was introduced. Flexible working hours were introduced in January 1977. The factory has had the same management and the same foremen from 1967 until 1983.

Cable making

The production of cable forms began in January 1967. By January 1975, 89 workers had been employed in this production (29 women and 60 men). Total production time 1967 to 1974 was 170 man-labour years. The work situation is illustrated in Figs. 1 to 3. About 5% of the time is used to hammer nails into a wooden board according to a detailed instruction sheet. Then (about 45% of the production time) the worker lays thin insulated wire between the nails. Approximately 35% of the time is used to sew the wires together with strong plastic bands. The final 15% of total production time is used to check the wiring and remove the cable from the table.

Fig. 1 Cable making. The old workplace

Table 1: Number of workers employed at the different work systems 1967 to 1974

Work system	Total 1967–1974	Calendar year 1967	1968	1969	1970	1971	1972	1973	1974
Cable making	170	10	15	20	25	25	25	25	25
8B	506	26	28	42	70	102	94	79	65
Minimat	48	–	–	–	8	10	10	10	10
11B	3	–	–	–	–	–	–	–	3
Total	727	36	43	62	103	137	129	114	103

There are two sizes of wooden boards, 2 m x 1·5 m and 4 m x 1·5 m. The boards were mounted with fixed centre height before 1975, but the slope of the board could be altered in a stepwise manner. This mounting system did not allow any adjustment of the height of the work surface, to compensate for variations in the height of the workers and the cable forms. When working on large cable forms, the workers were forced to stretch considerably because of a large and too high working area.

Fig. 2 Cable making. The table is mounted on a hydraulic stand

Sewing of cable forms and laying of wires when working with the large forms were always done standing. It was possible to work seated when making small forms, but then the table top had to be angled almost horizontally to leave room for the feet underneath the lower edge of the table. This made the worker bend forward since the cable form was usually larger than the reaching area with a normal seated posture.

A new mounting system for the wooden board, based on a hydraulic cylinder, was introduced in the last half of 1975 (Fig. 2). This system allowed continuous adjustment of height and slope of the table. The large tables were made adjustable in the same way in 1977 (Fig. 3). Independent adjustment of height and slope of the table allowed each worker to find his own optimal work posture depending on his height and the size of the cable form, thereby reducing the strain on neck, shoulders and low back. Illumination was also improved, by replacing an angle-poise lamp fitted with a conventional tungsten bulb by neon tube lighting (in 1975).

The 8B system

Part production of the telephone exchange system 8B began in Kongsvinger in January 1967. By January 1975 231 persons had been employed with this production (222 women, 9 men) for a total of 506 man-labour years. The work system referred to as 8B in this paper is illustrated in Figs. 4 to 6. About 10% of the work time is used to fasten the finished cable form to the metal frame, do other preparatory work and terminate the job. Otherwise, the work consists of connecting wires with bare ends to the needle shaped terminals on the metal frame. Before 1972 about 25% of the connections were made using tin soldering, and later about 10%. The rest is done by wrapping. (The wire is placed in a 'wrapping gun' which is then positioned on to the terminal. Thereafter the wrapping gun

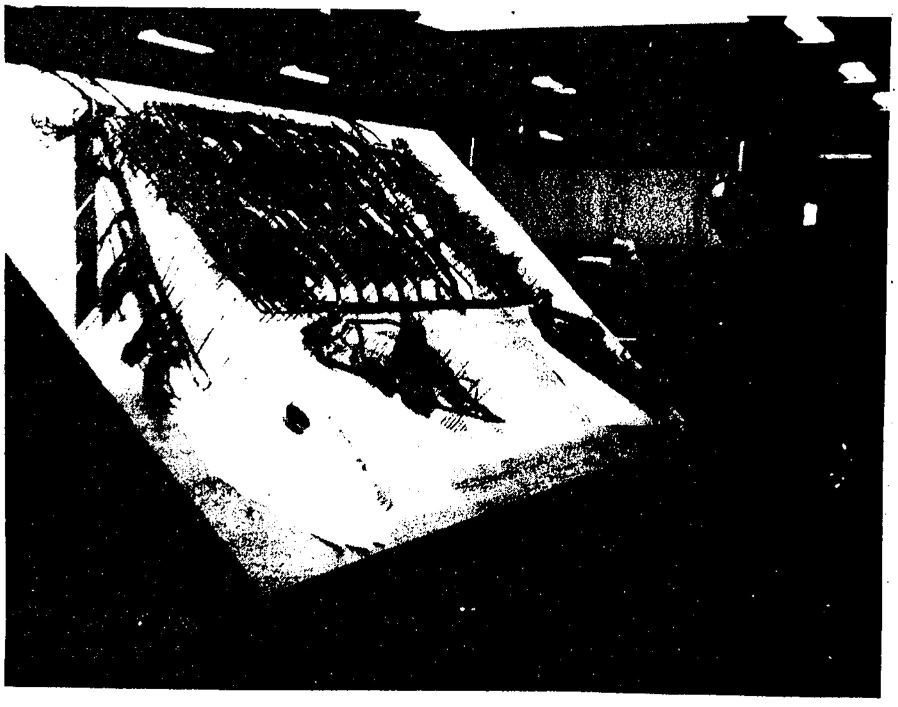

Fig. 3 Cable making on a large table. Note improved low-luminance lighting introduced after 1980

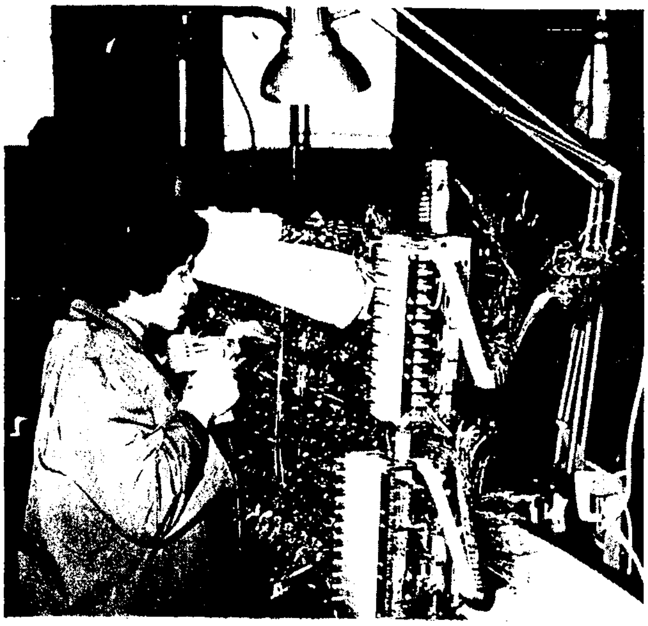

Fig. 4 The 8B system. Old, high sitting posture. The shoulders are lifted. Electric wrapping gun

Fig. 5 The 8B system. Old, high standing posture. The shoulders are lifted

spins the wire around the terminal.) The metal frame is 100 cm wide and 40 to 80 cm high, depending on the number of horizontal 'rows' on the frame (usually 6 to 12). Working time along one row varies between ½ and 1½ h. The work is then immediately continued on the row above or below the finished row. It is necessary to see small objects about 5 cm into the frame, which means that the angle between the line of sight and the horizontal plane must be small.

Before 1975 the metal frame was placed on a table of fixed height (Figs. 4 and 5). Work on the lower rows necessitated a forward bending posture in order to satisfy the vision requirement. Most workers preferred to keep a seated posture as long as possible. The chair was therefore adjusted upwards when the worker moved on to higher rows, until the thighs were pushed against the lower edge of the table surface.

The chair had a wooden seat and was described by many as hard and uncomfortable. A loose pillow was often used as seat padding. The chair had a wooden back support which was described as hard and badly shaped. The back support could be regulated forwards and backwards, but gave no support for the lumbar area of the back when bending forward. The chair had no arm rests. It was therefore not possible to support elevated arms while working on the middle rows, although the table acted as support when working on the lower two or three rows. The weight of the electric wrapping gun (about 1000 g) was not counterbalanced and this increased the static load on the muscles in the right shoulder and arm.

Work in the upper part of the frame had to be done standing (Fig. 5). Shoulders and arms were elevated, resulting in considerable static load on the shoulder and arm muscles.

Early in 1975 a new type of work place was introduced. The metal frame was placed on a hydraulic stand (Fig. 6) with a vertical movement of 60 cm, which was sufficient to allow both comfortable seated and standing postures. All seated work could be done at virtually the same height

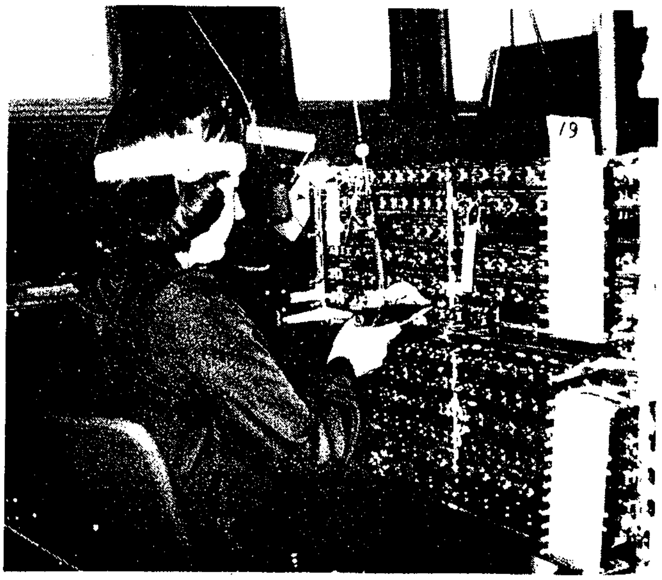

Fig. 6 The 8B system. New work place. Air pressure wrapping gun. The headband is used to record head angle

by adjusting the height of the frame. A lighter, air-propelled wrapping gun (350 g) with a counterbalancing system was also introduced.

In order to reduce static muscle load when working with elevated arms (necessary due to vision requirements) arm rests were mounted on an upholstered, padded chair (Fig. 7).

The height and slope of the arm rests were adjustable and it was possible to turn them towards or away from the body. The left, curved arm rest gave the worker good support for an arm pointed towards a work area in front of the body. The arm rests were particularly effective in reducing static muscle load since the vertical working height at any time was no higher then the height of a horizontal row (5–10 cm).

With the new work place most of the work can be done seated using the arm rests, since the frame can be lowered all the way until the lower edge touches the thighs. When working on the upper rows a standing posture is still necessary. The frame would normally be positioned lower than with the old work place, but the need for good vision makes it still necessary to bend forward, elevate the arms and use an elbow angle of less than 90°. Static muscle load is nevertheless reduced also when standing due to a somewhat better working height and a lighter wrapping gun.

The original angle-poise lamp was replaced by a neon tube lamp, which gave a stronger and more even light over a larger area.

Fig. 7 Chair with arm rests, introduced Spring 1975

The Minimat system

The production of the Minimat internal communication system began in 1970. The production work is done on a large wooden board mounted on a hydraulic stand. The slope of the wooden board can be continuously adjusted, but is usually kept vertical. The height can be adjusted within a range of 60 cm (Fig. 8). Most of the work consists of wrapping wire ends to needle-shaped terminals as in the 8B system. The worker can work on one horizontal row after the other, keeping the working height to 5–10 cm.

When working on the lower part of the wooden board, the worker can adopt a well balanced sitting posture. When working on the middle rows, the board must be lowered to such an extent that there is no room for the legs below it, resulting in a forward bending, somewhat twisted posture in order to reach the work area. For approximately 15% of the total work time, it is necessary to stand in order to reach the upper rows. The requirement for good vision is similar to that of the 8B system. The forearms are therefore lifted above elbow height resulting in static load of shoulder and arm muscles.

Until 1975 the same chair and wrapping gun as for the 8B system was used. In 1975 the new chair with arm rests and the lighter, counterbalanced wrapping gun described in the previous section was introduced. A neon light lamp was introduced, similar to that of the 8B system. Since 1975 there has been a continuous development of new products designed to improve the work situation. This has resulted in

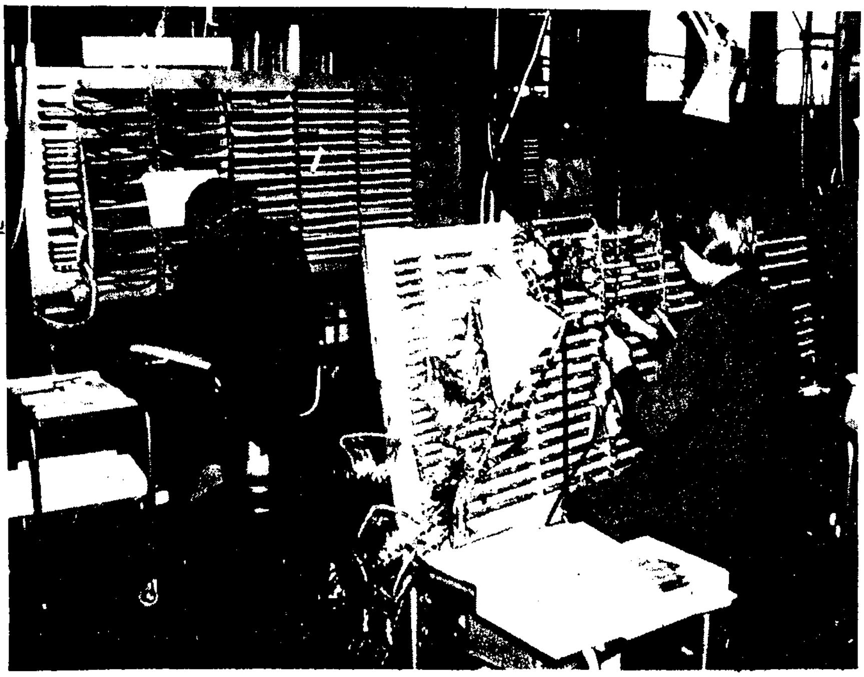

Fig. 8 The Minimat system. Sitting posture when working on the middle and lower rows. Note early arm rests on front chair

Fig. 9 The 10C system. Old, sitting posture

a new chair and a low-luminance lighting system which was introduced at Minimat, 10C and 11B after 1980 (shown in Fig. 12 for 11B).

The 10C system

Production of the 10C system began in 1974. The work object is a large metal frame, 236 cm x 60 cm, divided in seven to eight smaller 'sub-frames' which are mounted side by side along the length of the large frame (Figs. 9 to 11).

Most of the work (about 85%) consists of laying long wires between needle shaped terminals and connecting the wire ends to the terminals with a wrapping gun. Terminals which are joined together within a sub-frame (about 35% of total work time) are scattered over the whole working area, making the working height the same as the full height of the sub-frame (60 cm). This work is done seated (Fig. 9). Most wires join terminals in different sub-frames so that the wires cross several sub-frames or even the whole length of the large frame. This work (about 50% of total work time) is done standing (Fig. 10). The long working time (more than 100 h) has made it desirable for two workers to work together on the same frame.

At first the frame was placed in a stand which allowed step by step adjustment of the slope. It was also possible to adjust the height, but the whole frame had to be lifted by hand (weight 100 to 150 kg). Height adjustments of the frame were therefore never carried out in practice, but it was positioned midway between seated and standing posture. The seated posture caused static load of neck and back muscles due to forward bending since there was not room for the legs underneath the frame. The upper part of the area was above elbow height, resulting in static load on the shoulders and arm muscles.

For standing work, the frame was positioned horizontally. The working height was too low for some, resulting in a posture with neck and back bent forward. For others the working level was too high, making it necessary to lift shoulder and arms as well as bending the neck forward. Also, the wrapping gun was constructed for vertically mounted frames, so that the wrist had to be turned in the direction of the little finger when the frame was placed horizontally.

From the middle of 1975 the frame could be lowered or lifted to a suitable height, for both standing and seated work (Fig. 11). However, this did not reduce the working height when seated. Also, different body height of the two workers working together made it difficult to find an optimal adjustment when standing. It is therefore desirable that all work on a 10C frame is done by a single person, but lack of space has not allowed such an arrangement. Thus, the 10C system must still be considered strenuous.

Fig. 10 The 10C system. Old, standing posture

The 11B system

The production of the 11B telephone exchange began in 1974 (Fig. 12). The frame is 78 cm by 100 cm and consists of two-four 'shelves' mounted on top of each other. About 75% of the work time is used to connect wire ends to terminals using a wrapping gun. Most connections are done within one shelf, while terminals in different shelves are connected in 20% of the work time. The rest of the time is used for sewing the wires together, fitting plugs and various other finishing work. The frame was mounted at a fixed height for a short period until spring 1975, when the frame was mounted on a hydraulic stand similar to the 8B frame. However, the large working height and the visual demands (as for the 8B system) meant that the workers had to keep the arms above elbow height to avoid bending the neck and back forward. Wrapping of wires between terminals in different shelves results in large working height and much bending and lifting of the body and arms even when the frame is in the most favourable position.

In 1975 the wrapping guns were counterbalanced and chairs with armrests introduced. Most workers use the armrests only when the work area is restricted to one of the two lower shelves. Then they have a seated working posture with limited working height, comfortable height of the frame and leg room underneath the frame. All other work is usually

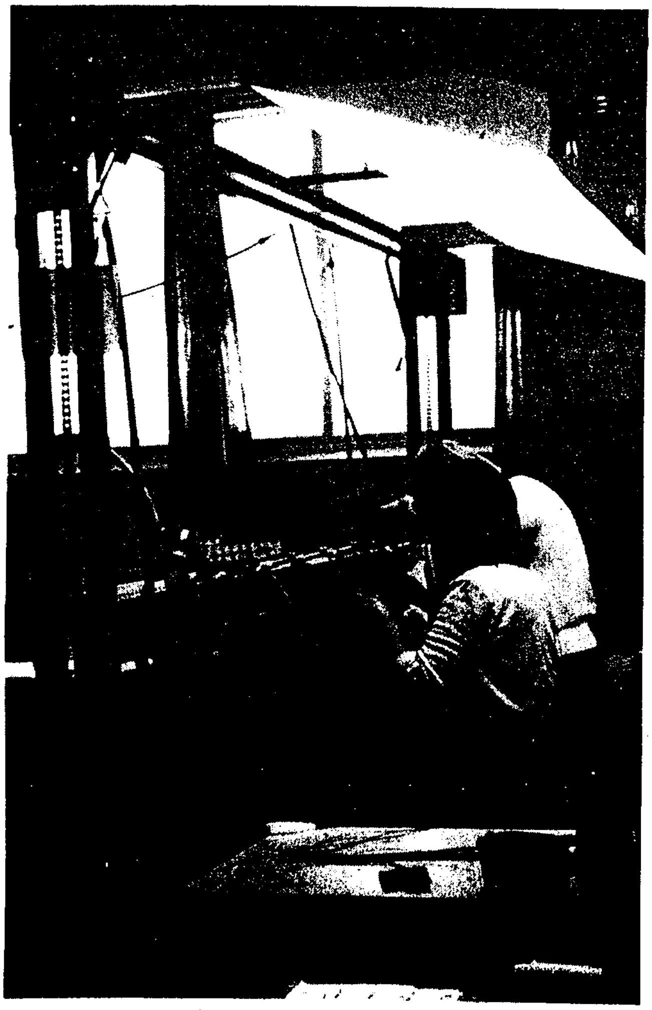

Fig. 11 The 10C system. Present work place with possibilities for regulating height and slope. Improved low-luminance lighting system

Fig. 12 The 11B system. Sitting posture when working on the lower rows of the frame. Note low-luminance lighting and new chair

done standing to avoid a forward bending, seated posture. Neon lights have been used since 1976, until 1980, when low-luminance lighting was introduced. A new chair was also introduced in 1980.

Results

Total sick leave at STK, Kongsvinger, for the period 1967 to 1974 was 11·2%, which is similar to the average sick leave of female industrial workers in Norway in the same time period (11·5%, Conference of Employees statistics). Also, the grouping of sick leave in the long term (duration more than 3 days, a doctor's certificate is required) and short term sick leave is similar to that of the industry as a whole (9·9% at STK, Kongsvinger *vs* an industrial average of 10·3% for long term sick leave, 1·3% *vs* 1·2% for short term sick leave). However, there are two factors which suggest that sick leave at STK, Kongsvinger, even so, has been unusually high. Firstly, the workers at STK, Kongsvinger, were young usually less than 25 years, and it is well known that long term sick leave in general is much reduced for this age group. Secondly, long term sick leave has not been uniform in this time period, but was low in the years 1967 to 1969 and then showed a substantial increase from 1970 to 1974, when it reached 16·9% of possible working time that year (Table 2). In contrast, short term sick leave remained at the same level throughout this period. Sick leave due to musculo-skeletal illnesses accounted for 5·3% of production time lost over the whole period, or more than half the total long term sick leave. The development of musculo-skeletal sick leave followed the same trend as total sick leave: low the first three years, then increasing rapidly during the years 1970 to 1974, reaching 10·0% of possible working time in 1974.

Turn-over of production workers is another interesting parameter since high turn-over also may indicate problems at work. Overall turn-over for the period 1967 to 1974 was high, 30·1% of the work force.

Thus, the rate of both sick leave and turn-over could be interpreted to indicate that the workers had considerable problems, and that these problems were of musculo-skeletal origin. This was also generally accepted by the management at the factory by the end of 1974. The likely cause of these problems was static muscle load in the shoulder and neck region (Westgaard and Aarås, 1984). Further analysis of the epidemiological data is therefore best done by considering the different work systems separately, since the work load varies from system to system. In particular, cable making specified a much more dynamic work situation than the other systems.

Table 3 shows musculo-skeletal sick leave, number of musculo-skeletal diagnoses and number of workers absent from work due to musculo-skeletal illness for the 8B system and cable making. Musculo-skeletal sick leave at the 8B system was 5·1% for the period 1967 to 1974. The sick leave at 8B each year did not differ much from that of the factory as a whole, which follows from the fact that 8B was by far the largest work system. Of the order of 20 workers were absent with musculo-skeletal illness each year in the years 1970 to 1974. Some workers had repeated sick leaves of this kind from year to year, making the total number of workers with musculo-skeletal sick leave at the 8B system 83. This is 35·9% of all workers employed at this system at any time until 1 January, 1975.

Table 2: Sick leave and turn-over at STK, Kongsvinger, in percent of possible working time (sick leave) or average number of people employed (turn-over)

	1967–1974	1967	1968	1969	1970	1971	1972	1973	1974
Short term sick leave (%)	1·3	1·5	1·1	1·3	1·6	1·3	1·1	1·4	1·3
Long term sick leave (%)	9·9	6·2	6·6	4·0	7·6	8·3	9·8	13·4	16·9
Musculo-skeletal sick leave (%)	5·3*	2·2	0·7	0·8	4·8	3·3	5·9	6·8	10·0
Turn-over (%)	30·1	2·8	25·6	27·4	41·7	35·0	36·4	27·2	20·4

*Includes time away from work in 1975 due to musculo-skeletal sick leaves starting in 1974

Table 3: Sick leave statistics of the 8B system and cable making

	8B								
	1967–1974	1967	1968	1969	1970	1971	1972	1973	1974
Musculo-skeletal sick leave (%)	5·1*	3·0	0·9	1·0	4·8	2·9	6·0	6·9	9·1
No of m-s diagnoses	124 (24·5%)	5	1	3	25	19	24	24	23
No of workers ill with m-s sick leave	83 (35·9%)	4	1	3	21	17	21	21	20
	Cable making								
	1967–1974	1967	1968	1969	1970	1971	1972	1973	1974
Musculo-skeletal sick leave (%)	4·7	0·2	0·3	0·4	4·1	3·8	2·8	6·1	11·9
No of m-s diagnoses	52 (30·6%)	1	1	4	6	8	12	12	8
No of workers ill with m-s sick leave	30 (33·7%)	1	1	4	6	6	8	7	7

*Includes time away from work in 1975 due to musculo-skeletal sick leaves starting 1974

Any difference in number of m-s diagnoses and number of workers with m-s sick leave is due to workers having more than one musculo-skeletal sick leave the same calendar year

The percentage shown for number of m-s diagnoses indicates number of m-s diagnoses as a fraction of man-labour years at 8B and cable making, respectively

Musculo-skeletal sick leave at cable making was 4·7% in the period 1967 to 1974. Workers at this system showed considerable variation in musculo-skeletal sick leave from year to year (2·8% in 1972, 11·9% in 1974), presumably due to the long duration of some sick leaves, combined with the low number of workers employed at this system. A total of 30 workers (33·7% of all workers employed at cable making by 1 January 1975) have been ill due to musculo-skeletal illness.

