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

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This paper explores the use of information on the position of the upper arm and head as an indicator of load on the shoulder and of risk of shoulder injury for workers performing electromechanical assembly work. Two tests were used in the evaluation of the method, examining whether or not: (1) the development of musculo-skeletal injuries among groups of workers could be related to postural angles of the upper arm, and (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 the head and back were measured using potentiometer-sensed pendulums. In most subjects, electromyography (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 alone as an 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 adopting a posture with a median arm flexion of less than 15°, a median arm abduction of 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.

1. Introduction

A series of publications describing health situations and load on the trapezius muscles of workers performing electromechanical 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 adopt postures with considerable static load on shoulder and neck muscles (Westgaard and Aarås 1984). A redesign of the workplaces reduced postural load on shoulder muscles, and a reduction in sick leave and labour turnover were observed (Westgaard and Aarås 1985). A group of workers

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employed at recent work systems recorded both a reduced load on the trapezius muscles and a 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 limitation 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 the low back (Schultz and Andersson 1981, Schultz *et al.* 1982, 1983), and has also been used for quantifying the load on the 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. Further, recording of postural angles of a joint makes it possible to calculate biomechanically the joint moment, which include the load on muscles and passive structures. Both tissues may be important for the development of pain and discomfort (Harms-Ringdahl 1985).

This paper explores the use of information on the position of the upper arm and head as an indicator of load on the shoulder. Two tests have been used in the evaluation of the method, and these examined whether or not:

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

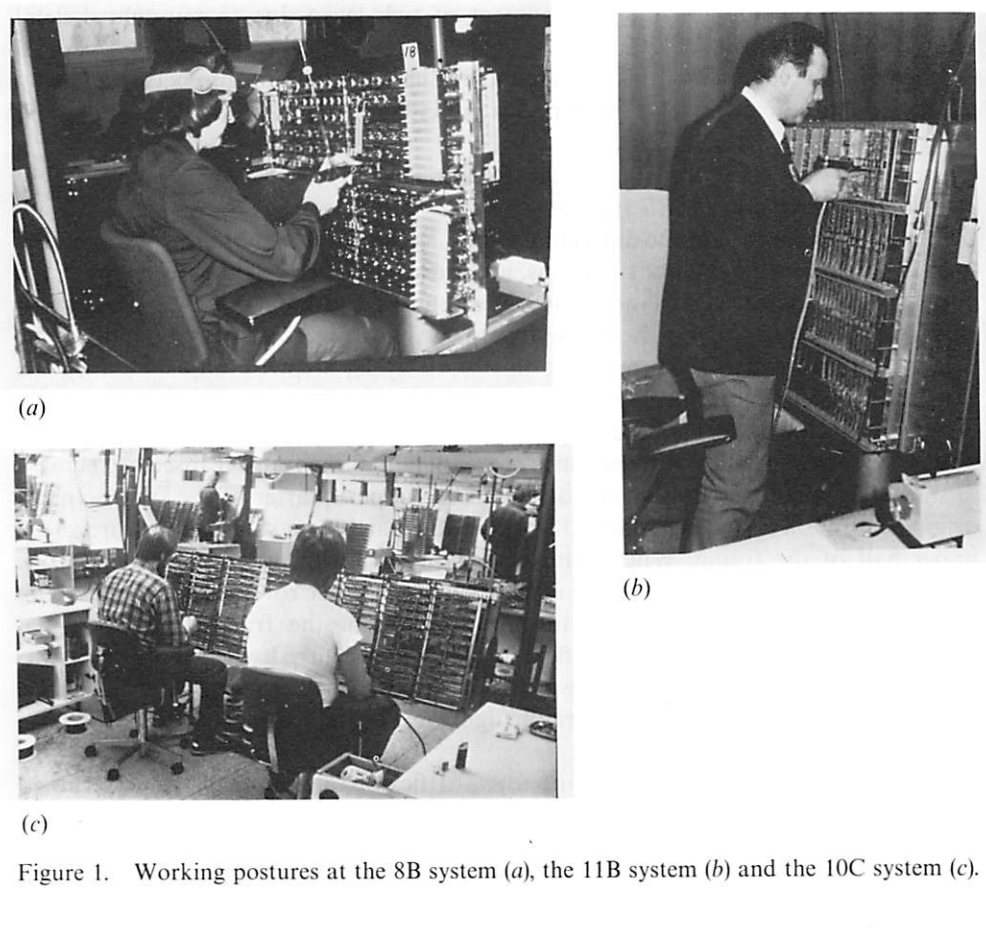
Correlations between arm position and trapezius load have already been demonstrated in controlled laboratory experiments (Hagberg 1981 a and b, Sigholm *et al.* 1984). The latter test concerned such correlations during the much less controlled conditions prevailing with occupational work tasks. Preliminary results of this study have already been published (Aarås *et al.* 1987).

