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Shoulder muscle load and muscle fatigue among industrial sewing-machine operators

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Summary. Physiological responses to physical work were assessed for 29 female industrial sewing-machine operators during an 8-h working day under ordinary working conditions. During sewing-machine work, the average (left and right) static load in the trapezius muscle was 9% of the maximal electromyogram (EMG) amplitude (% EMG_{max}), while the average mean load was 15% EMG_{max}, and the average peak load was 23% EMG_{max}. The static load level was unrelated to the muscle strength of the sewing-machine operators, which for the group as a whole was within the normal range. The load levels remained unchanged during the working day, while changes in the EMG mean power frequency and zero crossing frequency rate occurred, both indicating the development of muscle fatigue in left and right trapezius muscle during the working day. In line with this, the rating of perceived exertion in the shoulder and neck region increased during the working day. Dividing the group of sewing-machine operators into two groups, those with the highest frequency and those with the lowest frequency of shoulder/neck troubles showed that the former group had significantly lower muscle strength, despite the fact that no differences in the surface EMG during sewing were found between the two groups. It was concluded that industrial sewing-machine work involves a pattern of shoulder muscle activity which induces fatiguing processes in the shoulder and neck regions. Furthermore, since the static shoulder muscle load was independent of muscle strength, factors other than working posture may be of significance for the static shoulder muscle load.

Key words: Repetitive work – Static load – Electromyogram – Muscle fatigue – Shoulder/neck troubles

Introduction

The occurrence of musculoskeletal disorders and complaints of discomfort in the shoulder and neck region in sewing-machine operators has been reported to be high with the occurrence of symptoms over the last 12 months being approximately 75% (Sjøgaard et al. 1988; Blåder et al. 1991). In general, the occupations in which the occurrence of shoulder and neck symptoms are frequent demand high precision with a high rate of repetition, and requiring the elevation of the arms for long periods (Kvarnström 1983; Christensen 1986; Blåder et al. 1991). A large number of studies have addressed these issues during the recent decades (Kadefors 1978; Jonsson 1982; Sigholm et al. 1984; Christensen 1986; Veiersted et al. 1990), but only few studies have measured the responses throughout an 8-h working day.

It has been suggested that prolonged static contractions are a significant factor in the development of work-related muscle fatigue and symptoms. To quantify and demonstrate muscle load and the development of muscle fatigue, surface electromyogram (EMG) has often been used (Lindström et al. 1977; Jonsson 1978). The EMG changes such as the shift of EMG power spectrum to lower frequencies during isometric contractions has been used as an indicator of local muscle fatigue (Kwatny et al. 1970; Viitasalo and Komi 1975).

Measurements of EMG, muscle strength, anthropometry and work station dimension were combined in the present study to assess the responses during industrial sewing. The specific purpose was to measure shoulder muscle load during industrial sewing and to investigate whether shoulder muscle fatigue, indicated by electrophysiological signs of fatigue, developed during the working day and, in addition, to measure to what extent muscle load during sewing is related to muscle strength. The sewing-machine operators were divided into two groups in an attempt to identify possible differences between those with a high frequency of shoulder/neck symptoms and those with a lower frequency.

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Methods

Subjects

A group of 30 sewing-machine operators consented to participate in the present study after being informed about the conditions of the experiments. This subgroup was selected from a larger group of 303 female sewing-machine operators, who all participated in a questionnaire survey where the standard Nordic questionnaire on musculoskeletal symptoms was used in combination with specific questions about their working conditions (Kuorinka et al. 1987; Sjøgaard et al. 1988). The sewing-machine operators answered questions regarding trouble (ache, pain and discomfort) arising in the shoulder and neck region. Over the previous 12-month period the occurrence of reported troubles from the shoulder and/or neck had been 73% (Sjøgaard et al. 1988). The mean age of the 30 subjects studied was 36 (range 20–63) years, their mean body mass was 65 (range 45–90) kg and their mean body height was 165 (range 155–176) cm. With respect to musculoskeletal symptoms, age, body mass and body height, they were representative of the larger group.

The 30 subjects were divided in two groups according to their answers to the following question: "what is the total length of time that you have had shoulder or neck troubles during the last 12 months?" Half of them answered more than 7 days [high trouble group (HT)] and the rest less than 7 days [low trouble group (LT)]. The LT group was reduced to 14 subjects because 1 dropped out early in the experiment. No differences regarding age, body mass, or seniority between the two groups were found.