The durations of the musculo-skeletal sick leaves are shown in Fig. 13. Most sick leaves at the 8B system have a duration of 31 to 60 illness benefit days, and there are several causes of sick leave of more than half a year's duration. The individual episodes of musculo-skeletal illness must therefore be considered serious in terms of the workers' health. It is also clear that a majority of the complaints are localised to

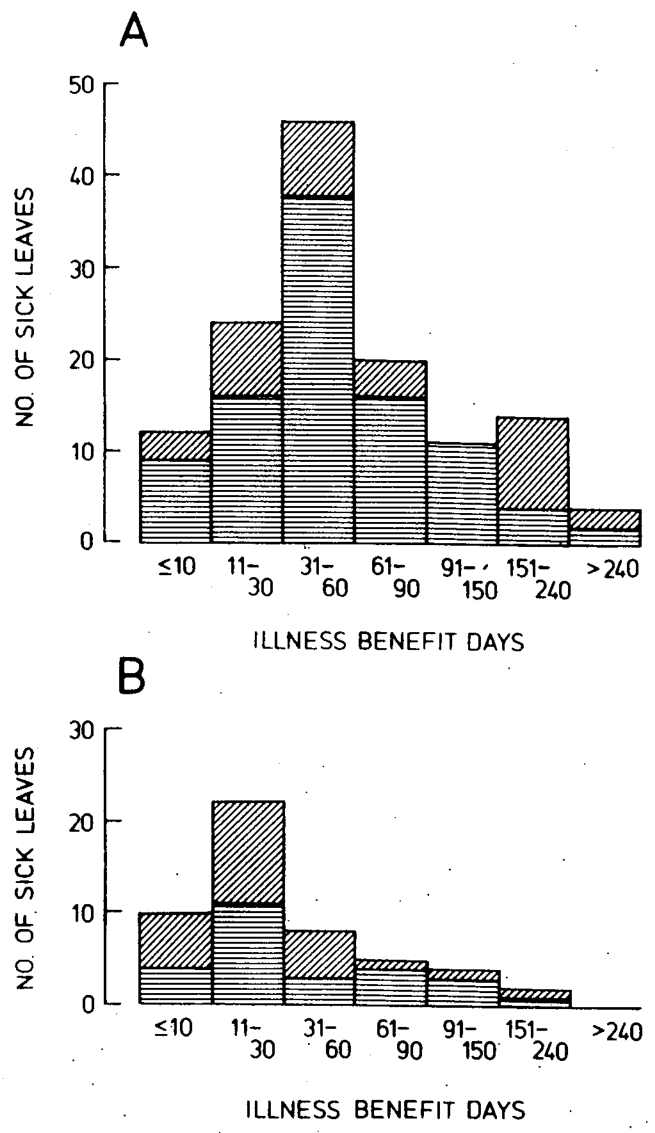

Fig.13 Duration of sick leaves due to musculo-skeletal illness at the 8B system (A) and cable making (B) for the period 1967 to 1974. The duration is measured in 'illness benefit' days (6 illness benefit days in a week). Sick leaves due to a complaint located to neck, shoulders or arms are indicated by horizontal hatching, low back complaints by diagonal hatching

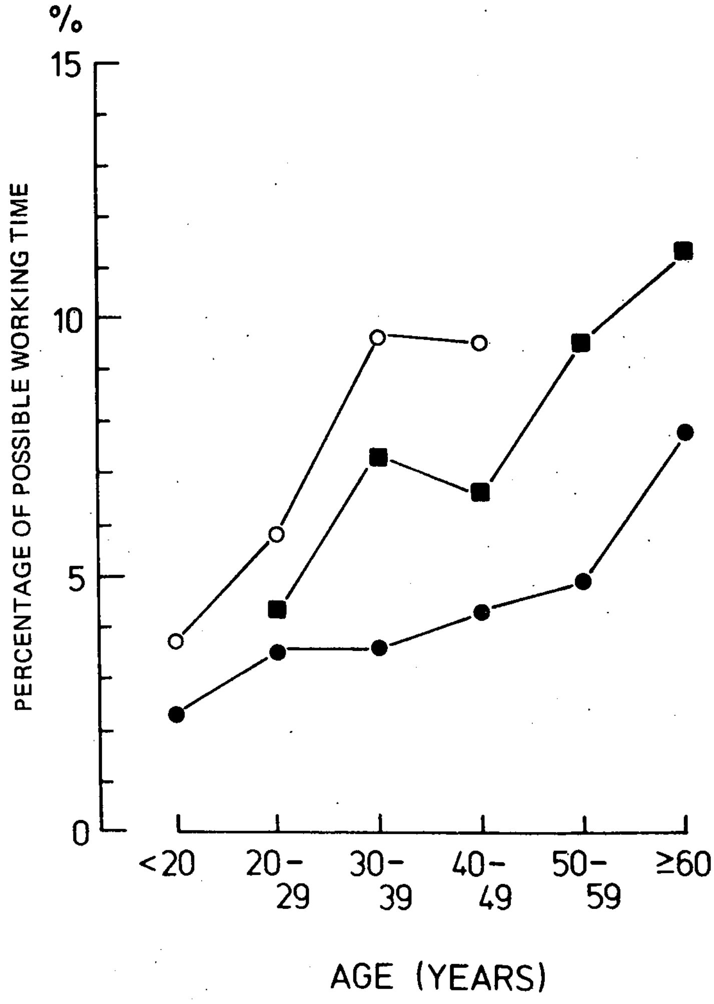

Fig. 14 Sick leave for different age groups, measured in percent of possible working time. Musculo-skeletal sick leave at the 8B system (open circles) is compared with total long-term sick leave of domestic assistants (filled squares) and women with administrative and clerical work (filled circles) in the Norwegian Telecommunication system (1976 statistics)

the shoulder and neck region (75% *vs* 25% low back diagnoses). The sick leaves were of shorter duration at cable making, most commonly 11 to 30 illness benefit days. Thus, the episodes of musculo-skeletal illness, although frequent also at cable making, have on average been less serious at this system than at the 8B system. Also, there is a difference in the localisation of the illnesses, with 49% low back diagnoses at cable making. The difference in duration of sick leaves is statistically significant by a chi-square test both when all musculo-skeletal sick leaves are included ($p < 0{\cdot}001$) and when only neck, shoulder, arm-diagnoses are considered ($p < 0{\cdot}01$).

Musculo-skeletal sick leave of different age groups of workers at the 8B system in the years 1970–1974 is shown in Fig. 14 together with all long term sick leave of different age groups of women with administrative and clerical work in the Norwegian telecommunication system, and of domestic assistants in the same company. Musculo-skeletal sick leave at the 8B system is about twice as high as total long-term sick leave for female workers of the same age doing general office work, and also higher than total long-term sick leave of female workers in a manual work situation generally considered strenuous. As musculo-skeletal sick leave amounts to about half the total sick leave of workers at the 8B system, it is clear that sick leave for this system was very high in the 5 years preceding the ergonomic adaptations, when the age of the workers is taken into account.

The sick leave statistics of STK's Kongsvinger plant have shown that the workers suffered a high rate of illness, primarily due to musculo-skeletal disorders. This is not by itself sufficient evidence to claim that conditions at work are detrimental to the health of the workers. However, if there is a causal relationship between strain at work and musculo-skeletal sick leave, one would expect that workers with long periods of employment are more likely to have experienced musculo-skeletal illness than workers recently employed. Also, the time from employment until their first musculo-skeletal sick leave could be a possible indication of strain in a work situation, if this time period is of the same length for most workers with such illness.

In Fig. 15 time of employment of all workers working with the 8B system before 1974 is shown. Due to high turnover, the largest group of workers was employed less than 1 year and the second largest between 1 and 2 years. Nevertheless, 31 workers were still employed at the factory by 1980, i e, had been working at the 8B system for at least 6 years. The hatched part of each column shows how many within the different groups have been absent from work due to musculo-skeletal sick leave. Fig. 15C (triangles) indicates fraction of workers at the 8B system with musculo-skeletal sick leave, as a function of time of employment. The fraction increases rapidly with time of employment, it is already 39% among those employed between 1 and 2 years and is about 70% for those employed more than 2 years. This is in contrast to Fig. 15B which shows similar data for a group of 92 women with general office work, and where only 1 of 35 workers employed for less than 5 years has suffered a musculo-skeletal illness resulting in a sick leave. The ratio of workers with musculo-skeletal sick leave in this group is shown in Fig. 15C (filled squares). There is a moderate increase in this ratio with long periods of employment, averaging about 40% for those employed 10 years or longer.

Fig. 16 shows time of employment until first musculo-skeletal sick leave for those having suffered such an illness. Workers at the 8B work system most frequently had their first episode within the first year of employment (16A), while workers at cable making most frequently suffered their first musculo-skeletal illness 1 to 2 years after employment (16B). This is particularly so if only women are considered. There is no clear grouping of time to first musculo-skeletal sick leave among the women with general office work, and certainly no tendency for such sick leaves to happen within the first two years after work (Fig. 16C). Fig. 17 shows time to first musculo-skeletal sick leave as a function of age for each individual case. It is clear that many of those working at the 8B system became ill due to musculo-skeletal complaints as early as 3 to 6 months after employment. Also, a majority of those who became ill were younger than 20 years when employed. There is no obvious effect of age for workers at the 8B system from the below 20 year to the 20 to 30 year and the 30 to 40 year age groups with respect to this parameter. Similarly, the same fraction of workers employed became ill in the below 20 group (40%) as in the 30 to 40 year group (41%). The main cause of the major increase in working days lost due to musculo-skeletal sick leave from the less than 20 year to the 30 to 40 year group (Fig. 14) is therefore that there was a tendency to longer duration of sick leaves with increasing age.

In order to further evaluate the symptoms of musculo-skeletal illness, the workers employed at the factory in the autumn of 1978 (97 men and women) were questioned

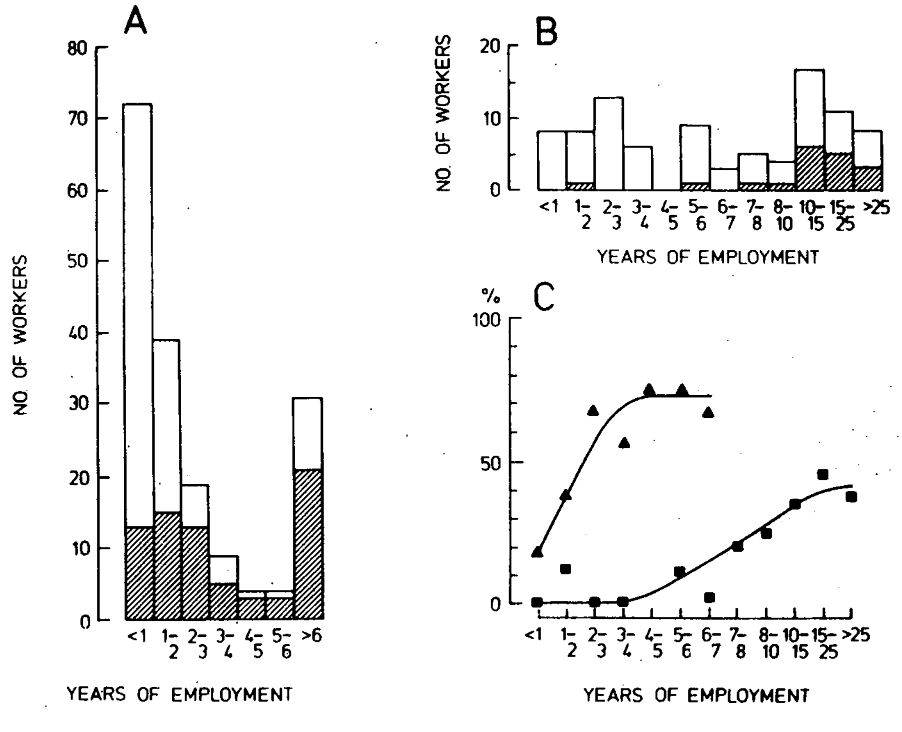

Fig. 15 A. The histogram indicates time of employment for all workers employed at the 8B system before 1974 by January 1980. The hatched part of each column shows how many within each group have experienced one or several sick leaves due to musculo-skeletal illness.
B. Similar data for a control group of women with administrative and clerical work.
C. Percent of workers at the 8B system (filled triangles) and with administrative/clerical work (filled squares) with musculo-skeletal sick leaves as a function of years of employment. The data in C are derived from A and B by dividing number of workers with musculo-skeletal sick leave by total number of workers within each group

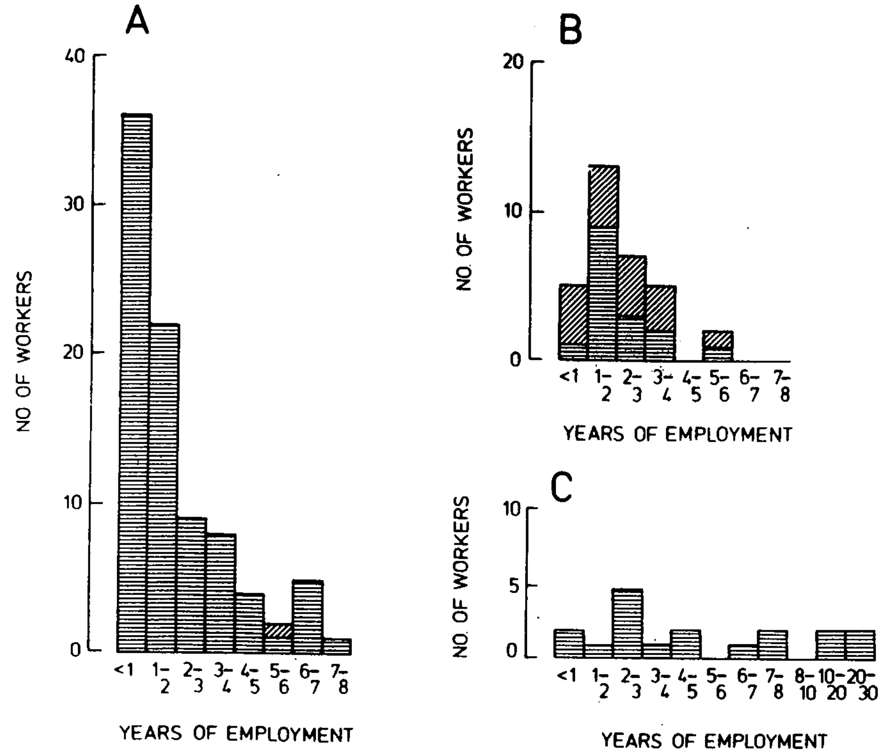

Fig. 16 Time from employment to first musculo-skeletal sick leave for workers at the 8B system (A), cable making (B) and with administrative/clerical work (C). Horizontal hatching indicates female workers, diagonal hatching men

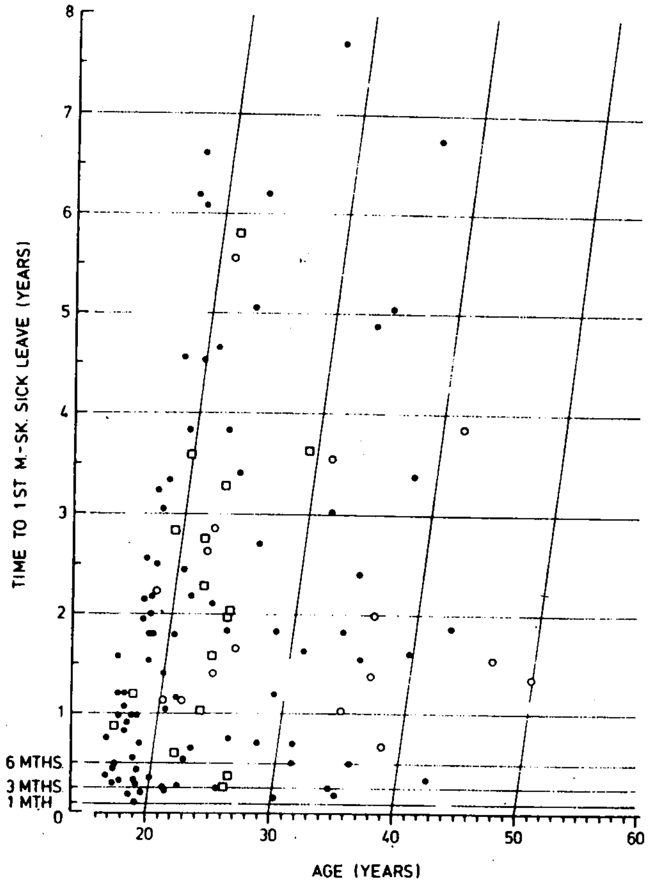

Fig. 17 Time from employment to first musculo-skeletal sick leave as a function of age for workers at the 8B system (filled symbols) and cable making (open symbols). Open and filled circles indicate women at cable making and 8B, open squares men at cable making. Diagonal lines show age development when age at employment is 20, 30, 40 or 50 years

regarding intensity and location of discomfort/pain while working. The intensity was indicated according to a scale from 0 to 5 (none, very little, little, some, considerable, very much). Fifty-six of the 97 workers had experienced a sick leave due to musculo-skeletal illness. Fifty-two of the 56 workers with such sick leaves indicated 3, 4 or 5 as the maximum level of discomfort (regardless of location on the body, Fig. 18A). This range may in part be due to genuine differences in the intensity of pain experienced, and in part due to differences in the perception of the discomfort. However, since pain is the major symptom of musculo-skeletal disorder, the levels 3, 4 and 5 apparently indicate substantial complaints of this kind. Among the 41 workers who had not experienced musculo-skeletal illness, 23 (56%) stated that they had experienced pain at level 3 or 4 (Fig. 18B). The age and sex distributions of the two groups were similar, as was the period of employment. One would therefore not expect any systematic variation in pain indication from one group to the other. Thus, 75 of 97 workers can be said to have suffered a significant musculo-skeletal symptom (level 3, 4 or 5) at work, by this reasoning.

Fig. 19 shows the percentage of workers having experienced a complaint of intensity 3, 4 or 5 at different parts of the body while working at the 8B system (open circles) or cable making (filled circles). Only those employed before 1974 are included, i e, with at least one year's experience of the old work situation. Complaints located to the head and neck have been much more frequent among workers at the 8B system than at cable making. Shoulder complaints have been frequent among both groups while complaints in the low back region have been relatively infrequent among workers at the 8B system, and more frequent among workers at cable making. There have been few complaints located to the lower part of the body.

The location of complaints on the basis of the interviews is in good agreement with the body location of the musculo-skeletal diagnoses and the likely location of the muscle load.

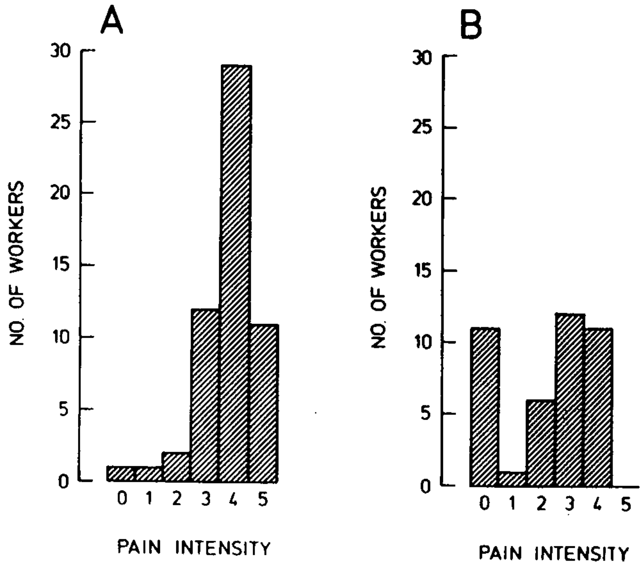

Fig. 18 Highest indication of discomfort/pain, regardless of location on body, by workers with (A) or without (B) sick leave due to musculo-skeletal disorders

Muscles in the neck and shoulders must be under considerable strain with work postures as illustrated in Figs. 4 and 5. Also, it is well known that neck tension may provoke tension headache. One would also expect fewer complaints in the low back region for workers at the 8B system due to the upright sitting or standing posture. In contrast, workers at cable making, with their forward bending posture and elevated arms, can be expected to develop complaints in the shoulders and the low back region.

Discussion

The object of this paper has been to present evidence which allows a quantitative evaluation of a possible relationship between adverse working conditions and the development of disorders in the musculo-skeletal system. This evidence may be summarised as follows:

- The work situations (in particular the 8B system) at STK's Kongsvinger factory in the years 1967 to 1974 imposed continuous muscle strain on specific muscles in the shoulder and neck region.
- There was a high rate of sick leave due to musculo-skeletal illnesses among the workers in these work situations (mostly young women). Sick leave due to these illnesses was low the first few years, thereafter increasing rapidly to a maximum of 10·0% in 1974.
- When comparing sick leave between workers of the same age, it was found that sick leave due to musculo-skeletal illnesses for workers in one of the work situations at STK, Kongsvinger, (the 8B system) was higher than total long-term sick leave for another group of workers with a generally strenuous occupation (domestic assistants), and much higher than total long-term sick leave among women with general office work.
- The occurrence of musculo-skeletal sick leave was much more frequent among those having been employed for more than 2 years (70%) than among those employed for shorter periods of time (the 8B system). Even so, 40% of those employed between 1 and 2 years had already experienced a prolonged sick leave of this kind. There was also a high rate of labour turn-over. In contrast, only one of 35 women with general office work and employed less than 5 years had suffered a similar kind of illness resulting in a sick leave.
- Workers at the 8B system most commonly had their first sick leave due to musculo-skeletal illness within the first year after employment, much earlier than workers at cable making. This category of sick leaves was of much longer duration at the 8B system than at cable making. There was no tendency for musculo-skeletal sick leaves to occur soon after employment within the control group of female workers with general office work.
- Symptoms of musculo-skeletal complaints have been very common among workers at the 8B system and cable making. The location on the body of the symptoms was in good agreement with the distribution of the medical diagnoses.

There is no doubt that there has been an unusually high rate of musculo-skeletal illness among the workers at STK, Kongsvinger, in general, and the 8B system in particular. It is also clear that the work situations have been strenuous, with the strain mainly affecting a limited number of muscles in the shoulder and neck region when working at the 8B system. However, musculo-skeletal illness may also develop as a result of other factors than work load, for instance as a complication because of other illnesses, due to general defects of the musculo-skeletal system, due to muscle spasms as a consequence of problems of a psychological nature, or to strenuous leisure time activities. Thus, one should not conclude that the work situation is the major causal factor

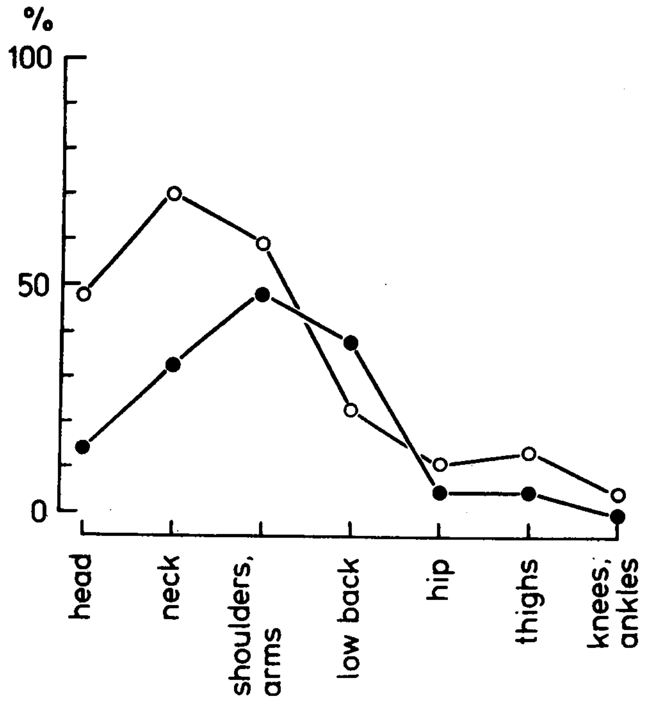

Fig. 19 Percent of workers at the 8B system (open circles) and cable making (filled circles) with a significant musculo-skeletal symptom (i e, a painful experience of intensity 3, 4 or 5 while working) at different locations on the body

for any individual case of musculo-skeletal disorder. However, it is very unlikely that those employed at the 8B system have a sufficiently different life situation to other women of the same age to explain the group differences in sick leave due to musculo-skeletal disorders. The work load and, specifically, the strain on shoulder and neck muscles, must therefore be considered a major causal factor in the development of musculo-skeletal disorders among workers at STK, Kongsvinger, and the 8B system in particular.

In this analysis, musculo-skeletal sick leave has been used as an indicator of musculo-skeletal disorders. This indicator implies that someone has made an appointment to see a doctor, usually because of symptoms of pain, and the doctor, following a medical examination, has agreed that the condition is sufficiently serious to make the patient unable to work, This is not necessarily the best indicator of a pathophysiological condition of the musculo-skeletal system, since many other factors may influence the decision to see a doctor. It is well known that sick leave varies considerably from country to country, and is particularly high in the Scandinavian countries. Ignoring for the moment any differences in the statistical basis, such differences could be due to the welfare system in these countries which ensures very high job safety and no economic loss when someone is absent from work due to illness. This does not imply that the sick leaves were inappropriate. On the contrary, the interviews showed that many had suffered long periods with intense pain prior to sick leave, and that many in fact did not see a doctor despite considerable problems of this kind. Gross differences in rate of sick leave between countries could therefore be due to alternative strategies in trying to cope with ailments. If muscle soreness or pain becomes a problem, the worker may choose to terminate the job, use pain-killing drugs, receive physiotherapy outside working hours, or simply try to tolerate a high level of pain, rather than accept a sick leave. Alternatively, there may be subtle differences in the opportunity to avoid muscle load in apparently similar work situations (differences in frequency of rest pauses, less work load, possibilities of job rotation, etc), but we feel that such factors are unlikely to be grossly different from one industrialised country to another. We therefore suggest that the social system of the Scandinavian countries contributes to making the rate of sick leave due to musculo-skeletal illness a sensitive indicator of underlying musculo-skeletal symptoms which is common to workers in similar, constrained work situations throughout the industrialised countries (Partridge *et al*, 1965; Ferguson, 1971; Maeda, 1977; Kuorinka and Koskinen, 1979; Maeda *et al*, 1980; Westerling and Jonsson, 1980).

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The effect of improved workplace design on the development of work-related musculo-skeletal illnesses

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An earlier paper (Westgaard and Aarås, 1984) described the work environment and the health situation of production workers at a small Norwegian factory, prior to an extensive ergonomics effort which primarily aimed to reduce static muscle strain by constructing new workplaces. It was concluded that the old work situation significantly contributed to a high level of musculo-skeletal disorders, most likely because the old work situation made it necessary to work with high level of muscle load for long periods of the working day. This second paper concerns the other important query which initiated this study: Have the extensive ergonomics and environmental efforts at this factory had any effect in terms of improved health of the workers? The factory, the old workplaces and the ergonomics adaptations were described in the preceding paper, and are therefore not included here.