2. 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 1988). 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 re-adopting 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 this study.

Postural angles were recorded from 14 subjects. Six females working at the 8B system had a median age of 42·6 years (range 30–52 years). The stature for the six subjects varied between 155 and 175 cm, mean 162 cm. This anthropometric parameter may influence postural load when working at non-adjustable workplaces. At the 10C system, postural angles were recorded from two females, both 33 years old and one male, 34 years old. Three females working at the 11B system had a mean age of 32·2 years (range 29–39 years). Both the 10C and the 11B workplaces were height adjustable, reducing the effect of stature as a factor influencing the postural load. Postural angles were also recorded from two males, at the CF (cable making) system.

All work tasks except for cable making consisted of joining wires to the needle shaped terminals on metal frames using a wrapping gun. At the 8B system, the vertically mounted frame was 100 cm wide and 40 to 80 cm high (figure 1 (*a*)). 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 1 at the bottom to row 12 at the top of the frame. Wiring of terminals at the 10C system was performed seated within an almost vertical area of 30 by 60 cm for 35% of the work time. In another 50% of the work time, wiring was carried out standing with the frame placed horizontally and a work area of 200 by 60 cm (figure 1 (*b*)). At the 11B system, the wiring of terminals was mainly performed standing with the work area 78 cm wide and 20 to 100 cm high, depending on whether wiring was performed within one of four shelves or between shelves (figure 1 (*c*)). A more complete



(*a*) (*b*) (*c*)

Figure 1. Working postures at the 8B system (*a*), the 11B system (*b*) and the 10C system (*c*).

description of the different work systems, identified by the same labels as in this paper, is given by Westgaard and Aarås (1984).

The system for recording and quantification of surface EMG has been described elsewhere (Westgaard 1987). Simultaneous recordings of postural angles and surface EMG from the trapezius muscles were performed for five of the subjects at the 8B system, three at the 10C system, three at the 11B system and two at the CF system. The output signals from the angle-measuring equipment, the 'physiometer', were stored on a 14-channel tape recorder (Racal Store-14) and later analysed on a minicomputer 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 a method used for quantification of electromyographic recordings (Jonsson 1982). The amplitude probability given by this function indicates the 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 previous 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.

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

3. Results

3.1. *Postural angles at the 8B system*

Continuous recordings of the different postural angles for one subject, working in the redesigned and original work situations, are shown in figure 2. 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 1 to row 12 at the new, adjustable workplace (figure 2(*a*)). Throughout this work cycle, stepwise adjustment of the working height was performed. When working at the highest rows with a seated posture, adjustment was limited by the position of the thighs underneath the frame. 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 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 original work situtions, 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 workplace. The short periods with flexion up to 90° occurred when the subject was lifting and fastening the cable form within the frame. Arm abduction during the same recording was low and rather invariant (figure 2(*b*)), indicating that the main arm movement was in the sagittal plane.

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. There was a slow movement of the head towards less flexion when the working height was increasing at the end of the recording. The back showed little

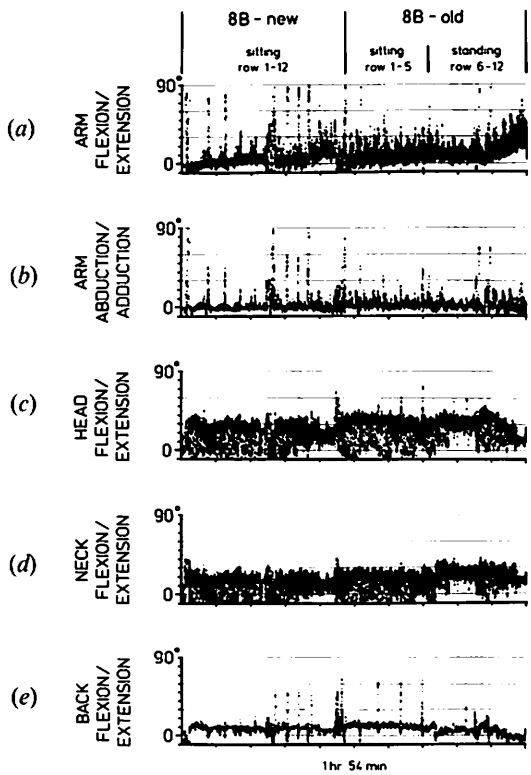


Figure 2. Continuous recording of postural angles from subject 3 at the 8B system. Each point in the recording indicates mean angle in 0·5 second intervals. The subject was working first in the redesigned work situation from row 1 (low) to row 12 (high), then on the same rows in the original work situation. Work postures are indicated at the top of the figure.

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.