Working conditions

The subjects were employed at three Danish textile factories having different levels of technology. They worked for 39 (30–40) h each week, the seniority was 13 (5–40) years and they were paid on piece rates. They worked in a sitting position and operated the same type of sewing-machine every day. No rotation among different work stations occurred. The work was composed of short work cycles, with an average duration of less than 1 min for 70% of the sewing-machine operators, corresponding to at least 400 pieces of cloth every day. The duration of the morning and afternoon work cycles was similar, indicating a constant work intensity during the day. This was tested on a smaller group of 10 sewing-machine operators. The work stations were individually adjusted to body size and most of them had their own lighting. Working height for the hands was just above the working table and the operators could not relax their arms on the table since their tasks demanded continuous movements of the hands relative to the table.

Procedure

Day 1. Anthropometric data and work station dimensions were measured. In addition, maximal isometric voluntary contraction (MVC) during shoulder flexion, shoulder elevation, trunk extension, and trunk flexion was measured. At least 3 days were allowed between day 1 and day 2.

Day 2. When the workers arrived at the factory in the morning, EMG and electrocardiogram electrodes were mounted and MVC (shoulder flexion) was recorded simultaneously with maximal voluntary EMG amplitudes (EMG_{max}). The EMG was recorded from 21 subjects employed at two of the factories. To evaluate shoulder muscle load during the working day, EMG signals were recorded for seven periods of typical work at the sewing-machines. These recordings were performed, approximately once an hour, with four recordings before and three after lunch. The first recording in the morning took place after approximately 20 min of work. Each recording period had a minimal duration of 10 min. In addition, submaximal isometric test contractions by the shoulder muscles were performed. Test 1 was performed in the morning after approximately 30 min of work, test 2 just before lunch and test 3 at the end of the working day. Finally, a few rhythmic arm movements in the sagittal plane were performed, moving the arms from 180° shoulder flexion (forward) to 60° shoulder extension (backward) with a frequency of approximately 0.5 Hz.

Blood pressure and rating of the perceived exertion (RPE) in the shoulder region were measured at the end of work period 1, 4 and 7. In addition, RPE was measured after 1 and 2 min in the test contractions.

At the end of the working day EMG_{max} and MVC (shoulder flexion) were remeasured. The total experimental intervention caused a reduction in working time of 90 min in the normal 8-h working day.

Anthropometry and work station design

To relate body size to the work station dimensions for each individual, the following was measured: body height, sitting height (from chair to top of head), upper arm length and distance from seat of the chair to acromion. At the work stations, the height of the working table, thickness of the working table, chair height and height of the foot support were measured. In addition, photographs, in the sagittal plane, of typical work positions were taken. These photographs were used for measuring neck inclination in relation to the vertical axis and to measure the distance from the eyes to the needle.

RPE, heart rate, and blood pressure

During sewing-machine work, as well as during the test contractions, RPE related to the shoulder and neck region was recorded for the workers, using a 10-level scale (Borg 1982). Heart rate was measured precordially and continuously sampled on a Memolog (Novo). Blood pressure was measured with the cuff technique at heart level.

Muscle strength and test contraction

The MVC were measured with strain gauge dynamometers. The best of three trials for each type of contraction was chosen as the maximal value. Bilateral shoulder elevation strength was performed with the subjects in a standing position while elevating their shoulders against straps, which were fixed to the floor. Shoulder flexion strength and test contractions were performed in a standing position with 90° shoulder flexion, elbows straight and palms facing the floor. During shoulder flexion a strap was applied just proximal to the elbow joints at the centre of gravity of the arms (Pheasant 1986). During test contractions, a 2-kg load was placed just proximal to each elbow joint and the duration of each test contraction was 2 min. The relative load during the test contractions was calculated as $(2+a)\cdot 9.81\cdot 100\cdot [s+(9.81a)]^{-1}$. Arm mass ($a$) was calculated as 5% of the body mass. The unit of shoulder flexion strength (s) is given in newtons. The lever arm was measured as the distance from acromion to the centre of the strap and used to calculate the external shoulder flexion torque. Shoulder flexion torque was calculated by adding the shoulder torque due to the arm mass to the external shoulder flexion torque.

Electromyography

The myoelectric signals were picked up by means of bipolar surface electrodes (Medicotest-A-10-VS, Ag/AgCl) which were placed above left and right trapezius pars descendens muscle and left infraspinatus muscle with a distance of 2 cm between the recording areas. The signals were transmitted using commercially available telemetric equipment (Medinik IC-600-C) and stored on a tape recorder (Brüel and Kjær 7005). During recording, the quality of the signals was checked on an oscilloscope (Leader LB0-308S) and later the recorded EMG were displayed on paper (Siemens-Elema Mingograf 4) for further signal quality control. Recordings were abandoned if visible noise was present. This occurred especially for recordings from the infraspinatus muscle due to movements of the skin relative to the muscle.