Keywords: Musculo-skeletal system, working conditions, occupational health

Methods

The epidemiological methods and material are similar to those of the preceding paper. In addition, electromyographic recordings of muscle load on the upper and lower trapezius muscle while working on the 8B system are presented in this paper. The recordings were obtained by surface electrodes of our own construction with two electrodes and a preamplifier integrated in one recording unit. The electrodes are circular with a diameter of 6 mm and a centre distance of 20 mm. The signals were stored by using an Oxford Medilog portable tape recorder, and later analysed by using a Nord-10 computer with a specially developed on-line program. The analysis is based on numeric integration of the rectified EMG signal over 2 s intervals, resulting in discrete values which are a measure of average electrical activity of the muscle in this interval. These values, as a fraction of the values at maximal voluntary contraction, were used as a measure of muscle force. This is a true measure of muscle force only if the relationship between integrated electrical activity and muscle force is a linear one. While this may be so for some muscles (Bigland and Lippold, 1954), there are many examples of a non-linear relationship of this kind (Lindström *et al*, 1974; Komi and Viitasalo, 1976; Chaffin *et al*, 1980), and it is therefore necessary to calibrate force and EMG activity at varying levels of muscle force to be able to predict accurately the absolute level of force. However, a linear relationship between force and integrated EMG activity is usually a good approximation at the low levels of force present in these work situations. Thus, the estimates of muscle force based on the EMG recordings are uncertain in terms of the absolute level of load since there was no force-EMG calibration, but a reduction of the integrated EMG signal of 50% from one work situation to another can be interpreted to signify the same relative reduction in muscle force.

Results

Table 1 shows the number of production workers at the different systems from 1975 until the end of 1982. In this period the employment at cable making and Minimat remained stable, the 8B system was terminated at the Kongsvinger factory, the 11B system fell back to a low level after a few years with relatively high employment, while the 10C system has shown a steady increase until 1982. Total production time for each of these systems has been between 97 and 244 man-labour years.

Table 1: **Number of workers employed at the different work systems 1975 – 1982**

Work system	Total 1975–1982	Calendar year 1975	1976	1977	1978	1979	1980	1981	1982
Cable making	244	30	30	30	23	31	30	30	40
8B	97	35	20	20	9	11	2	0	0
Minimat	140	10	10	10	14	20	20	16	40
10C	222	14	14	18	24	22	46	56	28
11B	123	12	20	20	22	11	19	13	6
Total	826	101	94	98	92	95	117	115	114

The effect of ergonomic adaptations in muscle strain

The main purpose of the ergonomics adaptations was to reduce strain on specific muscles in the shoulders and neck region. The effect was assessed by electromyographic recordings from the relevant muscles while working at the 8B system. Figs. 1 and 2 give examples of the results. Fig. 1A shows a 51 min recording from the upper right trapezius muscle while the worker has been working along the same row (8th row, high sitting posture) on the frame of the 8B system. Each point indicates average muscular activity of a 2 s interval in percent of activity at maximal voluntary contraction, as described in "Methods". The worker finished the left half of the row first, using the old workplace. There was a pause while the frame was moved to the new workplace and work continued on the right half of the same row adopting the new posture. There was static contraction of the upper right trapezius muscle throughout the experiment (no 2 s periods near zero), but the median value was reduced from 25% in the old work situation to 13% in the new one. Thus the muscle load was substantially higher in both work situations than is considered acceptable (Bjørksten and Jonsson, 1977). The ergonomics adaptations have nevertheless reduced the load on the upper trapezius muscle by half when working in this row.

Fig. 1B shows a similar recording from upper right trapezius when working on the 11th row (standing posture). In this experiment, work began with the new posture. There was a pause while working with the new posture and a new pause while the frame was moved to the old workplace. The muscle strain was less than on the 8th row for this person, but even so the load significantly increased as the worker moved from the new to the old workplace.

Fig. 2 shows EMG recordings from a whole working day. The recording lasted 5 h 35 min, divided into four recording periods of 1 h 43 min, 1 h 51 min, 1 h 31 min and 30 min. The results are presented in the same way as in Fig. 1, and recordings from upper right and lower right trapezius are shown. This working day was divided into three parts. In the first of these and in the first part of the second recording period, insulation was removed from the wire ends and the frame was prepared for the wrapping work. Wrapping was then done on the left half of the frame from first to tenth row in the new work situation. Finally, the same work was done on the right half of the frame, using the old workplace.

There was a low level of muscle load most of the time during the preparatory work, but the load on the upper trapezius increased in the last half of the first recording period and was high and very variable in the first part of the second period. This was when the cable form was fastened to the frame. When wrapping of wire ends to the terminals started (▼), the muscle activity became less variable, i e, the muscle contraction was more static. The muscle activity was interrupted by a short pause soon after the wrapping started and by lunch, as indicated on the figure. Work on the upper

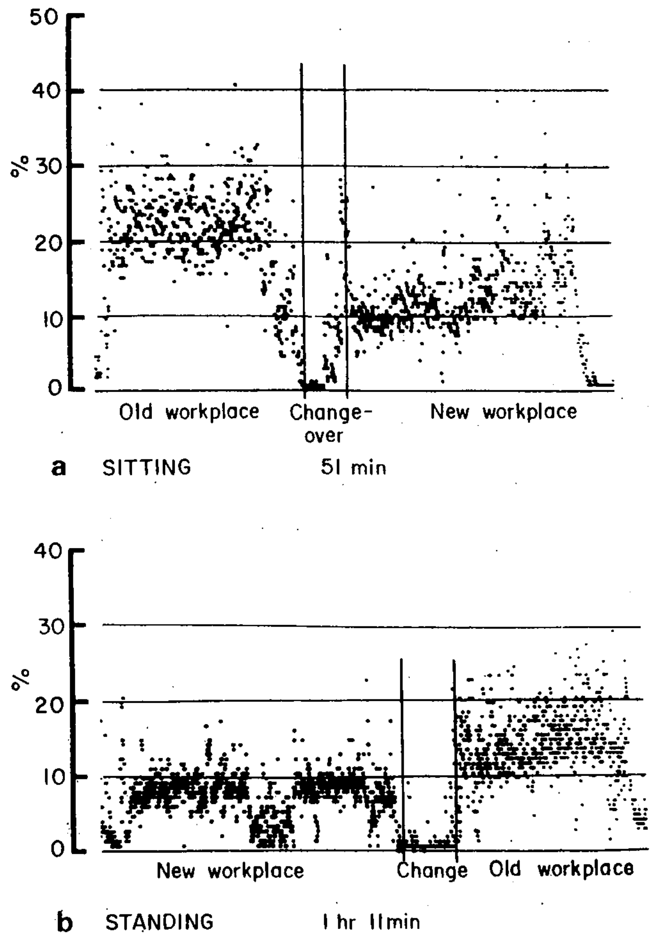

Fig. 1 Muscle load on upper right trapezius muscle based on EMG recordings (in % of EMG activity at maximal contraction). A. Old, high sitting posture, then new posture. B. New, then old standing posture.

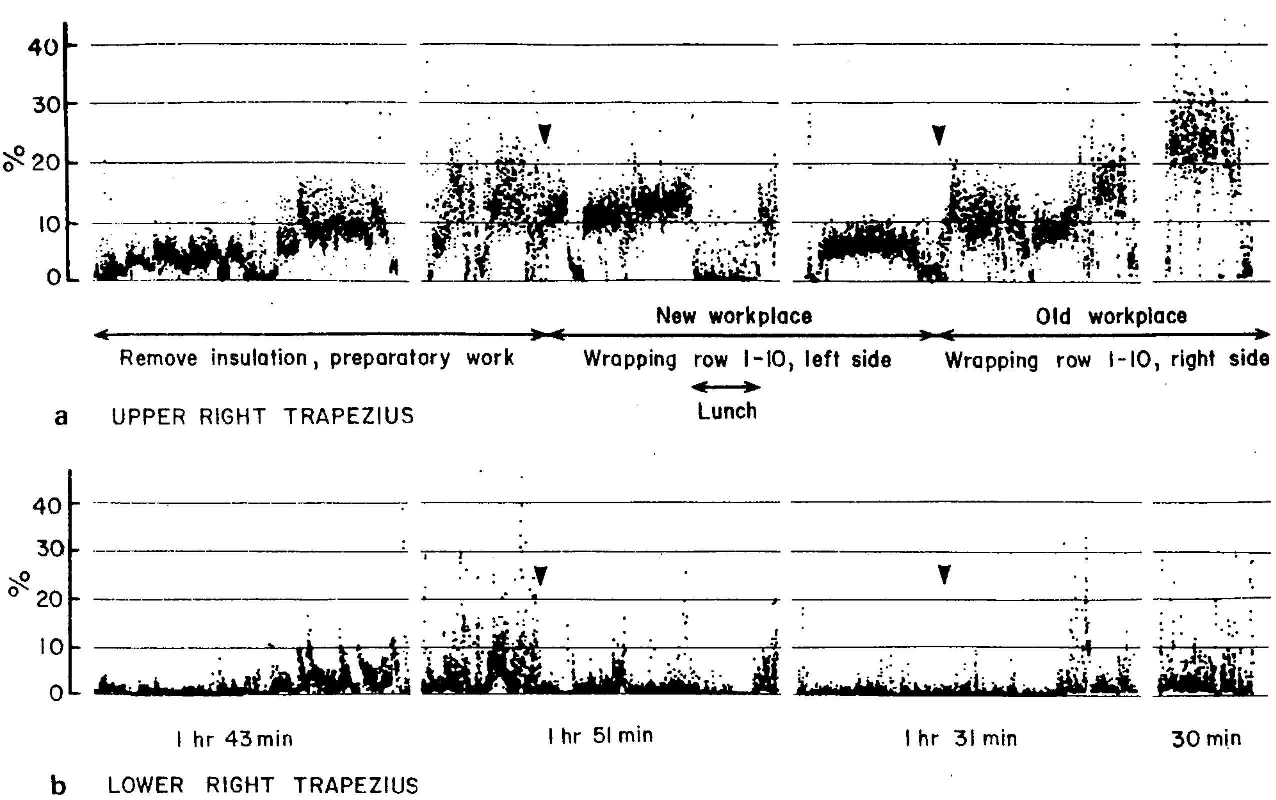

Fig. 2 Muscle load (in % of EMG activity at maximal contraction) on upper and lower right trapezius muscles throughout a working day consisting of preparatory work, then wrapping wire ends using the new workplace and finally the old workplace. Further details in the text.

rows continued after lunch (first part of third recording period) and the muscle activity was now reduced, compared with the lower rows (before lunch). This is probably due to the lowering of the frame and the standing posture of the worker which allows further relaxation of the shoulder muscles.

The level of activity with the old posture (▼) was similar to that with the new posture when working on the lower rows, but this time the muscle load increased with increased working height up to a mean level of about 25% on the upper rows (fourth recording period). In comparison, the mean level of muscle activity in the new work situation was never higher than 12 – 14%. Normally it would be necessary to work with high load on the upper trapezius for about 2 h each day. The ergonomics adaptations of the 8B workplace – if the results presented here are typical – have reduced the load on specific muscles by half throughout a significant period of the working day, but the load is probably still higher than considered acceptable.

Sick leave statistics

Long term sick leave was relatively stable in the years 1975 to 1982, averaging 9·4% of possible working time for the whole period (Table 2). This is similar to average sick leave in the period 1967 to 1974, but in this first period long-term sick leave showed a steep increase to 13·4 in 1973 and to 16·9% in 1974. Fig. 3 illustrates the development of long-term sick leave from 1967 to 1982. The sharp interruption of the upward trend in 1975 coincided with the implementation of the ergonomics adaptations. The hatched part of the columns in Fig. 3 indicates sick leave due to musculo-skeletal complaints (also shown in Table 2). The development of musculo-skeletal sick leave mirrors the development of total long-term sick leave, but with some variation from year to year which must be expected on account of the occasional very long sick leave and the relatively low number of production workers. Average musculo-skeletal sick leave in the years 1975 to 1982 was 3·1% of total production time, while it was 5·3% in the period 1967 to 1974 (Table 2). This reduction is statistically significant ($p < 0{\cdot}01$), and even more dramatic when compared with the two years immediately preceding the ergonomics adaptations (6·8 and 10·0%). In contrast, musculo-skeletal sick leave in 1975 was 5·5%, or 2·9% if sick leave beginning in 1974 is excluded.

Simultaneously with the reduction in long-term sick leave there has been a statistically significant ($p < 0{\cdot}001$) reduction in labour turn-over (Table 2). Turn-over in the years 1975 to 1982 was 7·6% of total man-labour years (i e, average number of workers), while it was 30·1% in the period 1967 to 1974. Fig. 4 shows the development of labour turn-over from 1967 to 1982. In contrast to long-term sick leave and labour turn-over, short-term sick leave has remained stable (Table 2).

These results indicate a clear positive effect of the ergonomics adaptations in terms of improved health and job acceptability among the workers. However, the changes in the production programme resulted in new work situations for many of the workers, independent of the ergonomics adaptations. In order to assess the effect of the adaptations as such, it is necessary to compare sick leave statistics of workers with the same work task before and after their introduction. This is only possible for cable making and the

Table 2: Sick leave and turn-over at STK Kongsvinger in percent of possible working time/average number of people employed

	1967–1974†	1975–1982	1975	1976	1977	1978	1979	1980	1981	1982
Short term sick leave (%)	1·3	1·5	1·5	1·7	1·8	1·8	1·7	1·2	1·3	1·2
Long term sick leave (%)	9·9	9·4	10·0	9·3	7·9	8·8	10·6	10·6	9·8	8·5
Musculo-skeletal sick leave (%)	5·3	3·1	5·5 (2·9*)	2·3	4·3	5·0	3·1	2·6	2·4	2·9
Turn-over (%)	30·1	7·6	21·8	6·4	4·1	6·5	4·2	7·7	8·7	1·7

†From Table 2 in the preceding paper

*Excludes sick leave in 1975 from musculo-skeletal sick leaves starting in 1974

8B system where there has been a reasonable production volume both with the old and the new work situations.

Table 3 gives the results. Musculo-skeletal sick leave at cable making was reduced by two thirds, from 4·7% in the period 1967 to 1974 to 1·6% in the period 1975 to 1982. The number of sick leaves with musculo-skeletal diagnoses was also significantly reduced from 30·6% of total man-labour years in 1967–1974 to 14·3% of total man-labour years in 1975–1982. Thus, there has been a clear and statistically significant reduction in sick leave due to musculo-skeletal illnesses of workers employed only at cable making.

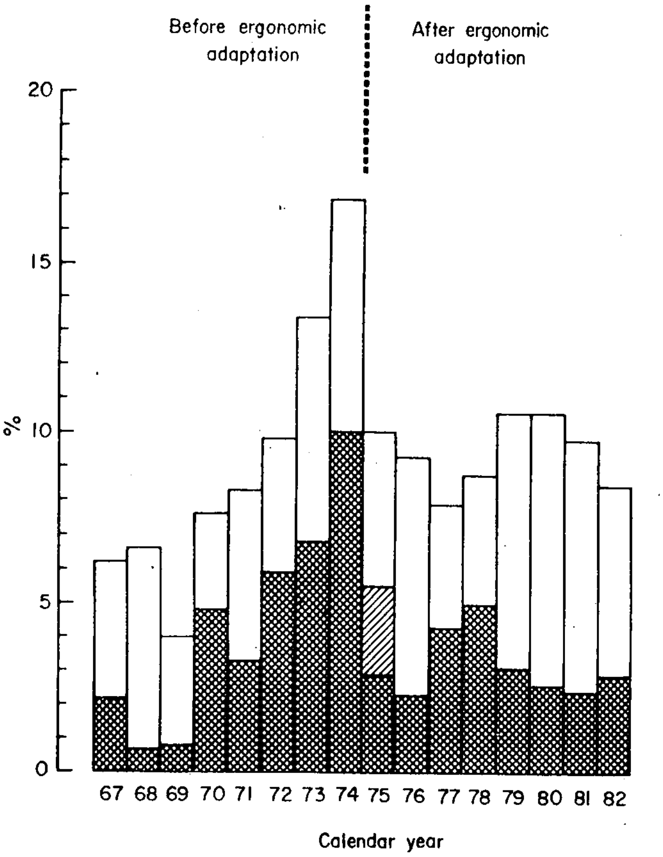

Fig. 3 Long term sick leave (more than 3 days duration, % of possible working time each year) at STK, Kongsvinger in the years 1967 to 1982. The hatched parts of the columns indicate long term sick leave due to musculo-skeletal illness. Single hatching in 1975 indicates musculo-skeletal sick leave beginning in 1974.

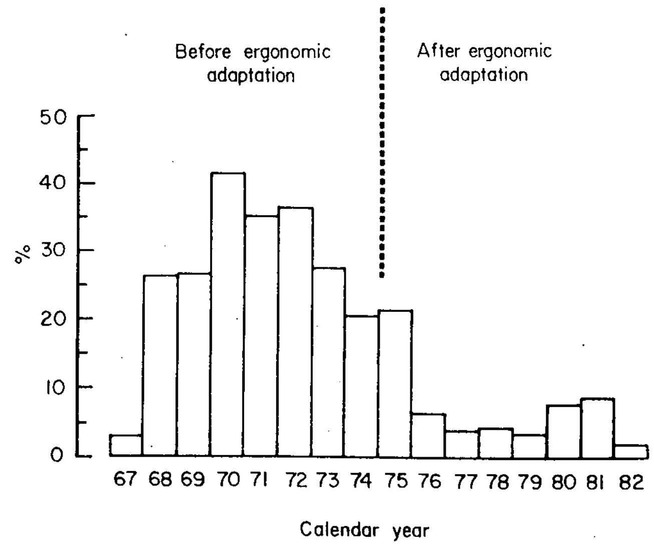

Fig. 4 Labour turn-over (% of average number of workers each year) at STK, Kongsvinger in the years 1967 to 1982.

The situation is less clear at the 8B system. Musculo-skeletal sick leave for the period 1975 to 1981 (4·6%) was not much reduced compared with the period 1967 to 1974 (5·1%). However, it was reduced relative to musculo-skeletal sick leave in 1973 and 1974 (6·9 and 9·1%), immediately preceding the ergonomics adaptations. Also, the number of sick leaves due to musculo-skeletal diagnoses in percentage of man-labour years was reduced by a third (16·5% *vs* 24·5%, $p < 0{\cdot}05$) signifying that such complaints have become less frequent, but of longer duration. This is mainly due to a single sick leave with a duration of more than a year, accounting for 1·2% of total sick leave after 1975 at the 8B system. Excluding this chance occurrence of a very long sick leave, musculo-skeletal sick leave at the 8B system in the years 1975 to 1981 was 3·3%, and clearly lower than average musculo-skeletal sick leave before the ergonomics adaptations.

Table 3: Sick leave statistics of the 8B system and cable making

	8B									
	1967–1974†	1975–1980	1975	1976	1977	1978	1979	1980	1981	1982
Musculo-skeletal sick leave (%)	5·1	4·6*	5·1 (1·3*)	4·4	7·4	10·4	1·7	25·4	–	–
No of m-s diagnoses	124 (24·5%)	16 (16·5%)	4	2	4	4	2	0	–	–
No of workers ill with m-s sick leave	83 (35·9%)	11 (33·3%)	4	2	4	4	2	0	–	–

	Cable making									
	1967–1974†	1975–1982	1975	1976	1977	1978	1979	1980	1981	1982
Musculo-skeletal sick leave (%)	4·7	1·6*	5·7 (3·3*)	0·4	1·6	1·2	0·9	0·4	1·7	2·7
No of m-s diagnoses	52 (30·6%)	35 (14·3%)	6	2	5	5	5	0	2	10
No of workers ill with m-s sick leave	30 (33·7%)	14 (42·4%)	5	2	5	5	5	0	2	9

†From Table 3 in preceding paper

*Excludes sick leave in 1975 from musculo-skeletal sick leaves starting in 1974

The percentage shown for number of m-s diagnoses indicates number of m-s diagnoses as a fraction of man-labour years at 8B and cable making, respectively

Interviews and questionnaires

Workers employed before 1974 were interviewed in the autumn of 1978 regarding symptoms of musculo-skeletal illness 'before' and 'now' for various parts of the body (Westgaard and Aarås, 1984). Fig. 5 shows the highest indication of discomfort, regardless of body location, 'before' and 'now' for workers employed at the 8B system (A) and cable making (B). The workers at the 8B system were in part employed at 10C, 11B and Minimat when interviewed, but they had all had some experience with the 8B system after the ergonomics adaptations. There is a clear reduction of about 1 unit in level of discomfort from the past to the present situation for workers at the 8B system, but most workers had experienced some discomfort in their work situations last year (1979). There was also a reduction in discomfort among workers at cable making, and no one had experienced discomfort/pain of the upper two intensities.

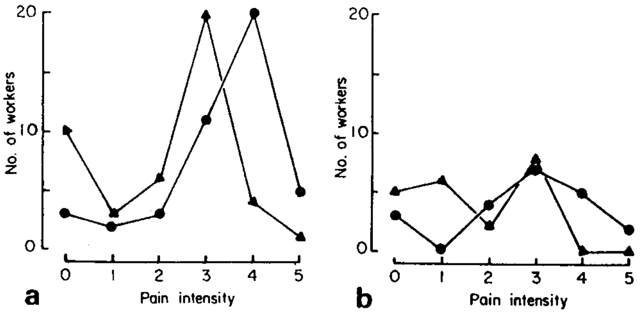

Fig. 5 Highest indication of discomfort, regardless of body location, "before" (●) and "now" (▲) by workers employed before 1974 on the 8B system (A) and cable making (B).

Seventy five percent (41 of 55 persons) of those indicating reduced pain, when asked whether they associated (changes in) pain intensity with any external occurrences, were of the opinion that the ergonomics adaptations of their workplace had a significant effect on their wellbeing. Of the others, (45 persons), 50% were of the opinion that the new workplaces were better, but felt little improvement with regard to the occurrence of pain. All workers had a positive attitude towards the new workplaces.

The workers were also asked to give their opinion of the reason for the reduction in musculo-skeletal illness in a questionnaire. They had to indicate whether they thought various factors were of very little, little, some or considerable significance. The answers are shown in Table 4. The factor considered to be most important by the workers was the possibility of altering the height and slope of the work table (93%). Almost as many thought that "easier to change work posture" and the introduction of a fixed pay structure were important (83 and 73%, respectively). It is of course difficult to separate the groups "possible to alter height and slope of work table" and "easier to change work posture". The main conclusion from the interviews was that the workers had a very positive attitude towards the ergonomics adaptations. The introduction of fixed pay was also considered to be of major significance for the reduction in musculo-skeletal sick leave, presumably because the workers were more able to relax in their work situation.

The workers were also asked to indicate what they thought could be the reason for the reduction in labour turn-over,

Table 4: **The workers' views on the reasons for the reduction in musculo-skeletal sick leave. The evaluation is based on a questionnaire to 87 workers.**

	No significance		Little significance		Some significance		Considerable significance		Total	
	No	%	No	%	No	%	No	%	No	%
Introduction of flexible working hours	27	32	13	15	16	19	28	33	84	99
Introduction of a fixed pay structure	3	4	6	7	13	15	61	73	83	99
Easier to alter the height and slope of the work table	1	1	1	1	4	5	77	93	83	100
Easier to change work posture	1	1	2	3	11	14	66	83	80	101
Easier to have short pauses	4	5	14	17	30	36	35	42	83	100
New sick leave benefit system	34	42	20	25	17	21	10	12	81	100
Other	–	–	–	–	2	–	2	–	4	–

and 50 workers (57%) thought that an improved work environment was the most important reason (Table 5). Thus, there was a strong feeling among the workers that the work environment at the factory had improved. This is probably due to both the ergonomics adaptations and to improved co-operation between workers and the management which in turn arose from the intensive environmental work programme at STK (Aarås and Westgaard, 1980).

Productivity

The development of productivity at STK Kongsvinger is shown for cable making (Fig. 6, open circles) and all other work systems combined (Fig. 6, filled circles). The values are shown in relative units, using an estimate of standard time for a well defined unit of work as a basis. The values for 8B, Minimat, 10C and 11B are not strictly comparable from year to year, since most of the work was carried out on the 8B system before 1975, while 10C, 11B and Minimat production dominated the last few years. However, the development of productivity at the four systems combined has been very similar to that of cable making, where the work tasks have remained unchanged from 1967 to 1983. In addition to the ergonomics adaptations, the introduction of a fixed pay system appears to have had a major influence on productivity. Fig. 6 shows that productivity initially was fairly low, then increasing rapidly from 1973 onwards. The ergonomics adaptations were implemented towards the end of this incline, but productivity remained high for at least one year afterwards. This was the first year with a marked drop in long-term sick leave, and it is important to note that the reduced sick leave was not due to less effort at work. It is also interesting (although not unexpected) to note that the highest level of productivity happened in the quarter which determined the level of wages in the fixed pay system, followed by a marked drop for a period after the introduction of fixed pay. This was followed by a sharp incline in productivity in 1978 and a slow reduction in the years 1979 to 1981 which continued in 1982 for cable making, but increasing again in 1982 for the other systems. However, the

Table 5: The workers' views on the reasons for the reduction in turn-over. The significance of different factors is indicated as 1 – important, 2 – less important, 3 – may be significant

	Significance (number of indications)		
Reason	**1**	**2**	**3**
Difficult to obtain alternative employment	11	11	1
The pay rate is good	25	12	1
Improved work environment	50	8	2
Other	1	2	1
Total	87	33	5

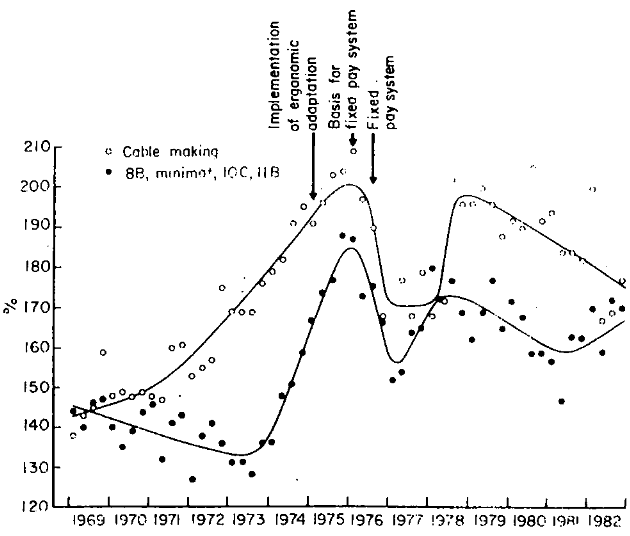

Fig. 6 Productivity at cable making (○) and the rest of the production systems (●). Productivity is shown relative to a nominal production norm.

main point of interest for the purpose of this paper is that productivity has on average been higher during the years following the ergonomics adaptations than the years preceding these.