The recording from each subject was divided into a maximum of five sections according to work task: seated posture at rows 1 to 6 of the original workplace, seated or standing posture at rows 7 to 12 of the original workplace, seated posture at rows 1 to 6 of the redesigned workplace, seated posture at rows 7 to 12 of the redesigned workplace, and standing posture at rows 9 to 12 of the redesigned workplace. High and low rows are considered separately owing 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 (figures 3 and 4). The bars thereby show variability of the postural angles at the 10 to 90% level. Numbers on the top of each bar identify the different subjects, the recording shown in figure 2 was from subject 3.

Figure 3 confirms that arm flexion/extension was 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 varied between −2° (extension) and

(a)

(b)

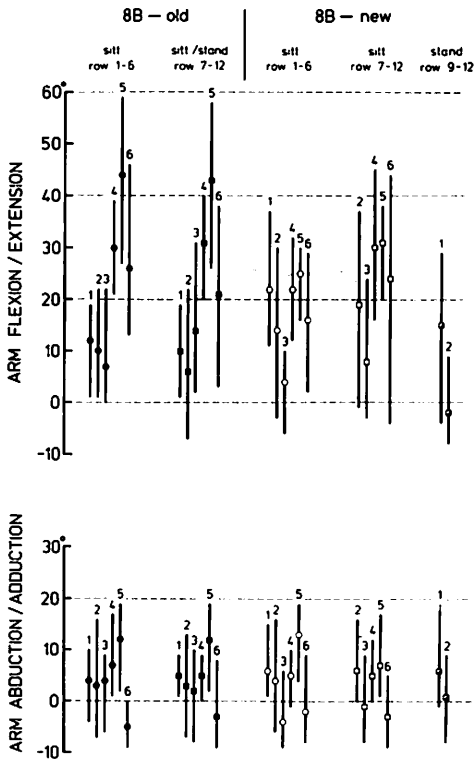


Figure 3. (*a*) Median flexion/extension of the right arm in the shoulder joint when working at low (filled circles) and high (filled squares) rows at the original 8B system, and low (open circles) and high (open and semi-open squares) rows at the redesigned 8B system. Work postures are indicated above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

44° for different subjects and work tasks, compared to the much smaller values of −5° (extension) to 13° for arm abduction.

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.

Arm flexion when working at high rows in the original work situation, was largely unchanged relative to lower rows for most subjects. This is partly due to the analytic procedure with averaging of the postural angle from row 7 to 12. When working at lower rows of the redesigned work stand, a considerable reduction in forward flexion was 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 had to adopt a standing posture at the original work stand.

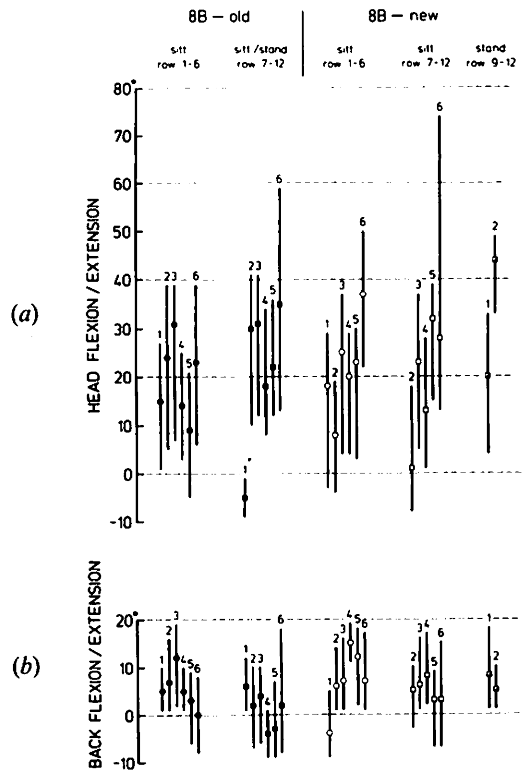


Figure 4. Head flexion/extension (*a*) and back flexion/extension (*b*), recorded simultaneously with results in figure 3. See figure 3 for definition of symbols.

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 the median angle of subject 2 showing 2° of extension. This is probably attributable to good visibility from above when working on the top row, allowing the frame to be positioned at a very low level.

Head position also showed considerable variability while working at the 8B system (figure 4(*a*)). There was a tendency to increased flexion when working at the higher rows in the original work situation. Which was probably caused by the change from a seated to a standing posture. There is little change in head position from the original to the redesigned work situations. 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 was very stable, with median values ranging from −4° (extension) to 15° (flexion). A tendency towards reduced flexion was observed when working at high rows, relative to low rows, both in the original and adapted work situation.

3.2. *Postural angles at the 10C system*

Figure 5 shows a representative recording of postural angles while working at the 10C system, the subject first adopting a standing posture with the frame placed horizontally, then seated with the frame in a near vertical position. Work in the standing

(a)
(b)
(c)
(d)
(e)

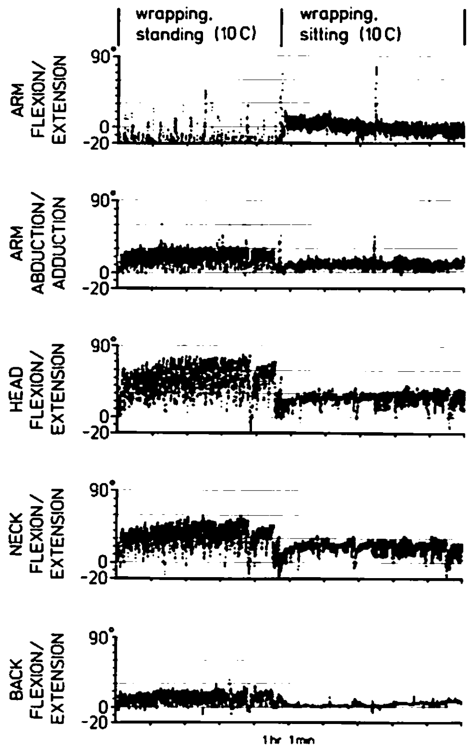


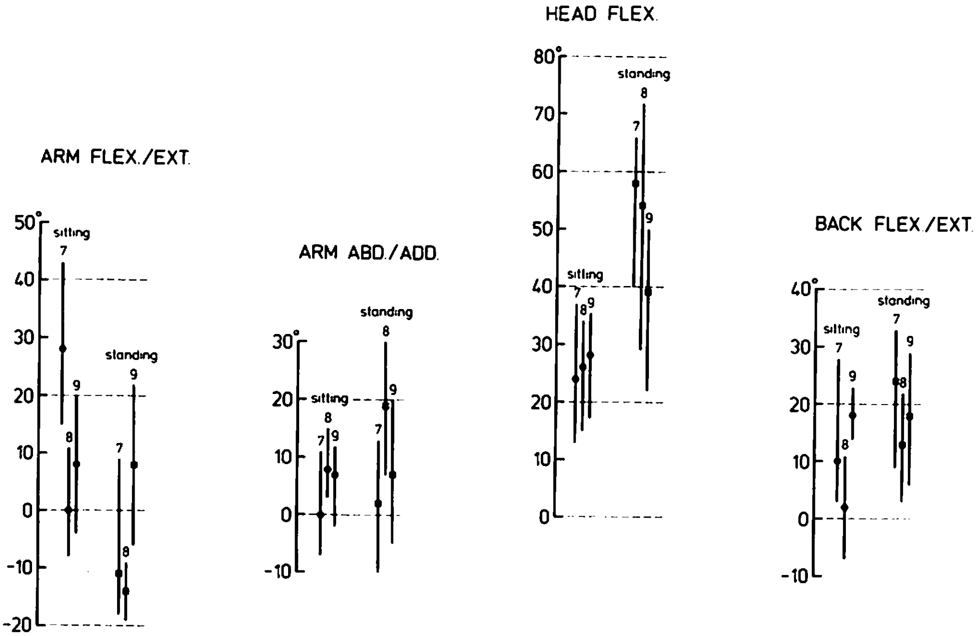
Figure 5. Postural angles from a 1 h 1 min recording at the 10C system, the subject first adopting a standing, then a seated posture. Each point in the recording indicates the mean angle in 0·5 second intervals.

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 the neutral position (figure 5(*a*)).

The arm was abducted throughout the whole recording period, but with more variability in standing posture (figure 5(*b*)). This difference between the seated and the standing posture was more pronounced for head position, where median forward flexion was much larger when standing, because of the need to look down on the frame (figure 5(*c*)).

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

Figure 6 shows median values and a 10 to 90% variability range of postural angles for three subjects at the 10C system, adopting seated and standing postures. The small number of subjects makes a general evaluation of postural angles at this system difficult. However, median arm flexion varied 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 was the dominant arm position in the sagittal plane for the most common, standing posture. This was reversed when seated, when the arm was often held in flexion. Two subjects recorded reduced arm flexion with the standing relative to the seated posture (figure 6(*a*)). Median abduction varied between 0° and 19°



(*a*) (*b*) (*c*) (*d*)

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, as in figure 3.

(figure 6(*b*)). Head flexion was higher than for the 8B system, especially for the dominant standing posture (figure 6(*c*)). Median back flexion varied between 2 and 19°, two subjects recording increased flexion with standing posture (figure 6(*d*)).

3.3. *Postural angles at the 11B system*

Figure 7 shows a 1 h 16 min recording of postural angles while working at the 11B system. Work was first performed seated at the second lowest of four shelves, then standing at the top shelf. The postural angles were moderate throughout the recording, indicating a well-balanced posture. A rhythmicity in arm flexion was seen when seated, indicating a repeating work pattern.