Discussion

Following the implementation of ergonomics adaptations to the workplaces at STK Kongsvinger in the beginning of 1975, a period of several years with increasing long-term sick leave was ended. A reduction in long-term sick leave of a third followed, from 16·9% of possible working time in 1974 to 10·0% in 1975. This reduction was mainly due to a reduction in musculo-skeletal sick leave. There was also a reduction in labour turn-over. Workers with experience of both the old and the new work situations reported less severe symptoms of musculo-skeletal complaints (in 1978), and they were of the opinion that this was mainly due to the introduction of new workplaces. It has been demonstrated that mean muscle loads of the affected muscles in some cases were reduced by about 50% when comparing the new work situations with the old ones. Finally, the workers have on average been more productive (i e, they have been working faster) after the introduction of new workplaces.

This evidence strongly suggests that the intensive work environmental effort at STK (Aarås and Westgaard, 1980), with a bias towards ergonomics adaptations of the workplace, has had a clear, positive effect. However, at this time it is of interest to consider the effect of ergonomics adaptations as such, rather than the effect of more general changes in working conditions. The analysis was therefore further extended by attempting to eliminate the effects of a product development, which resulted in new work situations for many workers independently of the ergonomics efforts. At two work systems, the 8B system and cable making, a sufficient number of workers was employed before and after the ergonomics adaptations to allow a direct comparison of sick leave. Workers at cable making recorded a clear reduction in total long-term sick leave and musculo-skeletal sick leave in the years 1975 to 1982, relative to the years 1967 to 1974. Thus, the conclusions based on evidence from the factory as a whole are also valid for workers at cable making in particular, and it appears reasonable to attribute the cause of this development to the ergonomics adaptations. A possible complication is the introduction of fixed pay in May 1976, but the reduction in sick leave was established much before then. This, together with the workers' opinions on probable causes for the improvement in their health situation, makes the change in pay structure a less important explanation, although it almost certainly has made a positive contribution towards the improved health of the workers.

The situation at the 8B system is less clear. Sick leave due to musculo-skeletal complaints was not much reduced in the years 1975 to 1980 (4·6%), relative to the years 1967 to 1974 (5·1%), but was significantly reduced relative to musculo-skeletal sick leave in 1973 and 1974 (6·9% and 9·1%, Table 2 of Westgaard and Aarås, 1984), and this may be a better basis for comparison. Furthermore, musculo-skeletal sick leave in 1975 to 1980 was reduced to 3·3% of possible working time if a single sick leave is excluded, and this represents a significant reduction compared with previous years. The number of sick leaves with musculo-skeletal diagnoses, in percent of man-labour years, is also down (16·5 *vs* 24·5%, Table 3). Many of the workers ill with musculo-skeletal complaints at the 8B system from 1975 onwards had suffered a similar complaint while working at the old workplace. This would normally reduce the tolerance to further muscle strain, and may contribute to increased sick leave. Thus the impression is that even for workers at the 8B system there has been a reduction in sick leave from musculo-skeletal complaints, presumably signifying improved health of this group of workers. The reported reduction in relevant symptoms and the workers' opinions of the effect of the ergonomics adaptations lent further support to this notion.

However, the effect of the ergonomics adaptations at the 8B system was less obvious than at cable making. This could be due to the fact that cable making is a dynamic work situation, while the new 8B work situation still demanded a fairly high static muscle load, although substantially reduced relative to the old one. The EMG recordings suggested a reduction in static muscle load from about 20% to 10% of maximal voluntary contraction. These values are very uncertain due to the lack of correlation with force, but there is every reason to suspect that the level of static muscle load is much higher than a recommended upper limit of 3–5% MVC, suggested by others (Bjørksten and Jonsson, 1977). We therefore conclude that the ergonomics adaptations have had a clear positive effect even for the 8B system, but without further reducing the level of static muscle load, musculo-skeletal complaints are likely to continue albeit at a lower rate.

A final comment regarding the continuing, quite high level of long-term sick leave in the latter years despite the substantial reduction in sick leave due to musculo-skeletal complaints. This is mainly due to the chance occurrence of a few sick leaves of about one year duration (neurological and other illnesses), which each account for nearly 1% of possible working days lost through sick leave.

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III

Further studies of postural load and musculo-skeletal injuries of workers at an electro-mechanical assembly plant

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Following two previous papers, a further analysis of epidemiological and physiological data collected at a small electro-mechanical assembly plant in Norway is presented. Data on trapezius load might allow argument of a causal relationship between the level of postural load and the risk of developing musculo-skeletal injury. The second part of the paper provides an epidemiological analysis of sick-leave statistics of workers at old and more recent work systems.

Keywords: Musculo-skeletal system, working conditions, occupational health

Introduction

This paper represents a further analysis of epidemiological and physiological material collected at a small electro-mechanical assembly plant in Norway. The overall aim of this work is to investigate the relationship between postural muscle load, particularly in the shoulder-neck region, and the development of musculo-skeletal illnesses resulting in sick leave.

Two papers from this study have previously been published (Westgaard and Aarås, 1984; 1985). In the first paper it was shown that a high rate of musculo-skeletal illnesses persisted among workers having to adopt postures which would generate considerable static load in shoulder and neck muscles. The second paper showed that ergonomic adaptations, aimed at reducing postural load, appeared to reduce the rate of musculo-skeletal injuries. Workers with experience of both the old and the new work situations reported less severe symptoms of musculo-skeletal disorders, and were of the opinion that this was mainly due to the introduction of new workplaces. A reduction in load on the trapezius muscles was indicated by electromyographic recordings at the workplace. However, the level of postural load as a fraction of maximal voluntary force in the same muscle was not known for the new and old work situations, mainly because no force-EMG calibration curves were obtained (see Jonsson, 1978), but also because few recordings were made at that time

Data on trapezius load, which are provided in this paper, are important in order to allow more general comparisons of the combined postural load and illness data with similar data from other work situations. If several such postural load/musculo-skeletal injury relationships show an internal consistency, it may be argued that there is a causal relationship (on a probability basis) between the level of postural load and the risk of developing musculo-skeletal injury. It may also be possible to predict the level and pattern of postural load which can be tolerated throughout a normal working day without ill effects.

The second part of this paper provides an epidemiological analysis of sick leave statistics for workers at more recent work systems, data not analysed in detail in the two first papers. Some supplementary statistics for workers at the old systems are also included. The combined physiological and epidemiological data for the different subgroups of workers in this factory are compared with each other, and the overall results of this study are discussed.

Methods

Epidemiology

The epidemiological methods and material are mostly similar to those of the preceding papers (Westgaard and Aarås, 1984; 1985). An exception is the calculation of percentage sick-leave which is based on the duration of sick-leaves in calendar days as a fraction of calendar days from the start to the final date of a working period. Percentage sick-leave calculated by this formula shows only minor deviations from the equivalent calculation based on net working days. The modification allows real duration and timing of sick-leaves to be preserved when using a recently developed computer program for sick-leave analysis.

In most of the statistical analyses, only female workers were included, in order to eliminate one cause of inhomogenity between different groups of workers.

Electromyography

The electromyographic recordings (EMG) of muscle load were made on the upper trapezius and medial deltoid muscles in the shoulder, a body region where a majority of workers at the plant had experienced symptoms of discomfort or pain. Also, these muscles would on biomechanical considerations be heavily loaded during the work operations of interest.

The EMG recordings were obtained by surface electrodes consisting of two electrodes and a preamplifier (Analog Devices AD 521JD) integrated into one recording unit. The signals were stored on a 7- or 14-channel tape recorder and later analysed by a minicomputer system (PDP 11/23 MINC). The analysis is based on digital, full-wave rectification and integration of the EMG signals over 0·5 s or 1 s intervals, resulting in discrete values which are a measure of average electrical muscle activity over this interval. These values were used to estimate force developed by the trapezius muscle, as a percentage of maximal voluntary contraction (%MVC) of the same muscle, following a calibration procedure with simultaneous recording of force and EMG activity at varying levels of muscle force. The EMG recordings from the deltoid were calibrated relative to EMG amplitude at maximal contraction. These recordings, therefore, do not estimate muscle force with any accuracy, but provide some insight in the level of force generated by these muscles.

The calibration procedure was carried out twice, before and after the recording from the work task. The force-EMG calibration curve was restricted to low force values and approximated by a straight line (Jonsson, 1978). The mean value of the two calibration values was used to estimate muscle force developed in the vocational recording. If the two calibration measurements deviated by more than 20% from the mean value, the recording was excluded.

Some subjects recorded either a higher or a lower level of EMG activity from the upper trapezius during maximal contraction with the arm abducted 90° in the shoulder joint and a counter-force applied just above the elbow joint, compared with a shoulder lift with the counter-force applied at the acromion level of the shoulder and the upper arm hanging along the body. If there was a difference in maximal activity of more than 50% between the two postures, the vocational recording from this trapezius muscle was excluded. This was considered necessary due to the difficulty in obtaining a reliable force-EMG calibration curve for recordings of work tasks which involved both abduction/flexion of the arms and lifting of the shoulders. The calibration curves of the remaining recordings were adjusted upwards by the ratio of the two maxima if abduction generated the higher EMG response, and were otherwise kept unchanged. The rationale for this procedure is that a normal working posture usually involves both an elevation of the shoulders and some abduction/flexion of the arms, therefore the steepest calibration curve was selected. Further details of the calibration procedure are provided by Westgaard (1986).

A total of 19 (out of 76) trapezius recordings were excluded for the above reasons, leaving 24 subjects with both recordings and nine subjects with one recording accepted. Five subjects had both trapezius recordings eliminated. When quantifying muscle load associated with a work task, the recording on either the left or right side which showed the highest load was selected. Usually this would be the right side, but exceptions were found, possibly reflecting individual adaptation to the work task. If one of the recordings was eliminated by the calibration procedure, the other was taken to represent highest load on the trapezius muscles. This would introduce some bias towards too low force values in our sample. However, the force values from the nine subjects in question did not deviate much from the group mean.

The quantitative analysis of muscle load was carried out by ranking the interval estimates (0·5 or 1 s duration) of muscle force from the recording period of interest, to produce a cumulative amplitude distribution function (Jonsson, 1982). The amplitude probability given by this curve indicates the time fraction of the recording period with the signal lower than or equal to a given level. Static force level is defined as the level of muscular contraction corresponding to probability level 0·1 – i e, muscle load is higher than this level for 90% of the recording period. Peak load is similarly defined as the load corresponding to probability level 0·9 – i e, the muscle has a lower force level in 90% of the recording period. Probability level 0·5 defines the median level of contraction.

Statistical methods

Except for frequencies, all results are given as medians with 95% confidence intervals and range. In particular, the statistical significance of differences in sick-leave at the three systems is tested by calculating mean number of days absent from work per year due to musculo-skeletal illnesses for each worker, and then determining the median and 95% confidence interval of the resulting distribution. To construct the confidence interval for the median the Bernoulli-Wilcoxon procedure was used (Lehman and D'Abrera, 1975).

All tests in this analysis are one-tailed (Sverdrup, 1976). Differences are considered to be statistically significant when the p-values are less or equal to a level of 5%.

For comparison within and between groups, the Wilcoxon signed midrank test was used (Lehman and D'Abrera, 1975). The probability of not getting a musculo-skeletal illness (Fig. 4) was analysed using Kaplan and Meier's method (1958). The Gehan test (1965) was applied for comparison of groups.

Results

The 8B system

This was the major work situation at the factory prior to the ergonomic adaptations of the workplaces in 1975. The work task, which consisted of joining wires to terminals of a vertically mounted frame, 100 cm wide and 40 to 80 cm high, is described in detail by Westgaard and Aarås (1984). While performing the task the work area was limited to about 1 cm^2 at a time, the working height increasing in a stepwise manner.

Fig. 1A shows a representative recording from the upper right trapezius while working at the 8B system. The wrapping operation is first done at the old and then the new workplace. The recording is qualitatively similar to that shown in Fig. 2 of Westgaard and Aarås (1985), but with the calibration this time given as percent MVC. The graded increase in muscle load with increasing working height is a prominent feature of the recording, first in the sitting posture at the old workplace, then repeated when working at the top rows with a standing posture. The increase in muscle load when working on the higher rows of the frame is largely avoided in the new work situation, except for some increase at the highest rows where the subject preferred to remain seated. Maximal static load level in the old work situation is

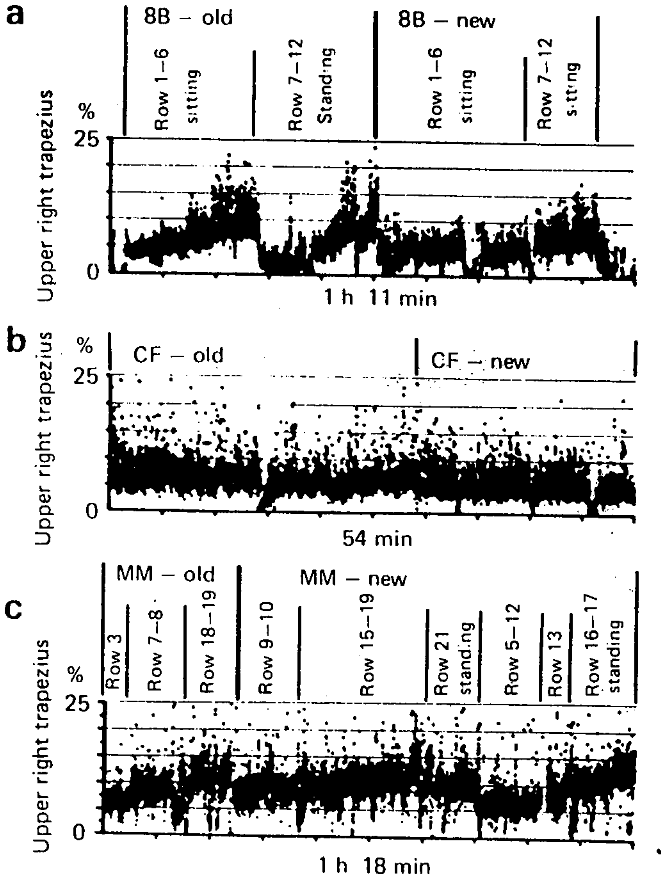

Fig. 1 Muscle load on the upper trapezius for three subjects working on the 8B (A), Cable making (B) and Minimat (C) systems. Working height is indicated by row number above the 8B and Minimat recordings. The trapezius recording with the highest load is shown. Each point in the recordings gives mean load in 0·5 s intervals, in percent of maximal voluntary contraction (MVC). The recordings are of variable length and show trapezius load in the old and the adapted work situations.

about 6% MVC, compared with 4% in the new situation. It also appears that a high level of static load was maintained for longer time periods in the old work situation.

Table 1 gives static muscle load on the upper trapezius for wiring operations in the old and new work situations. Median value and range are given separately for sitting and standing postures, these being added to give an overall total for all recordings in the two situations. There is a considerable reduction in median static load from the old to the new work situation, both with sitting (4·3 *vs* 1·9% MVC) and standing (5·2 *vs* 1·2% MVC) posture. The significance of the overall median value at the old work situation is difficult to interpret due to the slow changes in median load in the course of the working day, and will be commented upon in the Discussion section below.

A direct comparison of trapezius load while performing the same tasks in new and old work situations is shown in Table 2. This comparison was possible for recordings from eight subjects, and takes into account that some subjects would prefer to perform a work task with a sitting posture in the new work situation, while it was necessary to stand in the old situation. For these eight recordings the median static load was 4·3% in the old situation and 1·4% in the new situation. In each of the individual recordings, a reduced load was found in the new work situation relative to the old one, the difference ranging from 0·3 to 4·1% MVC, median value 1·4% MVC. The reduction in load with the new work situation was highly significant, $p < 0{\cdot}01$.

In the quantitative EMG analysis, emphasis has been put on the static load level of the upper trapezius as this appeared to be the most significant load parameter. Median and peak loads on the trapezius muscle would rarely exceed 8% and 14% MVC. The deltoid muscle always recorded a very low static load during wiring operations, less than 1% of the EMG value at maximal contraction. This is likely to be a much lower load than that sustained by the trapezius muscle, despite the uncertainty of the force-EMG calibration.

In addition to the wiring operations the 8B work duties included various preparatory tasks occupying about 10% of total working time. Median static load level was recorded at 2·5% for both the upper trapezius and the deltoid muscles

Table 1: Static load on upper trapezius muscle at old and new work situations

		Old work situation			New work situation		
Work system	Work operation	No	Static load median	Static load range	No	Static load median	Static load range
8B	Wiring, sitting	4	4·3	2·3 – 5·8	9	1·9	0·6 – 5·5
	Wiring, standing	6	5·2	0·8 – 5·5	2	1·2	0·5 – 1·8
	Wiring, variable*	4	3·1	1·8 – 5·4			
	Wiring, total	14	4·5	0·8 – 5·8	11	1·8	0·5 – 5·5
CF	Small forms, sitting				5	10·7	8·0 – 17·2
	Small forms, standing	4	5·5	0·7 – 6·2	4	3·3	0·8 – 6·4
	Large forms, standing	4	0·8	0·6 – 5·1	4	0·8	0·5 – 4·2
MM	Wiring	3	4·4	0·6 – 7·2	4	2·9	0·6 – 10·9

*Frequent change between sitting and standing posture

Table 2: Static load on upper trapezius muscle (subject-control study)

Work system		Old work situation	New work situation	Difference between old and new work situation
8B	No of subjects	8	8	
	Static load, median	4·3	1·4	1·4
	95% confidence interval	1·5 – 5·5	0·6 – 3·3	0·3 – 4·1
	Total range	0·8 – 5·8	0·5 – 5·0	0·2 – 4·5
	p-value			<0.01
CF	No of subjects	7	7	
	Static load, median	0·9	0·8	0
	95% confidence interval	0·6 – 5·5	0·6 – 6·1	– 0·6 – 0·6
	Total range	0·6 – 5·6	0·5 – 6·4	– 0·8 – 0·9
	p-value			>0.1

while performing this task, which did not change from the old to the new work situation. These tasks were performed infrequently, when a new frame was prepared.

The cable-making system

Workers at this system, which has existed throughout the time period considered in this study, produced cable forms used as backwiring for the 8B and Minimat systems. The production of cable forms was a much more dynamic work operation than the wiring operations of the 8B system (Westgaard and Aarås, 1984). The cable forms, which were of varying sizes, were produced on small (1 m x 1·5 m) or large (1 m x 3 m) table surfaces mounted nearly vertically.

The load on the trapezius muscles usually had a static component, despite the dynamic movement of the arms. The static load level was usually higher when working with the small cable forms (Table 1), possibly due to a tendency to maintain a forward flexion of the arms while working within the more restricted area of the small forms. This is supported by recordings of work on small forms in a seated posture, when considerable flexion of the arms was necessary and the static load level was very high (median value 10·7% MVC, Table 1). However, this posture would usually not be adopted by the workers.

Fig. 1B shows a recording from the upper right trapezius muscle while working on a small cable form in the old and the adapted work situations. The adaptation consisted of changing the centre height of the table from 105 cm in the old situation to a new height varying between 101 and 130 cm, depending upon the individual. In theory, the overall size and near vertical positioning of the table surface also allowed considerable flexibility in optimising the position of the cable form in the old work situation. Thus, only moderate adjustment of working height was required, which may be the reason why trapezius load did not change to any appreciable extent from the old to the new work situation. (The reduction in median static load for standing posture at small forms, from 5·5 to 3·3% MVC, in Table 1 is not significant.) This result is confirmed by recordings from seven subjects, four working on large and three on small cable forms, performing the same work tasks both in the old and the new work situations. For these subjects there was no difference in static load levels at the two work situations (Table 2).

Median and peak loads on the trapezius muscle were again low when working in a standing posture, maximum 11% and 17% MVC respectively for one subject working on a small cable form in the old work situation. Loads on the deltoid muscles were also very low, both for sitting and standing work.

The Minimat system

The work tasks of this system were similar to the 8B system (Westgaard and Aarås, 1984), and a similar continuous increase in trapezius load with increasing work height is seen at this system (Fig. 1C). Trapezius load is reduced when changing from a seated (rows 15–19) to a standing (row 21) posture. When comparing rows 3 and 7–8 in the old situation with rows 5–12 in the new one, it appears that the ergonomic adaptations have contributed to reduced tension in the trapezius muscles for this subject.

The experimental material is limited due to the closure of the system at the time the recordings were made. An overall reduction in static trapezius load is indicated, from a median value of 4·4% MVC in the old situation to 2·9% in the new one, but considerable individual variability in the level of static load, from 0·6 to 10·9% MVC in the new work situation, precludes drawing general conclusions.

Median and peak loads on the trapezius muscle were in general low, but with one subject recording 18 and 27% MVC, respectively. The load on the deltoid muscles was low both in the old and new work situations.

The 10C system

Wrapping of terminals at the 10C system (Westgaard and Aarås, 1984) was performed seated within an area of 30 x 60 cm for 35% of the work time. For 50% of the work time the wrapping was carried out in a standing position with the frame placed horizontally. The work area was then 200 x 60 cm. The system workplace has always been adjustable with regard to height and tilt of the frame.

Fig. 2A shows a typical recording from the trapezius muscle while working at this system, first with a standing posture and the frame placed horizontally, then seated with the frame in a near vertical position. A considerable increase in static trapezius load is seen when changing from standing to seated posture (0·7 *vs* 3·5% MVC). This was a general

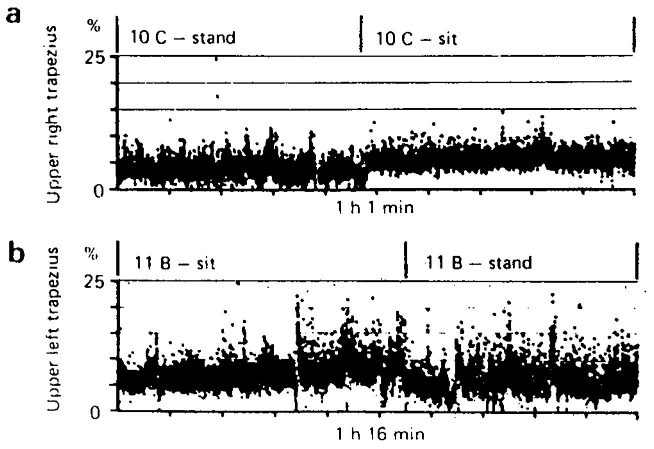

Fig. 2 Muscle load on the upper trapezius for two subjects working on the 10C (A) and 11B (B) systems. Work is performed in both sitting (sitt) and standing (stand) posture. The figure is otherwise similar to Fig. 1.

finding (Table 3), the median value for static trapezius load being 3·8% MVC when working in a seated and 1·0% MVC when working in a standing posture. Thus, half the work on this system was carried out with very low static load on the trapezius.

Median and peak loads on the trapezius were low, below 10% and 17% MVC. The load on the deltoid muscles was also low, median values for static and peak loads being 0·7% and 7%.

The 11B system

More than 75% of the work time at this system was used to connect wire to terminals, using a wrapping gun. Most of the connections were made within one shelf (of four), representing a work area of 78 x 20 cm, while 20% of the time was used to connect terminals in different shelves. Wrapping restricted to the two lowest shelves, accounting for less than 20% of total work time, was usually performed seated while the rest of the wrapping work had to be performed standing.

Muscle load was recorded from three subjects, two of whom carried out work within the same work area both with a seated and a standing posture. One of these recordings from the trapezius muscle is shown in Fig. 2B, and it is seen that static muscle load is much higher in the seated position

Table 3: Static load on upper trapezius muscle at sitting and standing postures (10C, 11B)

Work system	Work operation	No	Static load median	Static load range
10C	Wiring, sitting	8	3·8	1·0 – 4·8
	Wiring, standing	6	1·0	0·5 – 5·1
11B	Wiring, sitting	2	4·1	3·6 – 4·6
	Wiring, standing	4	1·3	0·9 – 1·8

(4·6% *vs* 1·4% MVC). This result was common to all subjects, the median static load being 4·1% MVC in the seated and 1·3% in the standing posture with little variation between subjects (Table 3). The standing posture was the normal one at this system, accounting for about 70% of total work time.

Median and peak loads on the trapezius muscle did not exceed 11 and 22% MVC, respectively. The load on the deltoid muscles was very low, peak load usually less than 5%.