Figure 8 shows the postural angles of three subjects working seated and/or standing at the 11B work system, the recording in figure 7 corresponding to subject 11. Considerable variability of postural angles between subjects was observed. This is to a large extent a reflection of differences in work tasks within the same system. Subject 10 performed wiring between the two lowest shelves with a seated posture, then with a standing posture, wiring first between the top and the second shelf (working height 85 to 160 cm), and thereafter between the two middle shelves. The work tasks of subject 11 have already been mentioned, while subject 12 performed wiring between the two middle shelves with a standing posture.

Figure 8 indicates considerable variability 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 because of the requirement of immediately thereafter moving to the 160 cm

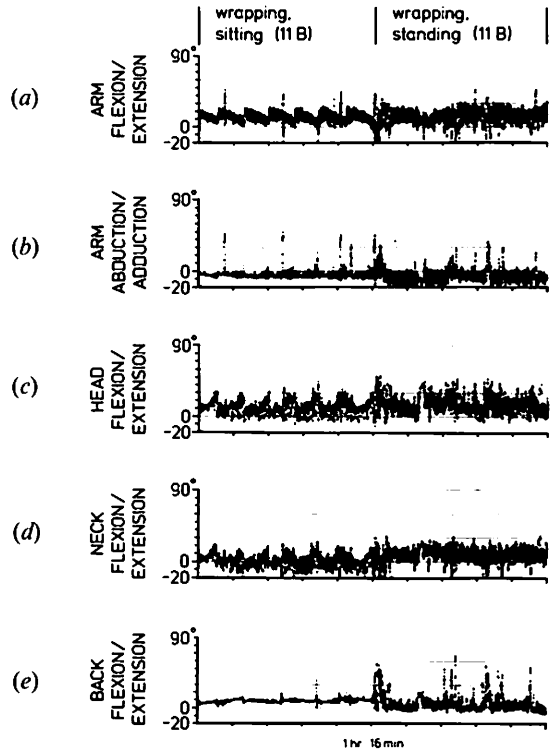


Figure 7. Postural angles from a 1 h 16 min recording at the 11b system, the subject first adopting a sitting, then a standing posture. Each point in the recording indicates the mean angle in 0·5 second intervals.

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 was largely unchanged, but where a substantial reduction in median angles was recorded. Median flexion of the arm was generally lower than at the old 8 B system, and median arm abduction was close to the 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 for 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.

3.4. *Relationship 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

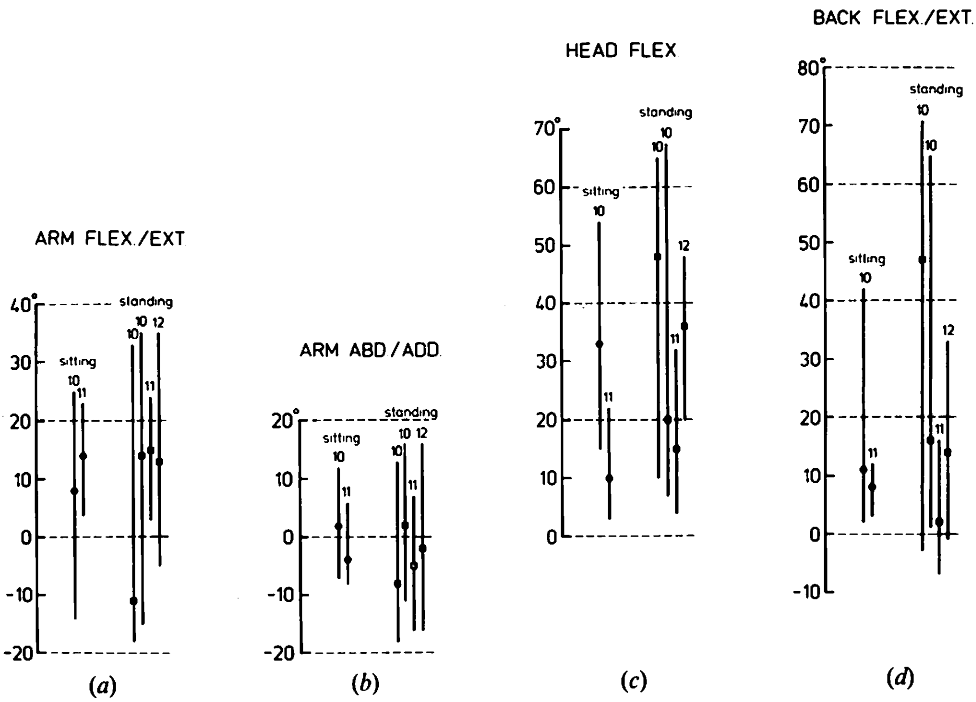


Figure 8. Arm flexion/extension (*a*), arm abduction/adduction (*b*), head flexion (*c*) and back flexion/extension (*d*) at the 11B system for sitting (filled circles) and standing (filled squares) postures. Median, 'static' and 'peak' angles are indicated, as in figure 3.

correlate with tapezius 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 workplace are selected, laboratory conditions are appoximated. As an example, figure 9(*a*)–(*d*) shows 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 recording. 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.

Figure 9 (*e*) shows a *x*–*y* plot of arm flexion and trapezius EMG, based on data from figure 9 (*a*), (*b*). A linear relationship 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 relationship, 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

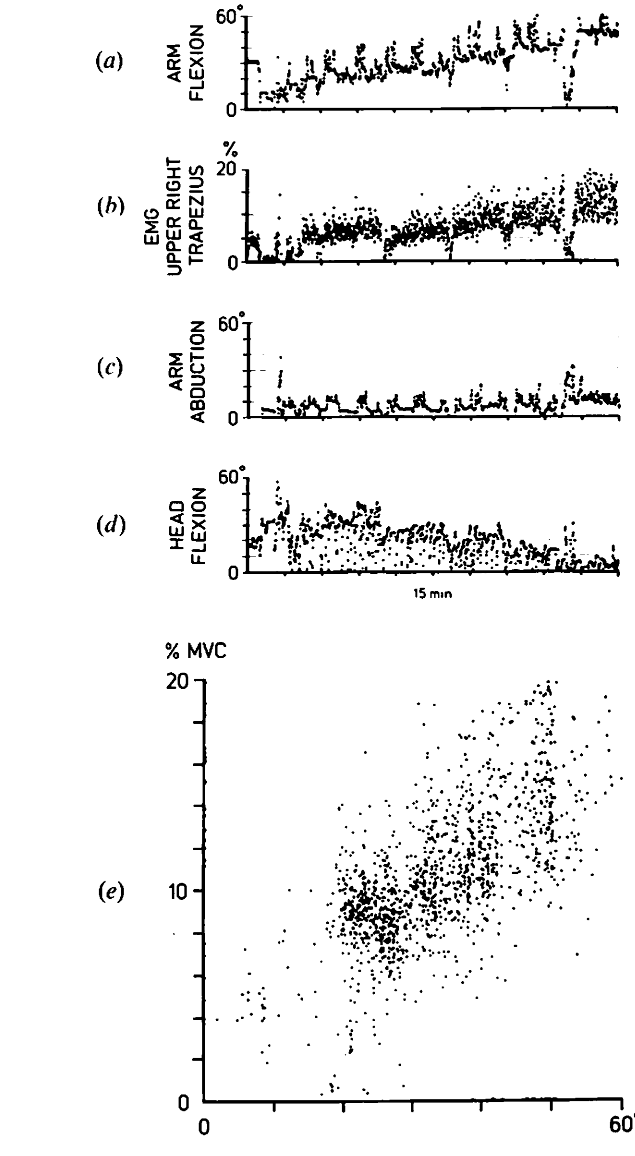


Figure 9. Arm flexion (*a*), EMG from upper right trapezius (*b*), arm abduction (*c*) and head flexion (*d*), recorded simultaneously while working at progressively higher rows at the original 8B system. Each point in the recording indicates mean angle or full-wave rectified and integrated EMG values in 0·5 second intervals. The EMG values are calibrated as a percentage of maximal voluntary contraction (Westgaard 1987). (*e*), *x*–*y* plot of arm flexion angle vs. trapezius EMG, is based on data in figure 9 (*a*) and (*b*).

noticed. Also, this relationship became curvilinear above about 30° of arm flexion for one subject, with trapezius EMG increasing relatively faster than arm flexion.

When considering all segments of recordings from the 8B system with relatively stable values for 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 figure 10 where filled

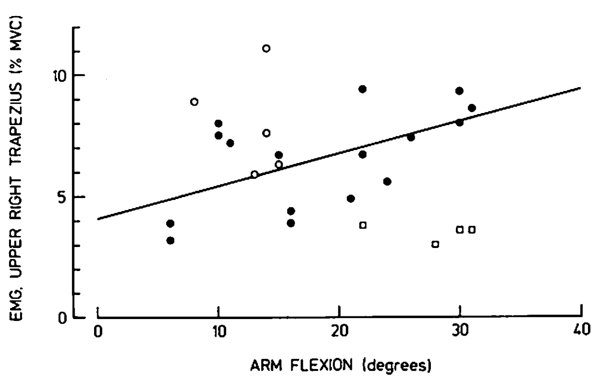


Figure 10. Corresponding values of median arm flexion in gleno-humeral joint and full-wave rectified and integrated median EMG values from the upper trapezius muscle when working at the original or redesigned 8B system (filled circles). Each point is based on stable sections of recordings of at least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

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 $r = 0{\cdot}65$, $P < 0{\cdot}01$.