Sick-leave statistics

Previous papers have presented sick-leave statistics for all workers at the factory and for workers at the cable making and 8B systems, the two most important work systems at the time of the ergonomic adaptations early in 1975. However, other work systems (10C, 11B, Minimat) gained in importance in the following years (Table 1 of Westgaard and Aarås, 1985). Results presented in this paper quantify load on the trapezius muscles while working on these systems, and it would be of interest to know the effect of such loads in terms of workers' health. Also, sick-leave statistics which show improved health of workers after the ergonomic adaptations, do not distinguish between workers employed before 1975, thus having been exposed to the considerable load levels of the old work situation, and workers employed after 1975. It would be of interest to see how the health situation of this latter group of workers has developed.

Table 4 gives the basic sick-leave statistics due to musculo-skeletal illnesses of female workers at the Minimat, 10C and 11B systems from the time of implementation of the ergonomic adaptations until 1983. Sick-leaves over these years were 3·2% (Minimat), 1·0% (10C) and 1·6% (11B), respectively. The musculo-skeletal sick-leave for the Minimat system was somewhat lower than for female workers at the 8B system after the ergonomic adaptations (4·6%, Table 3 of Westgaard and Aarås, 1985) and was significantly higher than for the 10C and 11B systems ($p < 0·03$). The individual episodes of musculo-skeletal sick-leave were both more frequent (Table 4) and of longer duration than for the 10C and 11B systems. This comparison of percentage sick-leave at different systems refers to workers employed over the same time period (1974/75 to 1983), which eliminates the possibility of differences in working conditions causing this difference. Workers at the different systems were in fact placed in the same factory hall, experiencing the same working environment, supervisors and social conditions. Times of employment were also similar for the three groups of workers (median values varying between 3·1 and 3·9 years, no statistically significant differences).

The development of musculo-skeletal illnesses with increasing time of employment for female workers employed at the 10C and 11B systems is shown in Fig. 3, and is compared with similar results for female workers employed at the 8B, cable making and Minimat systems before the ergonomic adaptations in 1975. The calculation of fraction of workers at the 8B system with a recorded musculo-skeletal sick-leave is similar to Fig. 15C of Westgaard and Aarås (1984), but with eight male workers excluded and a coarser grouping of the parameter 'years of employment' in order to improve the statistics of the calculations. Some workers included in the 10C and 11B statistics who have previously been employed at the 8B system are in this analysis treated as separate persons with time of employment on the recent work systems considered to be independent of the working period on the 8B system.

Table 4: Sick-leave statistics (musculo-skeletal illnesses) of female workers

Work system	Time period	Work time (man-labour years)	Sick-leave due to musculo-skeletal illness (% of man-labour years)	No of musculo-skeletal diagnoses (% of man-labour years)	Duration of musculo-skeletal sick-leaves per man-labour year	
					Median	95% confidence interval
Minimat	1975–83	123	3·2	18·7	0	0 – 7·7
10C	1974–83	124	1·0	8·1	0	0 – 0·1*
11B	1974–83	107	1·6	12·1	0	0 – 0·1*

* $p < 0{\cdot}03$, relative to the Minimat system

It is seen that workers at the 10C and 11B systems develop musculo-skeletal illnesses at a much lower rate than workers at the older systems before the ergonomic adaptations. No one employed for less than two years at the 10C or 11B systems has recorded a musculo-skeletal sick-leave (20–25% at the old systems); this difference is maintained for the groups employed 2–5 years and more than 5 years. When comparing workers employed at the three older systems with workers at the two recent systems, it was found that these differences were statistically significant, with $p < 0{\cdot}01$ for the 0–2 and 2–5 year groups and $p = 0{\cdot}05$ for workers employed more than 5 years. The different development of musculo-skeletal sick-leaves is not due to differences in age of employment at the different systems, the mean age at recruitment was 24·9 years at the 10C system and 24·4 years at the 11B system, compared with the similar value of 22·1 years at the 8B system. Apart from recording fewer sick-leaves at the 10C and 11B systems, those sick-leaves that did occur were of shorter duration. The mean duration of sick-leave at the 10C and 11B systems was 46·1 and 47·2 days, both significantly lower than for the old 8B system (72·8 days, $p < 0{\cdot}01$).

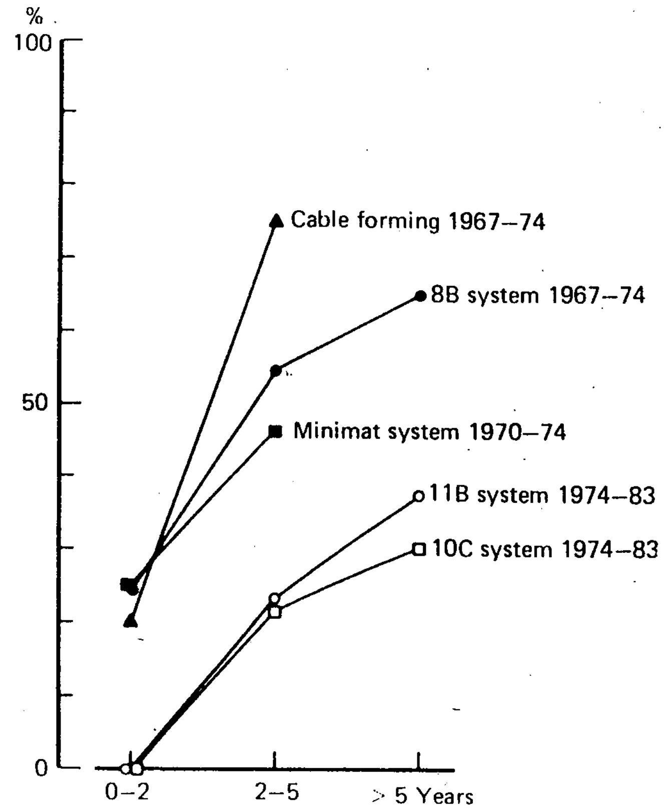

Fig. 3 Fraction of female workers with one or more recorded musculo-skeletal sick-leaves as a function of time of employment. Five groups of workers are shown: the 8B system, employed between 1967 and 1974 (filled circles); the Cable making system 1967–74 (filled triangles); the Minimat system 1970–74 (filled squares); the 11B system 1974–83 (open circles) and the 10C system 1974–83 (open squares). Number of subjects in each 'time of employment' group (less than 2 years, 2–5 years, more than 5 years): 128, 73, 20 (8B); 10, 12 (Cable making); 12, 13 (Minimat); 9, 13, 8 (11B); 5, 14, 10 (10C).

An alternative way of analysing this material involves the use of survival statistics – i e, determining the probability of not recording a sick-leave due to musculo-skeletal illness at different times after employment (see Methods). Fig. 4 shows the result of this analysis when comparing workers of both sexes employed on the old systems before the ergonomic adaptations, with workers employed on the new or adapted systems. The latter group of workers has a much higher probability of not becoming ill at any time during the first two years of employment (broken line) than workers at the old systems (solid line). Workers at the old systems before the ergonomic adaptations had in fact only a 33% probability of not recording a musculo-skeletal sick-leave after 2 years of employment. The difference in probability for the two groups of workers is highly significant, $p \ll 0{\cdot}01$ after 2 years of employment, and is not due to differences in age (mean age 24·9 and 23·2 years for workers at the new/adapted and old systems) or in proportion of male workers in the group (17 *vs* 21%). The reduced probability is due both to a lower fraction of workers becoming ill (Fig. 3) and to a slower onset for those eventually recording a musculo-skeletal sick-leave. The latter point is evident by considering the probability of not recording a musculo-skeletal sick-leave after 0·4 years of employment: workers at new/adapted systems record a 99% probability, compared with 77% for workers at the old workplaces (see also Figs. 16 and 17 of Westgaard and Aarås, 1984).

In Figs. 3 and 4 all musculo-skeletal sick-leaves, regardless of body location, are considered. Also, workers in each of the two groups in Fig. 4 were exposed to different patterns of muscle load. In order to evaluate the risk of developing

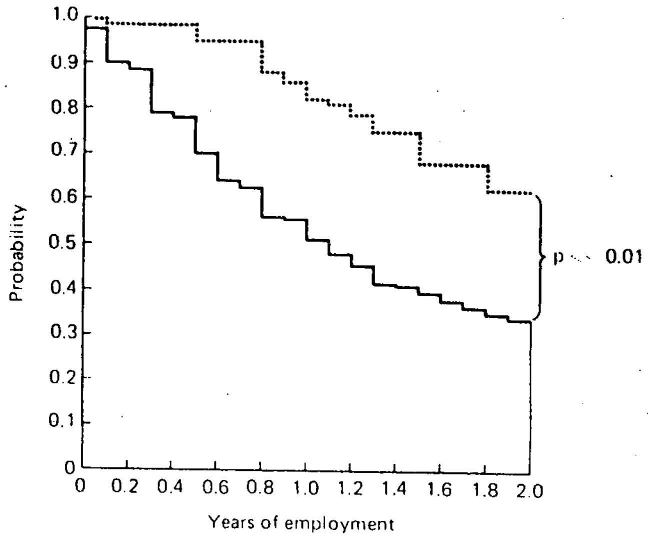

Fig. 4 Survival statistics of workers employed before (solid line) and after (broken line) implementation of ergonomic adaptations at the STK Kongsvinger plant. The two curves indicate the probability of not recording a musculo-skeletal sick-leave at different times after employment. Workers employed before the ergonomic adaptations were predominantly working at the 8B and cable making systems, after the adaptations at the 10C and 11B systems.

musculo-skeletal illnesses when working with different levels of load, groups of workers exposed to more homogeneous muscle loads should be defined, and these loads related to relevant illnesses in the body region of interest. Workers at the STK Kongsvinger factory were primarily loading shoulder and neck muscles; Fig. 5, which is constructed in the same way as Fig. 3, shows the development of musculo-skeletal illnesses in the shoulder and neck of female workers employed at the old 8B work situation and workers employed at the 10C or 11B systems after implementation of the ergonomic adaptations. Workers at the 10C and 11B systems are here considered to be a homogeneous group as the EMG recordings showed near identical trapezius load at the two systems, and the development of musculo-skeletal illnesses was very similar. Fig. 5 shows that the occurrence of musculo-skeletal illnesses in the shoulder-neck region was much reduced for the 10C/11B workers relative to those working at the 8B system ($p = 0{\cdot}02$ for the 2–5 year group). The difference between workers employed for other periods of time was not statistically significant, in part due to few workers in these groups.

The point was made by Westgaard and Aarås (1985) that the health situation for the workers at the Kongsvinger plant was much improved following the implementation of the ergonomic adaptations, independently of the introduction of the new work systems. This conclusion was based on the rate of sick-leave due to musculo-skeletal illnesses for workers at the 8B and cable making systems. This analysis can be further improved by eliminating the effect of labour turn-over on the data in Table 3 of Westgaard and Aarås (1985) – i e, by only considering workers employed both in the old and the new work situations for at least one year and with at least one recorded musculo-skeletal sick-leave. This analysis was only possible for workers at the 8B system, where 15 subjects satisfied these conditions. Table 5 gives the main results of this analysis. It is seen that median musculo-skeletal sick-leave (days per man-labour year) was 22·9 days in the old 8B work situation and 1·8 in the new one, a difference which is statistically significant ($p < 0{\cdot}02$). This result provides additional evidence of a genuine improvement of the health situation following the ergonomic adaptations of the 8B system, by eliminating inter-individual differences in general health condition and in ability to tolerate prolonged muscle load.

Discussion

The measurements of muscle load presented in this paper confirm that the introduction of height-adjustable work-stands, chairs with armrests and other measures to improve working postures had a positive effect in terms of reduced load on the trapezius muscle for workers at the major work system of the Kongsvinger factory at that time, the 8B system. This effect is summarised in Table 1 as a reduction in median static load from 4·5 to 1·8% MVC, comparing the old and the new work situations. The result is confirmed in Table 2, where each subject is serving as her own control.

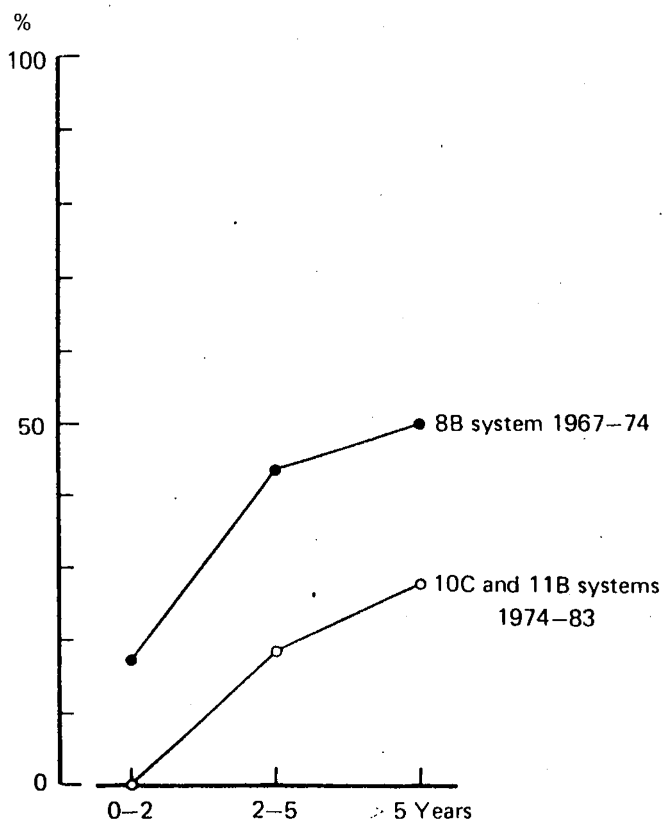

Fig. 5 Fraction of female workers with one or more recorded musculo-skeletal sick-leaves located to the shoulder and neck region as a function of time of employment. Two groups of workers are shown: the 8B system 1967–74 (filled circles) and the combined 10C/11B systems (open circles). Number of subjects in each 'time of employment' group is given in the figure legend of Fig. 3.

The values for median load mask slow variations in load throughout the working day, and it may be that trapezius load at the 8B system is better represented by the higher level of static load maintained for about half the working day. This view is supported by the finding that part-time workers performing sewing operations develop musculo-skeletal complaints to about the same extent as those with normal working time (Wærsted and Westgaard, 1986). If the high load levels maintained for part of the working day prove to be critical, then the ergonomic adaptations must be considered particularly effective, in that they preferentially reduce the highest load levels at the old system.

The overall impression of the load measurement was that the ergonomic adaptations were effective in reducing trapezius loads associated with abduction or flexion of the arms, but that a certain level of static load, in the order of 2%–4% MVC, would remain when performing a continuous work task with arms in front of the body while in a seated posture. The excessive forward flexion of the arms while working with small cable forms in a seated posture resulted in static trapezius loads of about 10% MVC. It is probably significant that work tasks carried out within a limited area, thereby allowing the use of armrests (8B and possibly Minimat), recorded a lower static load than work tasks performed within a larger area, where it is difficult to use arm support. This result points to the difficulty of eliminating static load on the shoulder muscles when the work task requires continuous use of elevated arms in front of the body, a notion supported by studies of Bendix *et al* (1985) showing high levels of static load when performing a standardised work task 5 cm above elbow height with seated, supported-standing and standing postures.

The load on the trapezius muscles is much reduced with a standing posture at the adjustable work stands, presumably due to the possibility of avoiding postures with excessive elevation of the arms. It therefore appears to be particularly advantageous in terms of load on the trapezius muscle to change from a seated to a standing posture, ignoring for the moment that the load on other muscles may increase. However, a seated posture is generally considered more comfortable and would usually be preferred even if this may cause more severe problems in the musculo-skeletal system on a longer time scale.

Sick-leave in the years following the ergonomic adaptations varied considerably between workers at different systems. Female workers at the 10C and 11B systems recorded a sick-leave of 1·0% and 1·6% of possible working time due to musculo-skeletal illnesses. Corresponding values for the 8B, Minimat and cable making systems were 4·6%, 3·2% and 1·6%, respectively (Table 4 and Table 3 of Westgaard and Aarås, 1985). Thus, the favourable development of sick-leave due to musculo-skeletal illnesses in the years following the ergonomic adaptations was to a large extent due to the emergence of the 11B and, in particular, the 10C system as the dominating systems at the factory. Nevertheless, reduced musculo-skeletal sick-leave was recorded for the 8B (5·1% *vs* 4·6%) and the cable making (4·7% *vs* 1·6%) system when comparing sick-leave of all workers at these systems before and after the ergonomic adaptations (Westgaard and Aarås, 1985). Table 5 in this paper provides further evidence of a genuine improvement in health condition of the same workers, coinciding with the ergonomic adaptations.

It has previously been suggested that the effects of the ergonomic adaptations in terms of workers' health were too large relative to the reduction in muscle load (Westgaard *et al*, 1986). The more extensive analysis of sick-leave in this paper suggests that this is not the case. Musculo-skeletal sick-leave at the 8B system was reduced from 5·1% to 4·6% following ergonomic adaptations which reduced median static load from 4·3% to 1·8% MVC. The reduction in sick-leave relative to the years immediately preceding the adaptations was larger, but not necessarily out of line with the reduction in muscle load.

The reduced sick leave at cable making is much more pronounced than would be expected on the basis of the EMG results, which at most indicated a minor effect for workers on small cable forms. However, at the time of the ergonomic adaptations the main work load at cable making was switched from producing forms for the 8B system to the Minimat system, which required much larger forms. Thus, there would be a general transfer of workers from tasks requiring relatively high static load (small forms) to less demanding tasks (large forms), independently of the ergonomic adaptations implemented. This change in work tasks, together with the probability of some beneficial effects of the ergonomic adaptations, would be sufficient to explain the large reduction in sick-leave at this system. However, this does not exclude that other less defined factors, such as attitudes of workers and management, may have contributed to the reduction in sick leave.

The proportion of workers with sick-leave due to musculo-skeletal illnesses relative to time of employment, and the survival statistics of Fig. 4, provide alternative estimates of the risk of contracting these illnesses for groups of workers exposed to the same muscle load. Unfortunately, these methods cannot be used to evaluate the effect of the ergonomic adaptations on the old systems since most workers employed after January 1975 were employed at the new systems. However, results based on groups of workers at the Kongsvinger factory may be compared with similar results from other projects (Westgaard *et al*, 1986). The rate

Table 5: Sick-leave statistics (musculo-skeletal illnesses) of workers employed at both old and new work situations

Work system	Time period	Work time (man-labour years)	Sick-leave due to musculo-skeletal illness (% of man-labour years)	No of musculo-skeletal diagnoses (% of man-labour years)	Duration of musculo-skeletal sick-leaves per man-labour year	
					Median	95% confidence interval
8B	1967–74	66	7·9	36·0	22·9	4·4 – 50·8
	1975–80	59	5·7	23·7	1·8	0 – 34·4*

* $p = 0{\cdot}02$

of musculo-skeletal illnesses in the shoulder and neck region for workers at the old 8B system is intermediate to groups of workers with intermediate (ca 5% MVC) and high (ca 10% MVC) static loads. Median static load at the old 8B system was 4·3% MVC, but a value between 5% and 10% MVC had to be maintained for long periods of the working day. This could be a more relevant estimate of the critical load level, as commented upon previously, and would then put the 8B result in line with that obtained from other work situations.

The frequency of such illnesses in the shoulder-neck region for the 10C/11B workers is higher than for groups of workers without continuous work loads (the control group of Westgaard and Aarås, 1984), but are lower than for service workers at North Sea oil platforms (Westgaard *et al*, 1986). The latter group recorded a near intermittent trapezius load (median static load 1% MVC), but had very long working hours (12 hours each day for 14 days). The result for the 10C/11B group suggests that shorter periods with relatively high loads are well tolerated, and that the overall work load at these systems is beginning to approximate a reasonable demand on individual muscles. These results suggest that a static load level of about 1% MVC can be acceptable if adequate breaks in the load pattern are allowed, but also that the same level of load is too high if it has to be maintained for time periods exceeding those of a normal working day. Shorter periods with a much higher muscle load are acceptable within a general load pattern with low static load. A suggested threshold level for acceptable load should therefore include guidelines both for intensity and duration of such loads, as well as duration of necessary pauses between periods with prolonged load. The result also indicates that a suggested threshold level of 2%–5% MVC for static load is too high (Jonsson, 1982). A possible explanation of this discrepancy is the detection of long-term effects associated with the very long exposure times in the current studies.

Finally, following the detailed and critical analysis of sick-leave at the Kongsvinger plant, it should be emphasised that this project must still be considered a successful implementation of ergonomic adaptations of the workplaces. The overall reduction in sick-leave is to some extent due to changes in production including the introduction of new work systems. However, the new workplaces were designed on the basis of the same ergonomic principles as used when adapting the workplaces of the old systems. Load measurements from the earliest versions of the 10C workplace indicated a static trapezius load of 6% to 10% MVC both with sitting and standing postures. It is therefore likely that an introduction of the new systems based on old workplaces would have caused considerable health problems, at least to the extent seen with the old 8B system.

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IV

Measurement of postural angles during work

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Abstract

A method for continuous measurement of postural angles (head angle, arm abduction, arm flexion and back angle) is described. The method involves attachment of potentiometer penduli at the head, shoulder and back. In laboratory tests the equipment ("Ergonometer") seems to adequately record the actual body angles. The system is relatively simple and robust and well suited for field studies.
The technique of postural angle measurements is planned to be used in assessment of work load. In such measurements several limitations must be considered. These include body supporting such as elbow support and load in hands. Both influence muscular load although the angle may be unchanged. Furthermore, angular velocity is important when assessing work load.

1. INTRODUCTION

The need to improve work posture has been documented in a number of studies which have shown a relationship between stressful postures at work and functional disturbance or pain in various parts of the musculo-skeletal system (Maeda et al. 1980, Stubbs 1980, Andersson 1984, Westgaard and Aarås 1984, 1985). In such studies the assessment of work load may be performed by measurement of EMG from selected muscle groups (eg. Aarås and Westgaard 1986). Other methods quantify work load by recording postures and body motion at the workplace (Karhu et al. 1977, Karhu et al. 1981, Corlett et al. 1977, Corlett and Manenica 1980, Hünting et al. 1980, Persson and Kilbom 1983).

In biomechanics, quantitative models for estimation of segmental work load can be designed by considering body segment motions and the muscle actions responsible for these motions. In these models the human body is decomposed as a set of articulated links in a kinetic chain. When resulting load moments are calculated at distinct articulations, postural angle measurements are necessary. The frequency distribution of angles of the neck, back, elbow and hands during work may be measured manually (Grandjean et al. 1982, Maeda et al. 1980). More sophisticated systems for 3-dimensional automated tracking of a large number of motion segments have recently been developed (Samuelson et al. 1987).

To perform *continuous* measurements of postural angles we constructed an equipment ("Ergonometer") based on potentiometer- sensed penduli attached to upper arm (flexion and abduction of the shoulder joint), head and back. This paper presents the methodology and testing of the equipment.

2. DESIGN PHILOSOPHY

The development of this equipment aimed at the following criteria:

* The method had to be cheap, easy applicable and suited for contiuous use.
* The equipment should record accurately the movements undertaken by the subjects during work.
* The measurements had to be repeatable under predescribed conditions, i.e. within the range of movements normally occurring in the actual work situation.
* The recording equipment should not interfere with the movements being recorded.
* The following angles were to be recorded: Head -, neck -, back -, upper arm flexion – and upper arm abduction angles.

3. TECHNICAL DESCRIPTION

The angle transducers consisted of a pendulum potentiometer (Fig. 1). This method was chosen because of its simplicity. Potentiometers with low rotational friction were essential to achieve tolerable mechanical hysteresis, which is especially important when slow movements are recorded.

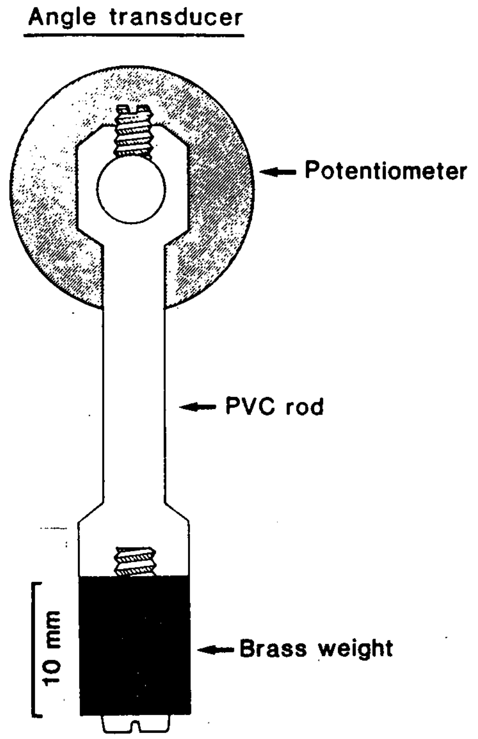

Figure 1: Schematic illustration of the potentiometer pendulum transducer. A standard Spectrol Model 157 potentiometer with a pendulum attached to the axis is used. In later versions ball bearings are applied to reduce the rotational friction.

Electronic cirquits.

The electronic cirquits for determining the head, back and arm angles are shown in figure 2. The RC-cirquit between IC1 and IC2 set the time constant to about 0.2 s. in order to reduce the effect of pendulum overshoot and afterswing during stacatto movements.

The calibration cirquit was included for easy electrical calibration of the "Ergonometer". The calibration steps are signals analogous to 0, 45 and 90 degrees of deflection.

Beside outputs from all channels to tape recorder/linear recorder head and back cirquits were also connected to a neck angle calculating cirquit (Fig. 3). In this cirquit neck angle is calculated as the difference between head and back angles at IC1. The inputs to IC1 are damped, and as a result the time constant of the neck angle recording is approximately 0.3 s.

All channels have buffered (IC5) gain-controlled outputs, as well as analogue displays.