Corresponding values for the 11B system tended to cluster at low flexion angles, high trapezius load. Values from the cable making system (Westgaard and Aarås 1984) clustered 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 a correlation between the two indicators of shoulder load.

3.5. *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 in the shoulder and neck region for female workers at the 8B, 10C and 11B systems.

The number of workers with one or more recorded periods of musculo-skeletal sick leave as fraction of total workers at risk due to injuries of the low back was 5%, 10% and 5% for workers employed less than 2 years (128 subjects), 2–5 years (73 subjects) and more than 5 years (20 subjects) at the 8B system. The comparable values for workers at the 10C/11B systems were 0%, 4% and 0% (14, 27 and 18 subjects), respectively.

4. Discussion

The position of the arm is of major importance for the load on active and passive structures of the gleno-humeral 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 gleno-humeral joint itself. However, the query remains as to whether or not postural angles can be used as a risk estimator for the 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.

Postural angles may be evaluated as risk estimators for shoulder injury by comparing postural angles of the arm for groups of workers, known to develop occupational shoulder injuries at different rates. In our material the health situation is known to improve for workers at the redesigned workplaces of the 8B system, relative to the original one (Westgaard and Aarås 1985, Aarås and Westgaard 1987). Also, workers at the 10C/11B systems (1975–1983), had a statistically significant lower incidence of musculo-skeletal sick leave than workers at the original 8B system (1967–1974). In both comparisons 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 workplaces.

In the comparison of arm movements, it was possible to concentrate on the flexion/extension of the right arm in the sagittal plane, as arm abduction was low and largely similar for workers at 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 significantly so, of workers at the 10C/11B systems to adopt 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. Thus, the improved health effects were not represented as a significant reduction in postural angles of the arm.

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. It would therefore be a reduction in shoulder load from the original to the redesigned 8B work system, owing to a reduction in external loads, independent 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 adopted a standing posture at the redesigned workplace, 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 adopting a standing rather than a seated posture.

Workers at the 10C and 11B systems also had the benefit of the lighter wrapping guns. Futhermore, 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 for some muscles, thereby protecting these from overexertion. This 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 have become significant if the measurements were extended to more subjects.

The above comments highlight some of the problems in using postural angles as load estimators. Several factors such as external loads (Chaffin 1973, Ashton-Miller (personal communication) 1986), the use of supports (Chaffin 1973), the position of the lower arm (Sigholm *et al.* 1984), shoulder elevation, speed and accuracy of movement (Westgaard and Bjørklund 1987) and general muscle tension components (Jacobson 1938, Westgaard and Bjørklund 1987) may contribute an increased load on the shoulder and thereby an increased risk of developing shoulder illnesses. These factors 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 EMG 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 positive correlation between arm flexion and trapezius EMG was demonstrated, as it has been in laboratory studies (Hagberg 1981 a, 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 factors infiuencing 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 factor most readily available for evaluating changes in postures as a result of ergonomic redesign of the workplaces. A reduction in 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 the 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 15 (*c*) 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). These authors 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. This is supported Dul *et al* (1982), who showed that the force which is counteracting the forward turning moment of the head at spinal level C7-Thl, 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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Cette étude explore l'utilisation de l'information se rapportant à la position du bras et de la tête en tant qu'indicateur de la charge sur l'épaule et de risque de traumatisme de l'épaule chez des assembleurs électro-mécaniciens. Deux épreuves ont été utilisées pour évaluer la méthode proposée. On a examiné:

1) si l'apparition de traumatismes musculo-squelettiques parmi des groupes d'ouvriers pouvait être mise en relation avec des angles de posture du bras supérieur ou;

2) S'il y avait une corrélation entre les deux indicateurs de la charge musculaire, la position du bras supérieur et l'EMG du trapèze supérieur.

On a utilisé un pendule à capteur potentiométrique pour mesurer les angles posturax de flexion-extension et d'abduction-adduction du bras droit sur l'articulation de l'épaule, ainsi que la flexion-extension de la tête et du dos. Pour la plupart des sujets, on a, en même temps, enregistré l'EMG sur les muscles trapèzes supérieurs.

L'ampleur des angles posturax de l'articulation scapulaire a influencé la charge scapulaire. Cependant plusieurs paramètres non quantifiés par les mesures des angles posturaux ont également augmenté la charge scapulaire indépendemment de la position du bras. Ceci doit être pris en compte si l'on veut utiliser les seuls angles posturaux en tant qu'indicateurs de la charge scapulaire. Cette constation a été confirmée par la corrélation positive significative entre la flexion du bras moyen et la charge du trapèze médian pour une activité physique bien définie et cette corrélation s'est réduite ou s'est annulée lorsque d'autres activités physiques exécutées avec d'autres movements corporels ou d'autre charges externes ont été incluses dans l'analyse.

On a observé 20% de congés de maladie dus à des traumatismes de l'épaule chez des ouvrières employées entre 2 et 5 ans et 30% chez celles travaillant plus de 5 ans dans une activité de maniement d'un outil pour lequel la posture adoptée entraînait une flexion du bras médian inférieure à 15° et une abduction du bras médian inférieure à 10°, pour un outil léger pesant 0,35 kg. Ceci représente une incidence significativement moindre que pour d'autres groupes de personnes soumises à des flexions plus importantes du bras.

Diese Abhandlung erforscht den Nutzen der Information über die Position der Oberarme und des Kopfes als ein Indikator der Belastung der Schulter und des Risikos einer Schulterverletzung für Arbeiter, die elektromechanische Montagearbeit ausführen. Bei der Bewertung der Methode wurden zwei Tests benutzt. Es wurde untersucht, ob 1) die Entwicklung von muskuloskelettalen Verletzungen innerhalb der Gruppen der Arbeiter in Beziehung gebracht werden konnte zu den Stellungswinkel des Oberarms oder ob 2) eine Korrelation zwischen den zwei Indikatoren der Schulterbelastung, Lage des Oberarms und EMG des oberen Trapeziusmuskels war. Stellungswinkel sowohl bei Flexion/Extension und Abduktion/Adduktion des rechten Oberarms im Schultergelenk als auch bei Flexion/Extension des Kopfes und Rückens wurden unter Gebrauch von 'Pendulums', die mit Potentiometern versehen waren, gemessen. Bei den meisten Versuchspersonen wurde simultan das EMG des oberen Trapeziusmuskels aufgezeichnet.

Die Höhe der Stellungswinkel des Schultergelenks beeinflußte die Schulterbelastung. Trotzdem, einige Parameter, nicht quantifizierbar durch Messungen des Stellungswinkels erhöhen unabhängig von der Armposition ebenfalls die Schulterbelastung und müssen berücksichtigt werden. Um die Stellungswinkel alleine als ein Indikator der Schulterbelastung zu benutzen. Dies wurde durch die Entdeckung einer signifikanten positiven Korrelation zwischen der mittleren Armflexion und der mittleren Belastung des Trapeziusmuskels für eine gut definierte Arbeitsaufgabe unterstützt. Eine Korrelation, die abgeschwächt wurde oder verlorenging, wenn andere Arbeitsaufgaben mit abweichenden Körperbewegungen oder äußere Lasten mit in der Analyse berücksichtigt werden.

Eine Gruppe von weiblichen Arbeitern, die eine Körperstellung mit einer mittleren Armflexion von weniger als 15°, eine mittlere Armabduktion von weniger als 10° einnahmen und ein leichtes (0,35 kg) handgeführtes Werkzeug benutzten, wiesen eine Fehlrate von 20% wegen Verletzungen der Schulter auf. Dies gilt für Arbeiter, die 2–5 Jahre beschäftigt waren.

Für die, die mehr als 5 Jahre beschäftigt waren, trat eine Fehlrate von 30% auf.

Das ist ein signifikant niedrigeres Auftreten als bei den anderen Gruppen, die mit größerer Armflexion arbeiteten.

本論文は電子機械組立作業を実施している作業者の肩の負担と損傷の指標としての上腕と頭の位置に関する情報の使用を調査する。2つの試験を実施して本方法を評価した。すなわち，1)作業者群間の筋骨格損傷の発生が上腕の姿勢角度に関係ずけらるか，また2)肩負担の2つの指標である上腕位置と上部僧帽筋 EMG に相関関係があるかを調査した。肩関節における右上腕の屈曲／伸展と外転／内転の姿勢角度および頭と背の屈曲／伸展の姿勢角度を電位差計検出振子を使用して測定した。大部分の被験者で EMG を上部僧帽筋から同時に測定した。

肩関節の姿勢角度の大きさは肩負担に影響した。しかし，姿勢角度測定によって数量化されないいくつかのパラメータも腕位置に関係なく肩負担を増大させるので，それを考慮して姿勢角度だけを肩負担の指標として使用する必要がある。これはよく定義された作業に関して中央値腕屈曲と中央値僧帽筋負担との有意の正の相関関係によって裏付られた。この相関関係は身体動作または外部負担が異なる他の作業が分析に含まれたときに弱まるかまたは消えるかした。

15度未満の中央値腕屈曲，10度未満の中央値腕外転の姿勢をとり，軽量(0.35 kg)の 手工具を使った女性作業者の一群における肩損傷による病気休暇発生率は 2 − 5 年勤続の作業者で20%，5 年以上勤続の作業者で30%であった。これはもっと高い腕屈曲で作業している他の作業者群の発生率よりもかなり低い。