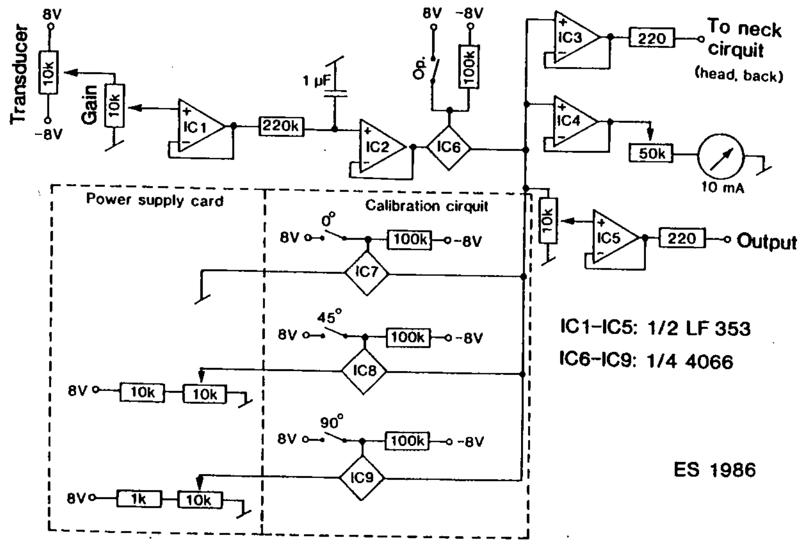

Figure 2: Electric diagram of the "Ergonometer" for head, arm and back angles. An electric calibration cirquit is shown within the interrupted lines. The RC-cirquit between IC1 and IC2 sets the time constant to about 0.2 s.

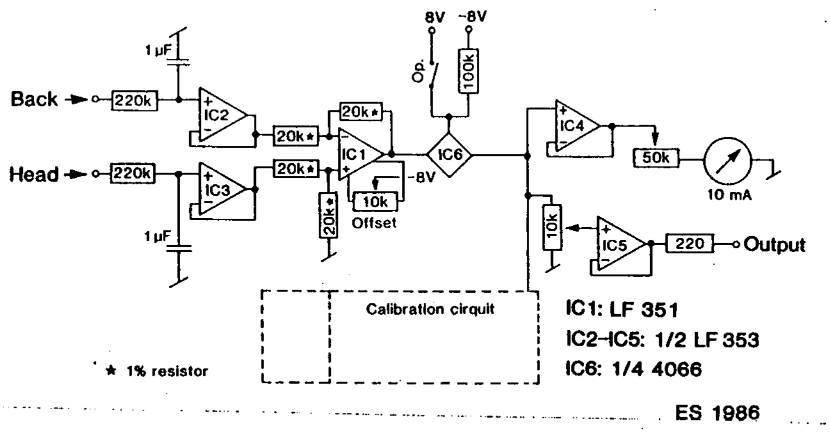

Figure 3: Electric diagram for continuous calculation of the neck angle from the head and back angles. The calibration cirquit is identical to the one shown in figure 2.

Zero calibration.
The potentiometer for measuring head movements was mounted in a head phone set (Fig. 4). Other potentiometers were fixed properly to the body by attachments plates for the upper arm and back. They were made possible to rotate for determining zero setpoint after body zero position was defined.

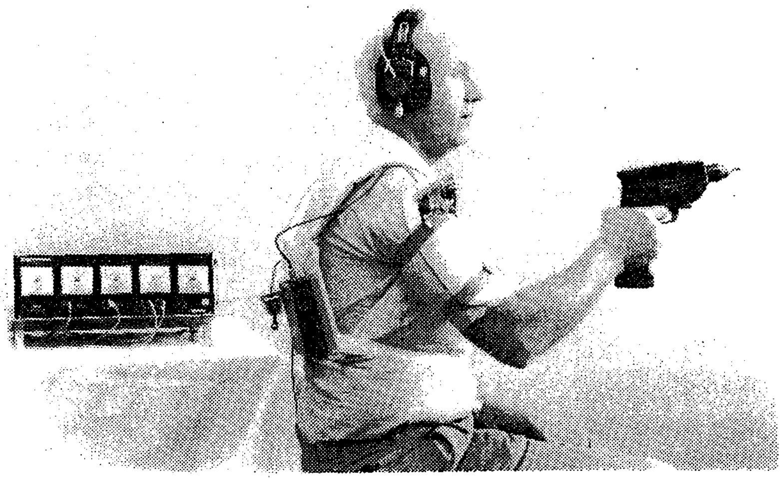

Figure 4: The "Ergonometer" with angle transducers attached to the head, shoulder (arm flexion and arm abduction) and back. The neck angle is continuously calculated as the difference between head and back angles.

Definition of body reference position.
To do reproducible measurements body position has to be defined where the postural angles are set to zero degree. A well-balanced upright position with relaxed shoulders and the upper arm hanging relaxed along the body was chosen as zero position. In this position the influence of the gravity forces on the musculo-skeletal system are minimal.

Definition of zero head angle required special attention, and was performed by sight line fixation. Because sharp vision is limited to a very small area of the retina it is possible to define the relationship between the eye itself and the line of sight. In resting eye position all external eye muscles are at equal tension. Static muscle stress occurs in these muscles when the sight line deviates from the resting position, and the head will alter position in relation to the sight line to lower this stress.

The reproducibility of head positioning was tested in 9 subjects by intermittenet fixation of the eyes on a red spot on white background at eye height 5 m in front of the subjects. The fixation period was approximately 10 s. Between these periods the subjects turned their head away. The result of these experiments is shown in figure 5. The mean difference between the recordings for each subject ranged between 0.57 and 1.13°, with an average of 0.85°. It was therefore concluded that defining of zero head angle by the sight line technique was a reproducible and fully acceptable method.

The reproducibility of arm zero value was tested similarly in a group of 5 subjects. For each subjects the upper arm was kept passively dependent in a series of ten times, and the angle recorded. The mean deviation from the midpoint for each subject ranged between 0.4 and 2.1° with an average of 1.2° for flexion, and between 0.3 and 1.6° with an average of 0.9° for abduction.

In later recordings all angles were set at zero before measurements of the working posture, and the zero values checked after each recording period.

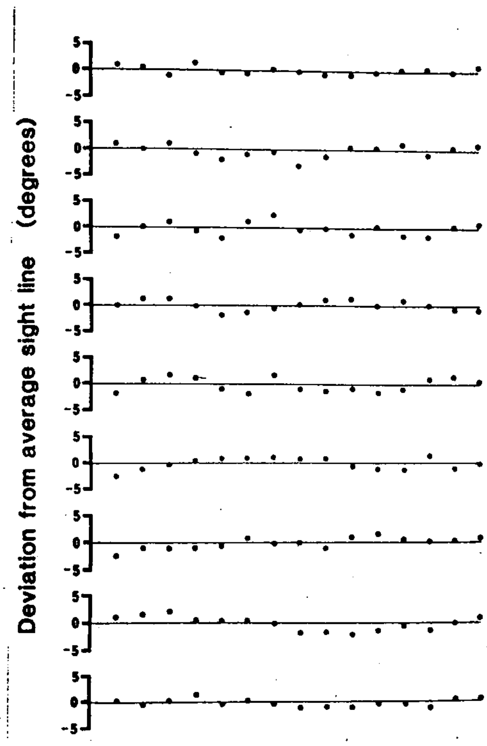

Figure 5: Test procedure for defining head zero value by sight line technique in nine subjects. These intermittently fixated the eyes for periods of 10 s on a red spot at eye height 5 m in front of the subjects. Between these periods the subjects turned their head away.

PHYSIOLOGICAL ASSESSMENT OF THE "ERGONOMETER".

In vitro assessment.

To compare the recorded angle with the real one we used a calibration setup as shown in figure 6. This test was performed to determine the error produced by the hysteresis of the pendulum potentiometer and the electronic damping of the signal. The calibration setup was designed to mimic the single plane movement (flexion) of the shoulder joint. A potentiometer (P1) was fastened to a ruler-like arm to give the exact movement of the arm. About 10 cm along the arm one of the pendulum potentiometers (P2) was attached. This distance was approximately the same as the distance from the shoulder joint to the "flexion" potentiometer. In this calibration setup P2-output (before "Ergonometer" damping) was also recorded. The arm was then manually given movements similar to arm movements used by workers at an electromechanical assembly plant.

Fig. 6A shows true movement (P1), pendulum potentiometer recorded movement (P2) and "Ergonometer" output for a 40° oscillatory movement at a frequency of about 0.25 Hz, followed by a step-like movement from low to high position at the same frequency. This mimics an arm movement at moderate to low speed, and it is seen that the P2 pendulum and the "Ergonometer" record the movement with reasonable accuracy. At the final stepwise movement the ergonometer underrepresents the angle by about 5° of the first 0.5 s after reaching the plateau, and by 1.5° the next 0.5 s. Much faster stepwise movements (within the range most likely to occur in occre wrapping etc., where the movement was halted for some period of time). Thus sufficient time is given for the "Ergonometer" output to approximate the real deflection.

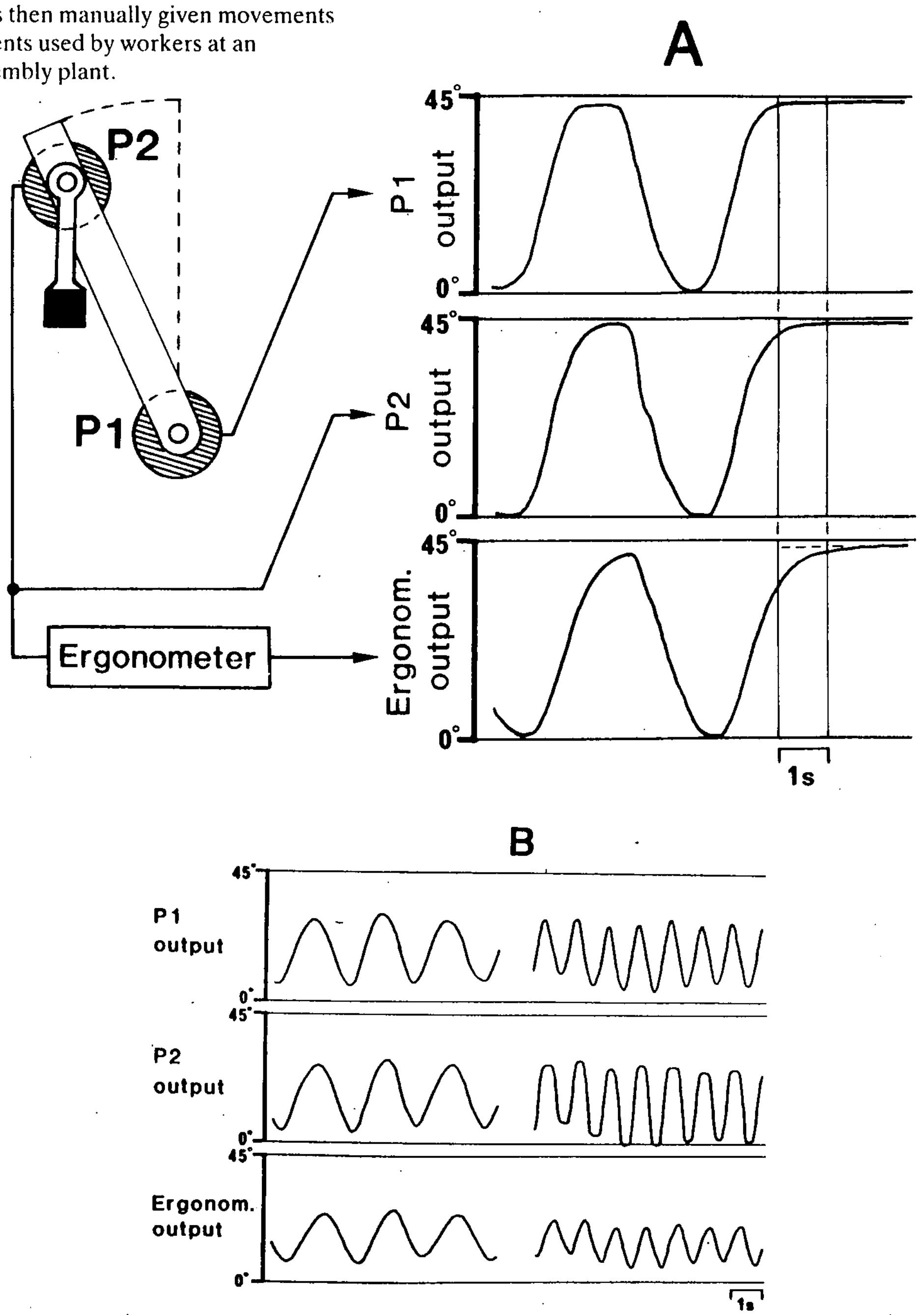

Figure 6: In vitro test setup for determination of the pendulum transducer characteristics (P2 output) and output from the "Ergonometer" (Ergonom. output) as compared to true angular movement of the transducer (P1 output). *A:* A stepwise movement indicates the time delay by the "Ergonometer" caused by the inherent electronic time constant of about 0.2 s. *B:* Oscillatory movements at a frequency of about 0.5 and 1 Hz (angular velocity of 21 and 34 °/s). This indicates considerable damping of "Ergonometer" output as compared to P1 output at higher frequencies. However, such fast movements are rare in occupational work situations.

Fig. 6B demonstrates results for oscillatory movements at a frequency of about 0.5 and 1 Hz (angular velocity 21 and 34 °/s). At 0.5 the P2 and "Ergonometer" outputs describe the true movement reasonably accurately, but with a slight phase lag and with a 29% reduction in peak-to-peak amplitude of the "Ergonometer" output due to the electronic damping. At 1 Hz the oscillation is approximating the resonance frequency of the P2 pendulum and the P2 amplitude is about 8% higher than the real movement (P1). However, the electronic damping ensures that the output from the "Ergonometer" is reduced by 38% relative to P1 amplitude. Thus, the "Ergonometer" is clearly not suited for recording of fast oscillatory movements. However, these are rarely required in occupational work situations. Fast oscillatory movements of body structures such as lower arms, hands and fingers are often observed in occupational settings (i.e. typing), but upper arms and trunk would then remain relatively stable. The performance of the "Ergonometer" is also reflected in the quantification of the signal which in our analyses is performed by averaging the signal over 0.5 or 1 s interval (Aarås, Westgaard and Stranden, 1986).

The "Ergonometer" was found to perform to the same standard at low-amplitude deflection. Sometimes the pendulum would perform a stacatto movement, but this was always smoothened by the electronic damping of the "Ergonometer". Slow test movements were performed to further indicate the mechanical hysteresis of the pendulum potentiometer. As shown in figure 7 the 3 output curves coincide well in all phases of the movement, but with the postural angle underrepresented by about 3° during the dynamic movements.

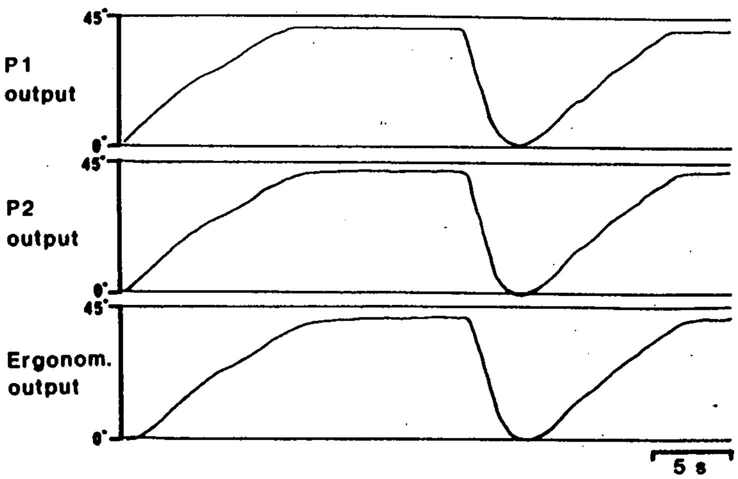

Figure 7: Similar in vitro test setup as in figure 6 for very slow movements for testing of transducer hysteresis because of internal rotational friction. Note the good correlation between the outputs. These are angular movements frequently seen at the back.

In vivo assessment.

In another test procedure the "Ergonometer" output during simulated ordinary work task was compared with video recording of the movements. Flexion of the shoulder joint was chosen for the study. The video camera was directed perpendicular to the plane of movement i.e. approximately the sagittal plane. The subject was seated and performed flexion of the shoulder joint by picking components from a component bin and assembled the parts on a table. Each maneuvre resulted in two angles – a top point angle (range 47–57°), and a low point angle (range 0–7°). The upper arm angle relative to vertical was measured on the video screen by a goniometer.

From 15 consecutive movements the difference between the video-recorded angle and the corresponding derived from the "Ergonometer" at the top point ranged between -2 and + 3°, with a mean of + 0.6°. The difference between the low point angles ranged between 0 and + 2°, with a mean of + 0.7°.

These recordings indicated that on average the "Ergonometer" underestimated slightly the angle of the real movements.

4. DISCUSSION

The "Ergonometer" seems to describe the postural angles of upper arm, head, back and neck adequately. The system is relatively simple and robust and thus well suited for field studies.

The small variation in head angle when the subjects repetitively looked at a fixed spot (Fig. 5) confirms that resting eye position is limited to a small area in the retina. Therefore the method of eye fixation is acceptable when defining zero head angle and checking the zero position after use of the "Ergonometer".

The angle transducer consists of a pendulum potentiometer. In this technique the friction force (mechanical hysteresis) of the potentiometer axis may present a source of error, especially in small smooth movements. In stacatto movements the pendulum will eventually oscillate into near-vertical position. Although we chose potentiometers with low rotational friction the viscosity of the potentiometer axis lubricant increased somewhat during the 15 months was used. Therefore the transducers were improved by applying ball bearings at the axis. Nevertheless, the change in friction was moderate, and the test for hysteresis presented in this study was performed after application series at the work places (Aarås, Westgård and Stranden 1986).

By the present technique with penduli the deflection of the body parts are referred to vertical and not to the main trunk position. For example, when bending the upper body forward while maintaining the upper arm in a fixed position relative to the horizontal plane, the arm-trunk angle increases wheras "Ergonometer" arm flexion remains constant. This may seem a source of error. However, postural angle measurements are especially useful if the recordings provide estimates of load on the musculoskeletal system. Muscle load is primary dependent on the orientation of body structures in the gravitational field. This is in fact the parameter measured by this pendulum potentiometer technique.

When postural angle measurements are used to assess work load, several limitations must be considered:

* Supporting elevated arms reduces the muscle load in the shoulder area. Chaffin (1973) showed that an elbow support reduced the load moment on the shoulders.

* Load in hands (tools, components) increase the muscular load although the angle may be unchanged.

* Angular velocity is also importent when assessing work load (Leskinen 1983).

In conclusion, measurements of postural angles with a pendulum potentiometer method seems to be acceptable both in terms of accuracy and repetability. When angle measurements are used in assessing work load, however, the limitations of the method listed above should be considered.

ACKNOWLEDGMENT

The authors wish to thank Professor Roland Ørtengren for helpful discussion when the test-procedures were designed.

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V

Postural angles as an indicator of postural load and muscular injury in occupational work situations.

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ABSTRACT

This paper explores the use of information on position of upper arm and head as an indicator of load on the shoulder and of risk of shoulder injury for workers performing electro-mechanical assembly work. Two tests were used in the evaluation of the method, by examining whether 1) development of musculo-skeletal injuries among groups of workers could be related to postural angles of the upper arm or 2) there was a correlation between the two indicators of shoulder load, position of upper arm and upper trapezius EMG. Postural angles of flexion/extension and abduction /adduction of the right upper arm in the shoulder joint as well as flexion/extension of head and back were measured by using potentiometer-sensed penduli. In most subjects EMG was simultaneously recorded from upper trapezius muscles.

The magnitude of the postural angles of the shoulder joint influenced the shoulder load. However, several parameters not quantified by postural angle measurements also increase the shoulder load independently of arm position, and must be taken into account in order to use postural angles as indicator of shoulder load. This was supported by finding a significant positive correlation between the median arm flexion and the median trapezius load for a well defined work task, a correlation which was weakened or disappeared when other work tasks with different body movements or external loads were included in the analysis.

A group of female workers adapting a posture with median arm flexion less than 15°, median arm abduction less than 10° and using a light (0.35 kg) hand tool recorded a 20% incidence of sick leaves due to shoulder injuries for workers employed 2–5 years, and a 30% incidence for those employed more than 5 years. This is a significantly lower incidence than for other groups working with higher arm flexion.

INTRODUCTION

A series of publications describing health situations and load on the trapezius muscles of workers performing electro-mechanical assembly work has recently been published. The first paper documented a high rate of musculo-skeletal illness, particularly in the shoulder and neck, among workers having to adapt postures with considerable static load on shoulder and neck muscles (Westgaard and Aarås 1984). A redesign of the work places reduced postural load on shoulder muscles while performing the major work task in the plant, and a reduction in sick leave and labour turn-over were observed (Westgaard and Aarås 1985). A group of workers employed at recent work systems recorded both reduced load on the trapezius muscles and lower rate of sick leave due to musculo-skeletal injuries than workers at the original, major work system of the plant (Aarås and Westgaard 1987).

In these studies work load on the shoulder was quantified by electromyographic recordings from the descending part of the trapezius muscle. Electromyography is advantageous in being a direct, physiological estimate of load on relevant muscles. However, the method has limitations in that the calibration procedure for evaluation of muscle force from EMG recordings is susceptible to errors. It is usually not possible to record from all relevant muscles, and a single recording from a large muscle may not represent a true estimate of force output if there is inhomogeneous activation of the muscle, nor will the recording be representative of strain on passive structures in many cases (Dul et al. 1982; Harms-Ringdahl et al. 1986).

Observation of postural angles has been used as an alternative method for quantification of postural load. The method is well established for estimating load on low back (Schultz and Andersson 1981, Schultz et al. 1982, 1983), and has also been used for quantifying load on shoulder and neck (Corlett et al. 1979, Hünting et al. 1980, Grandjean et al. 1983, Kilbom et al. 1986). Observation of postural angles requires less specialized knowledge and has an easier calibration procedure than electromyography.

The method has the potential of providing a general indication of load on body segments, including load on passive structures which may be important for the development of pain and discomfort (Harms Ringdahl 1985).

This paper explores the use of information on position of upper arm and head as an indicator for load on the shoulder. Two tests have been used in the evaluation of the method, by examining whether:

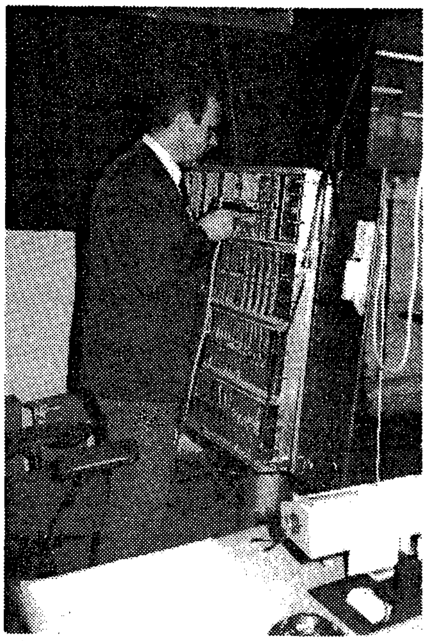
1) development of musculo-skeletal injuries among groups of workers can be related to postural angles of the upper arm, or
2) there is a correlation between the two indicators of the shoulder load, position of upper arm and upper trapezius EMG.

The work situations allowed identification of several groups of workers with different rates of musculo-skeletal injuries, establishing the basis for the first test. Correlations between arm position and trapezius load has already been demonstrated in controlled laboratory experiments (Hagberg 1981 a and b, Sigholm et al. 1984), the latter test concerned such correlations during the much less controlled conditions prevailing with occupational work tasks. Preliminary results of this study has already been published (Aarås et al. 1987).

METHODS

A system for continuous recording of flexion/extension of the back, head and neck as well as flexion/extension and abduction/ adduction of the right arm is described in a separate paper (Aarås and Stranden 1987). The postural angles were recorded as deviations from the reference body position: a well-balanced upright position with relaxed shoulders and the upper arm hanging relaxed along the body. Zero head angle was defined by a horizontal sight line fixation. Neck angle was calculated as the difference between head and back angles. The reference position when readapting this posture was found to vary only by a few degrees. The measuring performance of the equipment was also acceptable for oscillatory movements at moderately slow angular velocity (less than 20 degrees per second), which included virtually all assembly work in our study.

Postural angles were recorded from 14 subjects, 6 working at the 8B system (Fig. 1A), 3 at the 10C system (Fig. 1B), 3 at the 11B system (Fig. 1C) and 2 at the CF (cable making) system. A more complete description of the different work systems is given by Westgaard and Aarås (1984). Simultaneous recordings of surface EMG from the trapezius muscles were performed for 5 of the subjects at the 8B system, 3 at the 10C system, 3 at the 11B system and 2 at the CF system. The stature for the 6 subjects at the 8B system varied between 155 and 175 cm, mean 162 and SD 6,7 cm.



and the 11B system

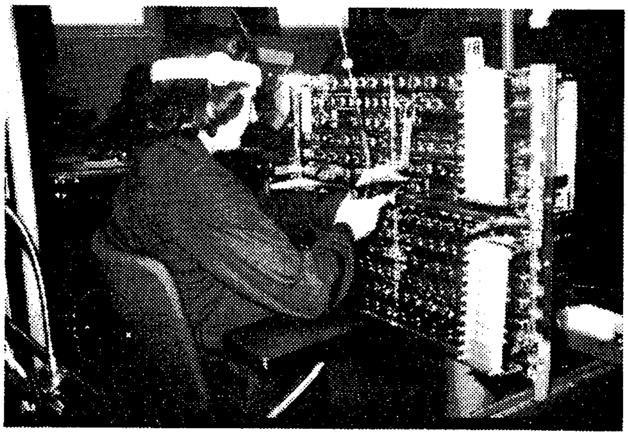


Figure 1. Working postures at the 8B system

the 10C system

The system for recording and quantification of surface EMG has been described elsewhere (Westgard 1987). The output signals from the angle measuring equipment "Ergonometer" were stored on a 14-channel tape recorder (Racal Store-14) and later analysed on a mini computer system (PDP 11/73). The analysis was based on digital averaging of the signals over 0.5 second intervals, resulting in discrete values which were a measure of average postural angle in this interval.

The quantitative analysis of postural angles was carried out by ranking the interval estimates of the postural angles to produce a cumulative amplitude distribution function, similar to that often used for quantification of electromyographic recordings (Jonsson 1982). The amplitude probability given by this function indicates time fraction of the recording period with the signal lower than or equal to a given level. Median postural angle is defined as the postural angle corresponding to probability level 0.5. Probability level 0.1 and 0.9 defines "static" and "peak" angle, respectively.

Epidemiological methods and material are similar to those of preceding papers (Westgaard and Aarås 1984, 1985; Aarås and Westgaard 1987). The present paper also includes statistics on the development of sick leave due to musculo-skeletal injuries in the low back. The incidence was calculated as the fraction of workers with one or more sick leaves due to such injuries relative to the total number of workers at risk in different time intervals (time of employment). This statistics establish a basis for evaluation of health effects related to flexion/extension of the back in the sagittal plane.

Pearson correlation analysis was used to evaluate the relationship between flexion in the shoulder joint and load on m.trapezius.

RESULTS

Postural angles at the 8B system.

At the 8B system the wiring task was performed at a vertically mounted frame, 100 cm wide and 40 cm (6 rows) to 80 cm (12 rows) high. When performing the wiring operation, the work area was limited to about one cm^2 at a time, but with the work height increasing in a stepwise manner from row one at the bottom to row 12 at the top of the frame. The wire was placed in a wrapping gun which was positioned onto the terminal. The wrapping gun then spun the wire around the terminal.

Continuous recordings of the different postural angles, working in the redesigned and original work situations, are shown in Fig. 2 for one of the subjects. The movement of the upper arm in the sagittal plane started in extension and moved forward to flexion when working upwards on the frame from row one to row 12 at the new, adjustable work place (Fig. 2A).

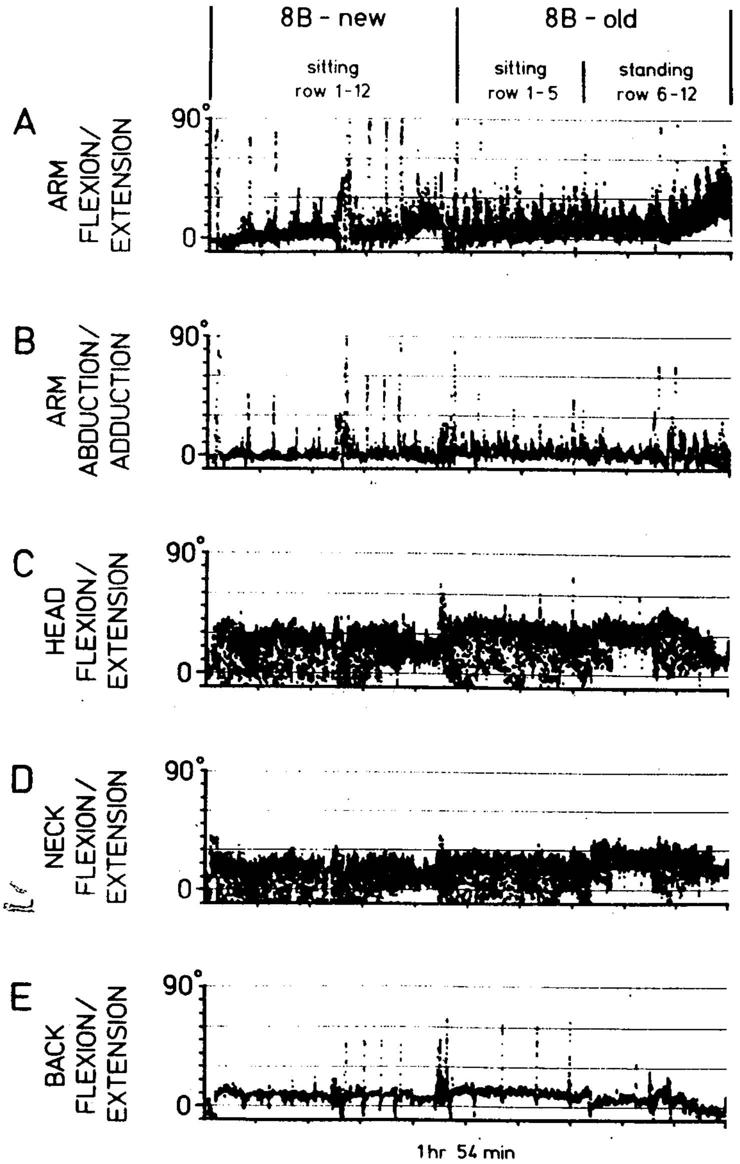


Figure 2. Postural angles from an 1 hr. 54 min. recording at the 8B system. Each point in the recording indicates mean angle in 0.5 second intervals. The subject was working first in the redesigned work situation from row 1 (low) to row 12 (high), then on the same rows in the original work situation. Work postures are indicated on top of the figure.

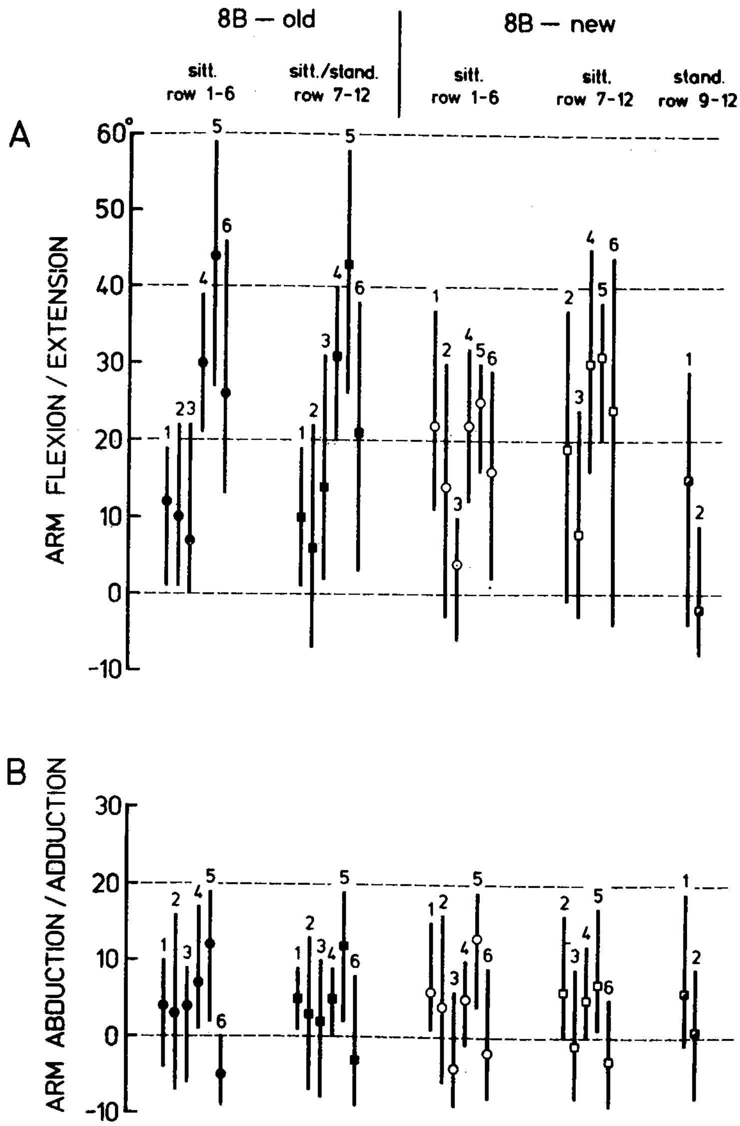


Figure 3. A. Median flexion/extension of the right arm in the shoulder joint when working at low (filled circles) and high (filled squares) rows at the original 8B system, and low (open circles) and high (open and semi-open squares) rows at the redesigned 8B system. Working postures are indicated above each group of symbols. "Static" and "peak" flexion/extension (see Methods for definitions) are indicated by lower and upper end points of the bars. The numbers on top of each bar identifies different subjects. B. Arm abduction/ adduction, recorded simultaneously with arm flexion/extension.

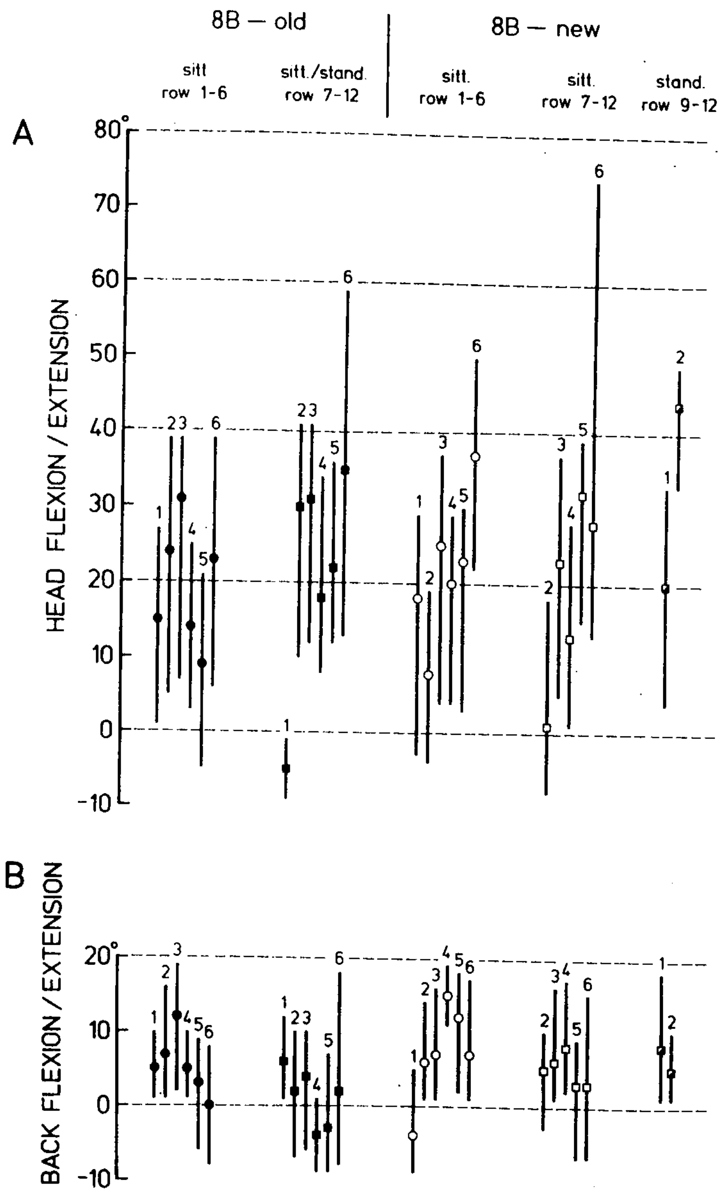


Figure 4. Head flexion/extension (A) and back flexion/extension, recorded simultaneously with results in Fig. 3. See Fig. 3 for definition of symbols.

Throughout this work cycle stepwise adjustment of the working height was performed, but was limited by the position of the thighs underneath the frame, when working at the highest rows with a seated posture. This restriction, together with the considerable height of the frame, caused an increase in static flexion of the arm when working at the upper quarter of the frame. In the old, original situation it was necessary to work at least partly in a standing posture at the upper half of the frame. When comparing arm flexion in new and old work situations, this parameter had rather similar values at lower rows, but was increasing much more steeply during work towards the top of the frame at the original work place. The short periods with flexion up to 90° occurred when the subject was lifting and fastening the cableform within the frame. Arm abduction during the same recording was low and rather invariant (Fig. 2B), indicating that the main arm movement was in the sagittal plane, except for short periods with large abduction occurring simultaneously with the large flexion movements.

The head showed a predominant forward flexion of about 30°, but returned repeatedly to a neutral position when the subject was reading the instruction sheet on top of the frame. The slow movement of the head towards less flexion when the working height is increasing at the end of the recording should also be noticed. The back showed little variation in posture, maintaining a forward flexion of about 10° during the recording. Neck flexion/extension is simply the difference between head and back position.

Figs. 3 and 4 present results from all recordings at the 8B system. The recording from each subject is divided into a maximum of 5 sections according to work task: seated posture at rows 1 to 6 of the original work place, seated or standing posture at rows 7 to 12 of the original work place, seated posture at rows 1 to 6 of the redesigned work place, seated posture at rows 7 to 12 of the redesigned work place, and standing posture at rows 9 to 12 of the redesigned work place. High and low rows are considered separately due to the considerable difference in working height. For each subject and work task the median postural angle is indicated by a symbol, and probability levels 0.1 ('static' angle) and 0.9 ('peak' angle) by lower and upper end points of the bars. The bars thereby show variability of the postural angles at the 10 to 90% level. Numbers on top of each bar identify the different subjects, the recording shown in Fig. 2 is from subject no. 3.

Fig. 3 confirms that arm flexion/extension (Fig. 3A) is the dominant arm movement and that most work tasks were performed with the arm extended in front of the body. The 10 to 90% variability range for each subject/work task is much larger for arm flexion than for abduction. Median arm flexion vary between -2° (extension) and 44° for different subjects and work tasks, compared to the much smaller values of −5° (extension) to 13° for arm abduction (Fig. 3B). The comments below are therefore limited to the flexion/extension movement of the arm.

Interindividual variability of arm flexion remains a dominant feature also when only one work task and work situation is considered. This variability reflects the fact that the same work task may be carried out at many different postures. When working at the lower rows with the original work situation, subjects 1–3 performed the work task with little arm flexion (median flexion 7 to 12°), while subjects 4–6 recorded much higher arm flexions (median flexion 26 to 44°). This variability was not related to the stature of the subjects.

When performing the same work task at high rows in the original work situation, arm flexion remained largely unchanged relative to lower rows for most subjects. However, the considerable forward flexion of the arm while working at the top rows is not well represented by the quantification process, due to averaging of the postural angle for all rows 7 to 12. The steep increase in arm flexion angle for subject no. 3 (Fig. 3A) towards the end of the recording is only reflected as an increase of less than 10° in median and peak values, relative to the comparable values for the lower rows.

When working at lower rows of the redesigned work stand, a considerable reduction in forward flexion is observed for those recording high values in the original situation (subjects 4 to 6). This difference between original and redesigned work situations is less noticeable when working seated at high rows, mainly because the subjects adapted a standing posture at the original work stand whereas height adjustment was restricted when working seated in the redesigned work situation, due to thighs under the work piece.

Only two subjects chose a standing posture at the redesigned work stand, subject 1 for rows 9 to 12 and subject 2 for row 12. Both recorded very moderate arm flexion/extension when standing, with median angle of subject 2 showing 2° of extension. This is probably due to the restriction of this posture to work on the top row where visibility from above is good, allowing the frame to be positioned at a very low level.

Head position also showed considerable variability (the range of median values were from 5° of extension to 44° of flexion) while performing work at the 8B system (Fig. 4A). There is a tendency of increased flexion when working at the higher rows in the original work situation, again a reflection of the change from seated to standing posture. There is little change in head position from original to redesigned work situation. The low position of the frame for subject 2 when standing in the redesigned work situation, is confirmed by the large forward flexion of the head.

Back flexion/extension showed little variability, with median values ranging from – 4° (extension) to 15° (flexion). A tendency of reduced flexion is observed when working at high rows, relative to low rows, both in the original and adapted work situation.

Postural angles at the 10C system.

At the 10C system wiring of terminals was performed seated within an almost vertical area of 30 by 60 cm for about 35% of the work time. In another 50% of the work time wiring was carried out in a standing position with the frame placed horizontally. The work area was then 200 by 60 cm (Fig. 1B).

Fig. 5 shows a representative recording of postural angles while working at this system, the subject first adapting a standing posture with the frame placed horizontally, then seated with the frame in a near vertical position. Work in the standing position was mostly performed with extension in the shoulder joint, whereas most of the work in the sitting position was carried out with the arm close to neutral position (Fig. 5A).

The arm was abducted throughout the whole recording period, but with more variability in standing posture (Fig. 5B). This difference between seated and standing posture is more pronounced for head position, where median forward flexion is much larger when standing, due to the requirement of looking down on the frame (Fig. 5C).

Median back flexion is somewhat reduced from standing to seated posture, but the main feature is again reduced variability of the postural angle (Fig. 5E). Neck flexion is calculated as the difference between head and back position, and corresponds largely to head flexion.

Fig. 6 shows median values and 10 to 90% variability range of postural angles for 3 subjects at the 10C system, working with seated and standing postures. The small number of subjects makes a general evaluation of postural angles at this system difficult. However, median arm flexion varies between 0 and 28° with seated and between -14° and 7° with standing posture, which is less than found at the original 8B system. Extension is the dominant arm position in the sagittal plane for the most common, standing posture. This is reversed when seated, when the arm is often held in flexion. Two subjects recorded reduced arm flexion with standing relative to seated posture (Fig. 6A). Median abduction varied between 0° and 19° (Fig. 6B). Head flexion is higher than for the 8B system, especially for the dominant standing posture (Fig. 6C). Median back flexion varied between 2 and 19°, 2 subjects recording increased flexion with standing posture (Fig. 6D).

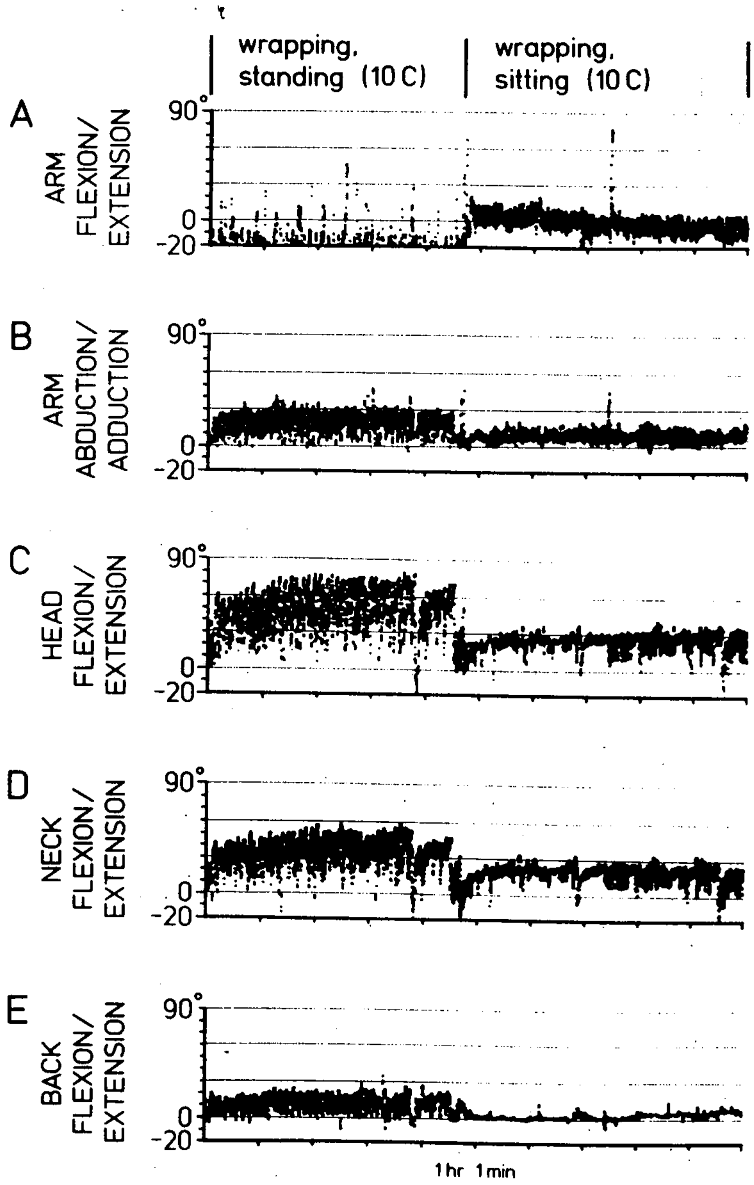


Figure 5. Postural angles from an 1 hr 1 min. recording at the 10C system, the subject first adapting a standing, then a seated posture. Each point in the recording indicates mean angle in 0.5 second intervals.

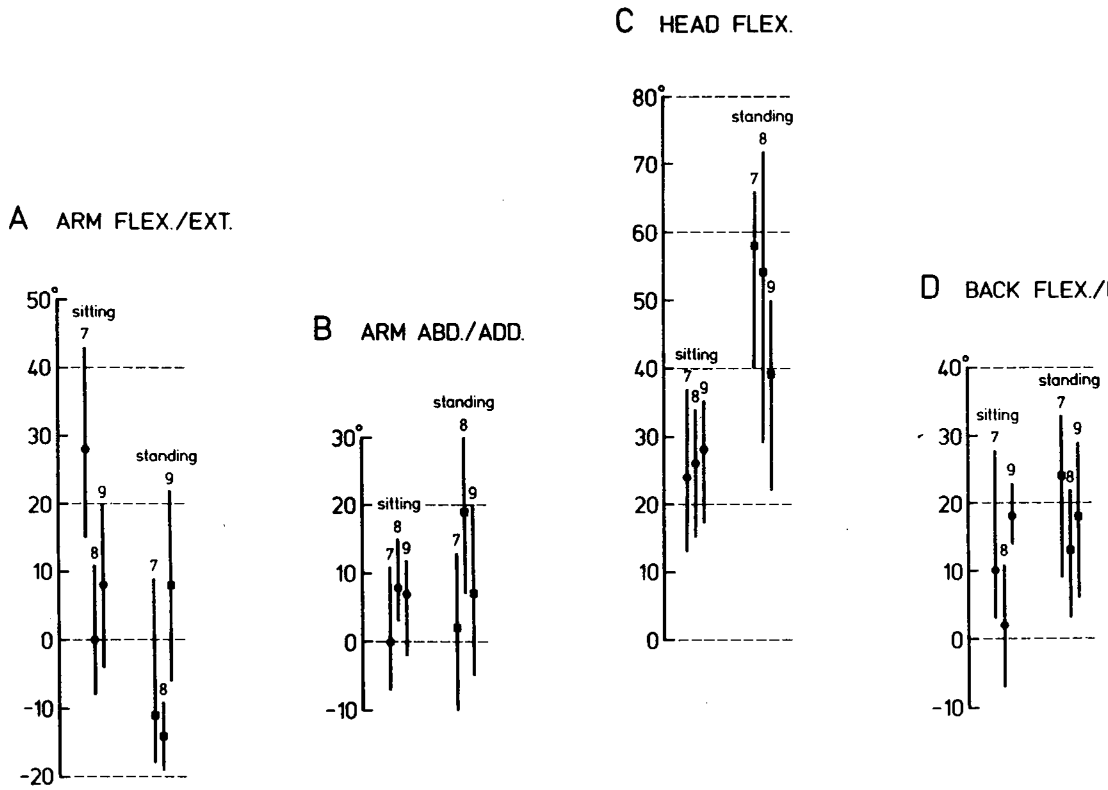


Figure 6. Arm flexion/extension (A), arm abduction/ adduction (B), head flexion (C) and back flexion/ extension (D) at the 10C system for sitting (filled circles) and standing (filled squares) postures. Median, "static" and "peak" angles are indicated, simularly to Fig. 3.

Postural angles at the 11B system.

About 80% of the working time at this system was used for wiring within an almost vertical frame, consisting of four shelves mounted on top of each other (Fig. 1C). For 60% of the time the connections were made within one shelf, representing a work area of 78 by 20 cm, while 20% of the time was used to connect terminals between different shelves. The work area was then maximum 78 by 100 cm. Wiring restricted to the two lowest shelves, accounting for less than 20% of total work time, was usually performed seated while the rest of the wiring work had to be performed in a standing posture.

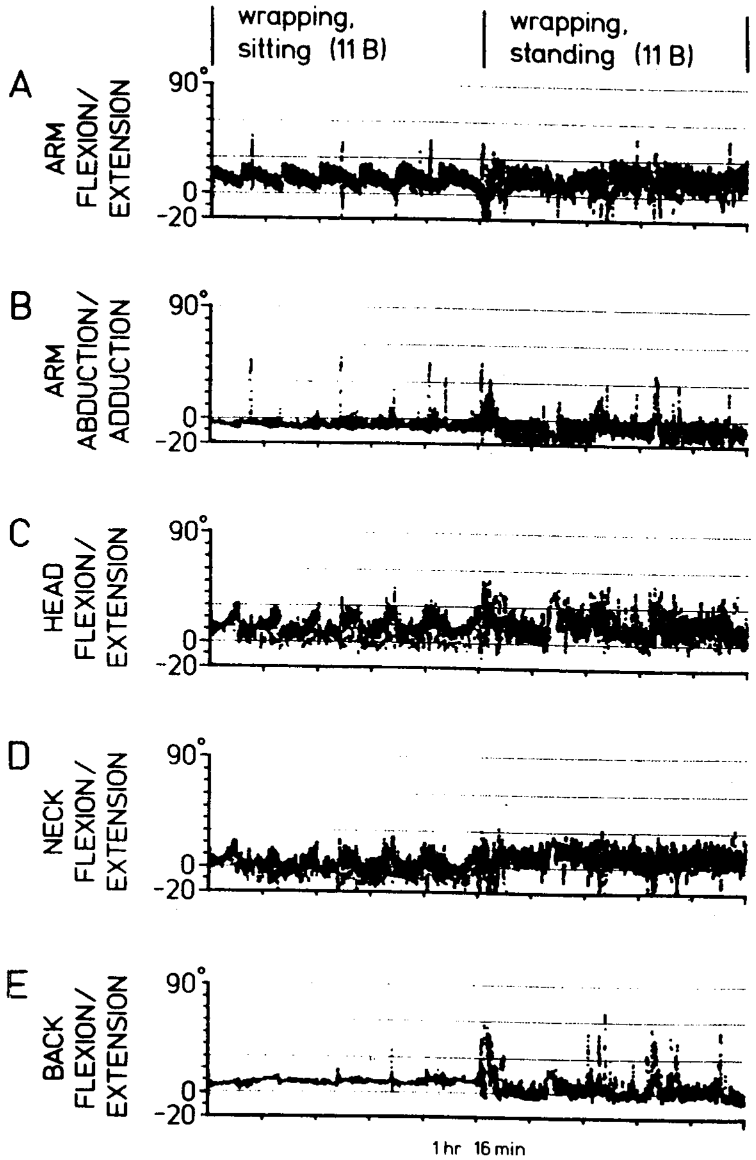


Figure 7. Postural angles from an 1 hr 16 min. recording at the 11B system, the subject first adapting a sitting, then a standing posture. Each point in the recording indicates mean angle in 0.5 second intervals.

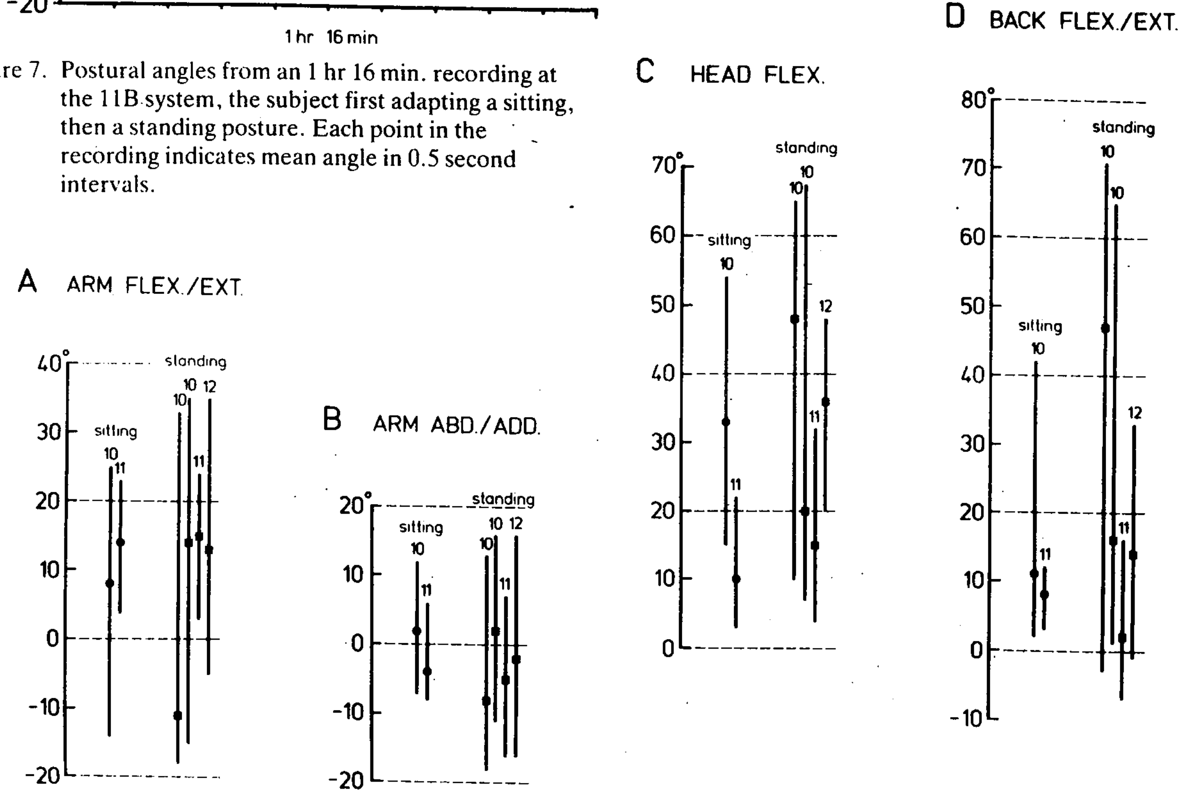


Figure 8. Arm flexion/extension (A), arm abduction/ adduction (B), head flexion (C) and back flexion/ extension (D) at det 11B system for sitting (filled circles) and standing (filled squares) postures. Median, "static" and "peak" angles are indicated, similarly to Fig. 3.

Fig. 7 shows a 1 hr 16 min recording of postural angles while working at the 11B system. Work was first performed seated at the 2nd lowest shelf, then standing at the top shelf. The postural angles were moderate throughout the recording, indicating a well-balanced posture. A rythmicity in arm flexion is seen when seated, indicating a repeating work pattern. However, arm flexion was less than 30° at virtually any time during the recording.

Fig. 8 shows postural angles of 3 subjects working seated and/or standing at the 11B work system, the recording in Fig. 7 corresponding to subject no. 11. The most striking feature of Fig. 8 is the considerable variability of postural angles between subjects. This is to a large extent a reflection of differences in work tasks within the same system. Subject no. 10 performs wiring between the two lowest shelves with seated posture, then with standing posture wiring first between the top and the 2nd shelf (working height 85 to 160 cm), thereafter between the two middle shelves. The work tasks of subject 11 are already mentioned, while subject 12 performed wiring between the two middle shelves with standing posture.

Fig. 8 indicates considerable variation in posture for subject 10 when performing the first standing work task. The lower working height of 85 cm in standing necessitated extreme forward flexion of the head and back, reflected in median values of 47° and 48° for these angles. The subject could not use a sitting posture due to the requirement of immediately thereafter moving to 160 cm working height. The same pattern of movement was continued when wiring in the more restricted work area of the two middle shelves, where the 10 to 90% variability of head and back flexion is largely unchanged, but a substantial reduction in median angles recorded. Median flexion of the arm is generally lower than at the old 8B system, and median arm abduction is close to neutral position. The range of movement of the upper arm in the sagittal plane shows that work to a large extent was performed with the arm alternating between flexion and extension for the three subjects at this system.

The requirement of accuracy of the arm movements and the position of the lower arm were similar for work on the original 8B system and the adapted 10C/11B systems. These are factors which normally will influence the shoulder load, although not quantified by recording the postural angles of the upper arm. Another important factor is the weight of hand-held tools, and the wrapping gun was about 0.5 kg heavier at the original 8B system than at the adapted 10C/11B systems, where the weight of the wrapping gun was 0.35 kg.

Correlation between postural angles and trapezius load.

A comparison of postural angles of the arm with the other available shoulder load estimator, upper trapezius EMG, provides a more direct test of postural angles as an indicator of shoulder load. Both arm flexion and abduction have been shown to correlate with trapezius load. However, in most of the present recordings arm abduction was low and nearly invariant, allowing a simple comparison of arm flexion with trapezius EMG.

If suitable sections of recordings from the work place is selected, laboratory conditions are approximated. As an example, Fig. 9A-D show a 15 min. simultaneous recording of arm flexion, rectified and integrated trapezius EMG, arm abduction and head flexion while the subject in a standing posture is working up towards the top of the frame at the original 8B work situation. A steadily inclining arm flexion was recorded, only interrupted by a short pause near the end of the record. Trapezius EMG largely followed the same pattern. Arm abduction was nearly constant at about 5°. Head flexion was negatively correlated with arm flexion, as the increase in working height allowed the head to straighten up. It is also seen that head flexion was negatively correlated with load on the upper trapezius muscle, indicating that arm position is more important than head position in determining load on this muscle.

Fig. 9E shows a xy-plot of arm flexion and trapezius EMG, based on data from Fig. 9A, B. A linear regression between the two parameters is suggested, with an increase in trapezius load of about 2% MVC for an increase in arm flexion of 10°. Three subjects with almost no abduction in the shoulder joint during work at the 8B system showed a similar correlation, indicating that the two load measurements may substitute for each other when recording from specific work situations. However, a considerable variability in the arm flexion-trapezius load relationship should be noticed. Also, the regression for one subject became curvilinear above about 30° of arm flexion, with trapezius EMG increasing relatively faster with increasing arm flexion.

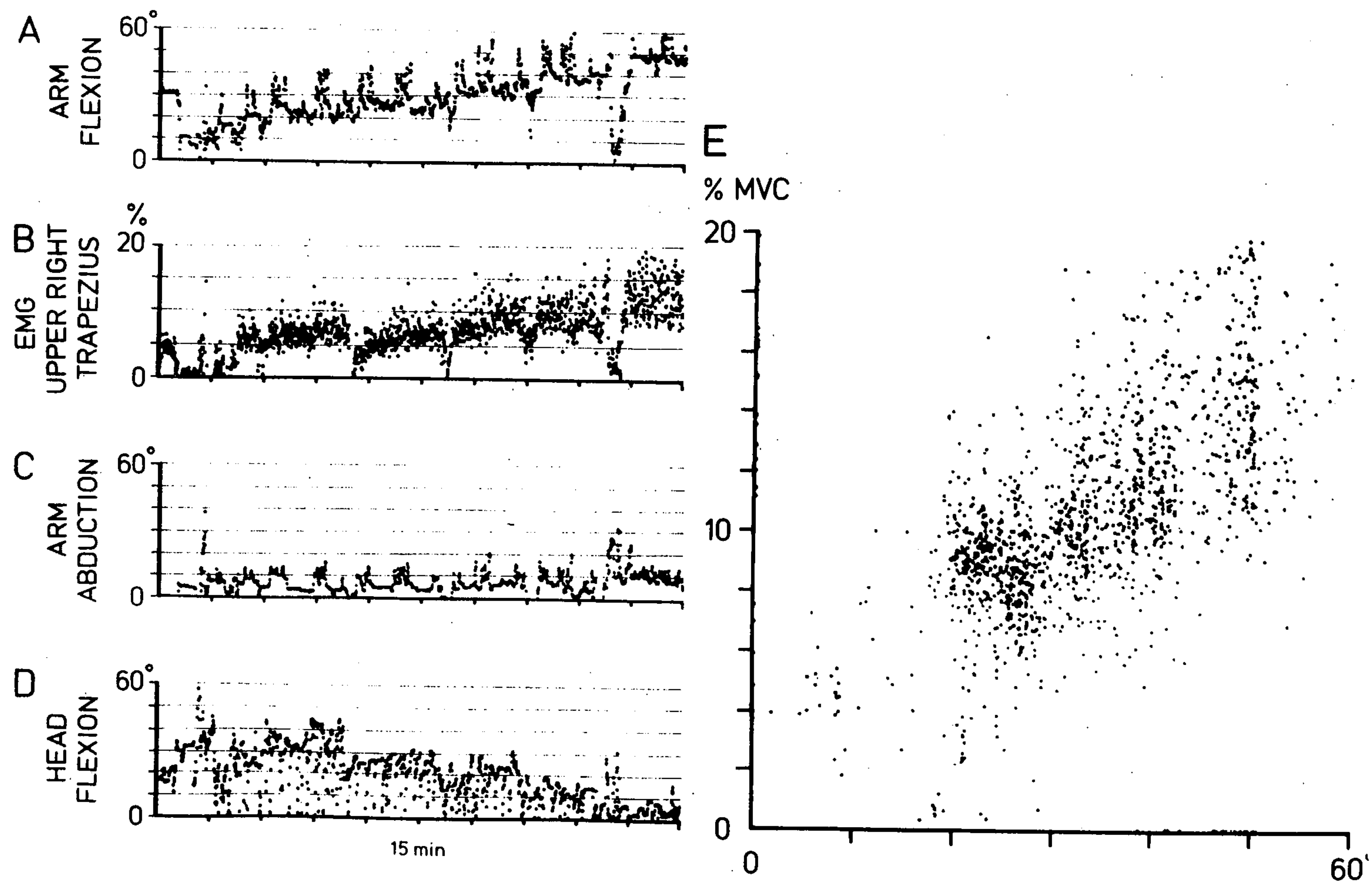


Figure 9. Arm flexion (A), EMG from upper right trapezius (B), arm abduction (C) and head flexion (D), recorded simultaneously while working at progressively higher rows at the original 8B system. Each point in the recording indicates mean angle or full-wave rectified and integrated EMG values in 0.5 second intervals. The EMG values are calibrated in percent of maximal volentary contraction (Westgaard 1987). E. XY-plot of arm flexion angle vs. trapezius EMG, based on data in Fig. 9A and B.

When considering all segments of recordings from the 8B system with relatively stable values of arm flexion and trapezius EMG, including seated and standing postures at original and redesigned work situations, a correlation between trapezius EMG and flexion of the arm is still evident. This is shown in Fig. 10 where filled circles indicate median values of arm flexion and trapezius EMG for different sections of 8B recordings. The regression line indicates a trapezius load of 4.1% MVC at zero arm flexion and an increase in trapezius load of 1.3% MVC for 10° arm flexion. The Pearson correlation coefficient was $r = 0.65$, $p < 0.01$.

Corresponding values for the 11B system tend to cluster at low flexion angles, high trapezius load. Values from the Cable making system (Westgaard and Aarås 1984) cluster at high flexion angles, low trapezius load. If values from the 11B and CF systems are considered together with the 8B values, there is no longer any sign of a correlation between the two indicators of shoulder load.

Sick leave statistics.

Previous papers have presented statistics on total sick leave due to musculo-skeletal illness and on sick leave due to pain and discomfort located to the shoulder and neck region for female workers at the 8B, 10C and 11B systems.

The fraction of workers with sick leave due to injuries of the low back was 5%, 10% and 5% for workers employed less than 2 years, 2–5 years and more than 5 years at the 8B system. The comparable values for workers at the 10C/11B systems were 0%, 4% and 0%, respectively.

DISCUSSION

The position of the arm is of major importance for the load characteristics of active and passive structures associated with the shoulder joint, and also for other structures of the shoulder girdle. Postural angles of the arm together with information on external loads may be the only possible load estimator for substructures of the shoulder joint itself. However, the query remains whether postural angles can be used as a risk estimator for development of shoulder injuries in occupational work situations. This use of postural angles is no longer an absolute measurement of load on the shoulder, but a relative measurement relating to load tolerance of the most sensitive structure under strain.

A general test of postural angles as risk estimator for shoulder injury is to compare postural angles of the arm for groups of workers, known to develop occupational shoulder injuries at different rates. Our material allows two such comparisons: original and redesigned work situations at the 8B system where the health situations is known to improve for workers at the redesigned work places. The same subjects performing the same work task in both work situations and with at least one recorded musculo-skeletal sick leave, showed a significant reduction of such sick leave (as a median duration per man-labour years) from 22.9 days in the original situation to 1.8 days in the redesigned one ($p < 0.02$, Aarås and Westgaard 1987). In a comparison of workers at the original 8B system (1967–1974) vs. workers at the 10C/11B systems (1975–1983), there was a statistically significant difference in the incidence of musculo-skeletal sick leave between subjects of the two groups with time of employment more than five years ($p = 0.05$). In both cases the workers have subjectively related the development of shoulder injuries to conditions at work, and the difference in health effects to the different ergonomic conditions of the original and redesigned work places.

In this comparison it was possible to concentrate on the flexion/ extension of the right arm in the sagittal plane, as arm abduction was low and largely invariant between workers at

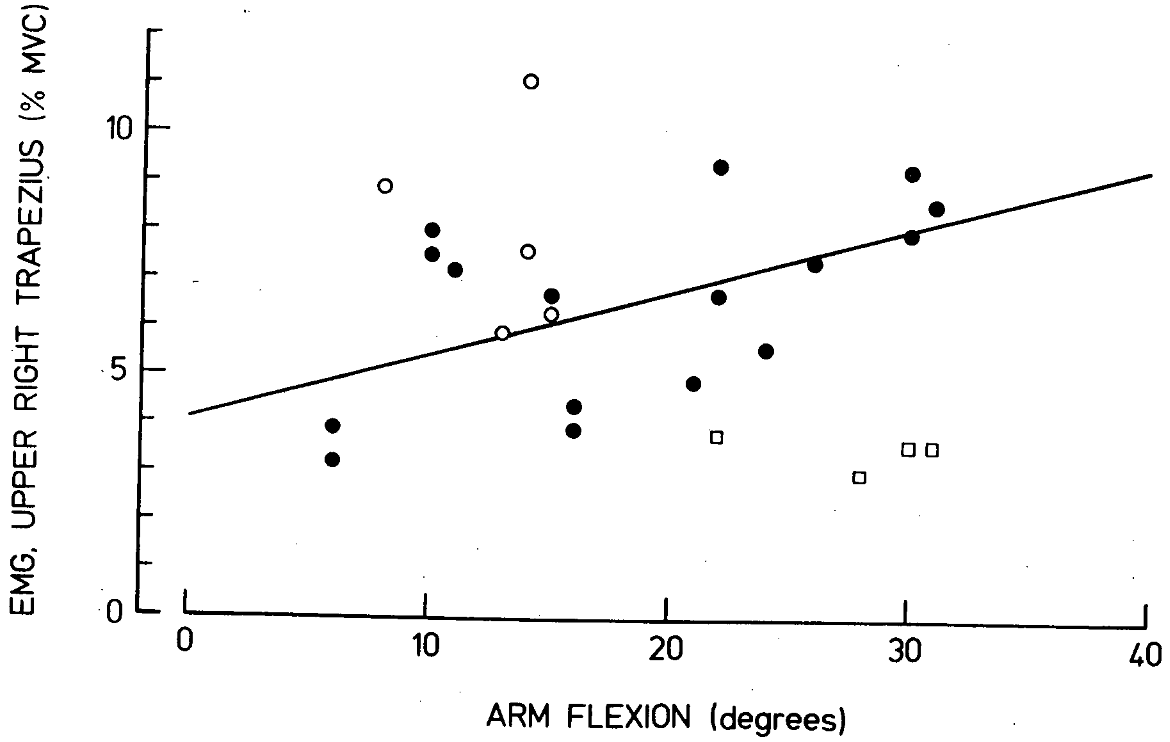


Figure 10. Corresponding values of median arm flexion in the shoulder joint and full-wave rectified and integrated median EMG values from the upper trapezius muscle when working at the original or redesigned 8B system (filled circles). Each point is based on stable sections of recordings of at least 10 min. duration. A regression line is shown to indicate correlation between these two parameters. Similar values for cable making (open squares) and the 11B system (open circles) are also shown.

different systems. The results were quite clear with regard to group effects. There was no statistically significant reduction in arm flexion for workers at the 8B system when they transferred from the original to the redesigned work situations. There was a tendency, but not significally so, of workers at the 10C/11B systems to adapt postures with lower arm flexion than for workers at the original 8B system. These conclusions relate to both median, "static" and "peak" values for arm flexion/extension.

However, when examining the results more closely, a less negative result emerges. The weight of the hand tool was reduced from 0.85 kg to almost nil from the original to the redesigned 8B work system by introducing a new wrapping gun which was counterbalanced. The counterbalancing system was not always used, but the wrapping gun was itself 0.5 kg lighter. Arm rests were introduced at the redesigned work system, and these were used to a large extent. Thus, there would be a reduction in shoulder load from the original to the redesigned 8B work system due to the reduction in external loads, independently of changes in arm position.

Workers with high flexion angles in the original work situation tended to reduce forward flexion of the arm in the redesigned work situations, while workers with low flexion of the arm in the original work situation tended to work with somewhat increased flexion angles in the new work situation. Thus, workers with uncomfortable postures due to excessive arm flexion in the original work situation, used the height adjustment of the redesigned work stands to reduce shoulder load. Workers with moderate arm flexion in the original work situation presumably achieved load reductions through other facilities of the redesigned work stand, such as the arm rests.

A seated posture was usually preferred in the redesigned work situation. This is in agreement with practical experience from working life, where a majority of workers prefer to remain seated despite increased load on the shoulder muscles. Working in a seated position offers advantages, such as improved precision and stability in addition to increased mobility of legs and feet (Grandjean 1980), less energy expenditure and less load on the legs compared to the standing position. However, two workers adapted a standing posture at the redesigned work place, both recording very low arm flexion. This is likely to be a general result. A significant feature of the new work stand would therefore be that it allows work to be carried out with a minimum of shoulder strain, by adapting a standing rather than seated posture.

Workers at the 10C and 11B systems also had the benefit of the lighter wrapping guns. Furthermore, the movement pattern of the arm in the sagittal plane spanned both extension and flexion, while workers at the original 8B system maintained their arm in a flexed posture throughout the working day. The more varied movement pattern at the 10C/11B systems may have created an alternating load pattern of some of the muscles being primary movers, thereby protecting these from overexertion. These factors may help explain the lower rate of shoulder illnesses among workers at the 10C/11B systems, relative to the original 8B system. Besides, the tendency of lower flexion angles for workers at the 10C/11B systems may become significant if the measurements were extended to more subjects.

The above comments highlights some of the problems in using postural angles as load estimators. Several parameters such as external loads (Chaffin 1973, Ashton-Miller 1986), the use of supports (Chaffin 1973), position of lower arm (Sigholm et al. 1984), shoulder elevation, speed and accuracy of movement (Westgaard and Bjørklund, 1987) and general muscle tension components (Jacobson 1944 , Westgaard and Bjørklund 1987) may contribute an increased load on the shoulder and thereby to an increased risk of developing shoulder illnesses.

These parameters are not quantified by postural angle measurements and must be taken into account separately. In contrast, muscle load measurements by electromyography, being a physiological measurement of muscle tension, automatically takes all such factors into account.

There are other problems in the use of EMG for estimating postural load, mentioned in the *Introduction*. However, in similar measurements of shoulder load using trapezius EMG as a load estimator, a reduced load was observed both for the redesigned 8B system relative to the original one and for the 10C/11B systems relative to the original 8B system (Aarås and Westgaard 1987). These results are consistent with the observed health effects.

Further support of a quantitative relationship between trapezius load and risk of developing an occupational illness is provided by results from other projects (Westgaard et al. 1986; Westgaard 1987).

A direct comparison of the two estimates of shoulder load in these work tasks, trapezius EMG and postural angles of the arm, was also performed. The result seemed clear: in work situations with standardized movements, a correlation between arm flexion and trapezius EMG was demonstrated, as it has been in laboratory studies (Hagberg 1981a, Sigholm et al. 1984). When different work tasks within the same work system were considered, the correlation remained, but had weakened. There was no longer any correlation between arm flexion and trapezius EMG if all results from different work systems were included. Thus, the two estimators of shoulder load recorded similar effects when minor, well-defined changes in arm position were performed, but did not substitute as general load estimators without consideration of parameters influencing the shoulder load, but not quantified by arm position.

Workers at cable making performed dynamic, almost ballistic arm movements when laying wires onto the cable form, nor did they carry the weight of tools. Hence the low trapezius load with high arm flexion. It is more difficult to explain the results from the 11B system. Workers at this system used the lighter wrapping gun, which would reduce the trapezius load for an unchanged flexion angle of the arm. More significantly, the large vertical working area of the 11B system, relative to the original 8B system, may have generated an increased element of shoulder elevation with the corresponding arm movement, resulting in increased trapezius load relative to the arm flexion angle.

However, postural angles seem to be the parameter most readily available for evaluating changes in postures as a result of ergonomics redesign of the work places. A reduction of arm flexion or abduction will certainly signify reduced shoulder load if other constraints or external loads are not introduced.

A suggested threshold level for acceptable mechanical load on the shoulder should consider both intensity and duration of such loads, as well as duration of necessary pauses between periods with prolonged mechanical load. It appears difficult to suggest limits for a safe level of arm position independently of the work pattern. Workers at the 10C/11B systems recorded a median arm flexion of less than 15° for 11 of 12 recordings. The development of musculo-skeletal sick leave due to shoulder injuries according to time of employment approximated the incidence of musculo-skeletal illness, regardless of body location, for a group of female workers without continuous work load (figure 15C of Westgaard and Aarås 1984). The weight of the hand tool (0.35 kg) would add to the load on the shoulder, but many workers use tools of at least this weight. Thus, a median arm flexion angle of 15° and a median arm abduction of less than 10° are beginning to approximate an acceptable arm position for continuous work tasks, when the external load is low. These values are much lower than limits for these angles proposed elsewhere (Chaffin and Andersson 1984).

Trapezius load was much less dependent on neck flexion than arm position, in agreement with the results of Harms-Ringdal et al. (1986). They also showed that EMG of neck muscles is not strongly related to the forward flexion of the head. Thus, EMG recordings of load on neck muscles are not valid estimators of neck strain.

Further support for these results are provided by Dul et al. (1982), indicating that the force which is counteracting the forward turning moment of the head at spinal level C7-Th1, is distributed between active muscle tension and passive muscle and ligament forces. Neck strain due to forward flexion of the head may therefore be best quantified by measuring neck (or head) angle. Workers at the 10C system performed wiring with median neck flexion varying between 19 and 39°. The corresponding range for head flexion was 39 to 58°. The low incidence of musculo-skeletal sick leave in the neck and shoulder region for workers at the 10C system, performing work with the above mentioned postural angles in the shoulder joint and neck/head flexion, indicates that the tolerable level of neck flexion in the sagittal plane may be higher than 15°, as recommended by Chaffin (1973).

Finally, our results are consistent with the suggestion by Jørgensen (1970) that most individuals are able to maintain a stooped posture with 20° forward inclination of the back. Median flexion of the back for workers at the 8B system ranged from -5 ° (extension) to 15°, and about 8% of the workers recorded a musculo-skeletal sick leave due to low back problems. There was no trend toward a higher rate of such injuries for workers with long periods of employment.

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