The EMG recordings from the sewing periods were low-pass filtered actively at 450 Hz, rectified and smoothed (time constant 0.1 s) and finally sampled with a frequency of 128 Hz into a HP1000 computer. Amplitude probability distribution functions (APDF) were calculated for the seven periods of work. From each 10-min period, 3-min EMG recordings were analysed when operating the sewing-machine only. In addition, one 10-min period was analysed for each operator, when they also performed other operations for short periods as part of their work, such as cleaning the machine, picking up things from the floor, and writing. The amplitude level was expressed relative to EMG_{max} amplitude as a percentage of EMG_{max} (% EMG_{max}). For the APDF, a probability level of 10% ($P=0.1$) was considered to represent the static load, 50% ($P=0.5$) to represent the mean load, and 90% ($P=0.9$) to represent the peak load (Jonsson 1978).

For comparison of the sewing-machine work with other kinds of contractions, APDF was also calculated for the test contractions and when the workers performed the rhythmic arm movements.

The EMG recordings from the 2-min test contractions were actively low-pass filtered and sampled with a frequency of 1024 Hz into the HP1000 computer. During the sampling each test contraction was divided into 25 segments of 2-s duration with pauses of 2 s in between. Two periods of 10-s duration, one at the beginning and one at the end of the test contraction were excluded. Fast Fourier transform algorithm was applied to each segment to obtain the power spectrum, from which mean power frequency (MPF) was calculated as described by Kwatny et al. (1970) and power root mean square amplitude (prms_{amp}) were calculated as the square root of the total spectrum energy. In addition, raw EMG was used to calculate zero crossing frequency (ZF) and root mean square amplitude (rms_{amp}). Finally, linear regression lines were fitted to each parameter to describe the time dependent development during each test contraction.

Statistics

The Wilcoxon matched-pairs signed-ranks test was used to test differences between the left and right trapezius muscle. The Mann-Whitney U-test was used to test differences between groups of subjects. Two-way analysis of variance (the Quade test) was used to test differences between the fatigue parameters from the three test contractions and Spearmans ρ was used to obtain rank correlations (Conover 1980). In addition, coefficient of correlation (r) was calculated for the muscle load during sewing and muscle strength as well as for anthropometric data and work station dimensions. All statistical comparisons were tested with a significance level of $P<0.05$. Changes described in the text, e.g. a decrease or an increase, are significant.

Results

Muscle strength

The average MVC values are presented in Table 1. No significant differences were found between the left and the right side, either during shoulder flexion or during shoulder elevation. Significant differences in muscle strength and torque between the two groups of workers were found during shoulder flexion, HT being weaker in the left shoulder compared to LT (Table 2). Within HT a significant difference was found between the left and the right side during shoulder elevation, the muscles on the left side being weaker compared to those on the right side (Table 2). No differences in muscle strength were found when measured in the morning and at the end of the working day.

Table 1. Maximal muscle strengths and shoulder flexion torques of 29 subjects

Test	Mean	SD	Range
Trunk flexion	388 N	116	170–580 N
Trunk extension	451 N	140	200–760 N
Shoulder elevation (right)	403 N	121	180–610 N
Shoulder elevation (left)	367 N	107	150–574 N
Shoulder flexion (right)	158 N	34	73–218 N
Shoulder flexion (left)	151 N	38	75–222 N
Shoulder flexion (right)	35 N·m	9	18– 56 N·m
Shoulder flexion (left)	34 N·m	9	19– 49 N·m

Table 2. Maximal muscle strengths compared among the 14 subjects in LT and the 15 subjects in HT

Test	Mean	SD	Range
Shoulder elevation (right) (LT)	411 N	102	250–600 N
Shoulder elevation (right) (HT)	395 N	139	150–610 N
Shoulder elevation (left) (LT)	392 N	99	250–575 N
Shoulder elevation (left) (HT)	344 N[b]	112	150–500 N
Shoulder flexion (right) (LT)	173 N	30	138–218 N
Shoulder flexion (right) (HT)	144 N[a]	32	73–202 N
Shoulder flexion (left) (LT)	166 N	33	115–215 N
Shoulder flexion (left) (HT)	137 N[a]	38	75–202 N
Shoulder flexion (right) (LT)	39 N·m	9	28– 56 N
Shoulder flexion (right) (HT)	32 N·m[a]	8	18– 40 N·m
Shoulder flexion (left) (LT)	37 N·m	8	24– 49 N·m
Shoulder flexion (left) (HT)	30 N·m[a]	9	18– 44 N·m

[a] High trouble group (HT) was weaker than low trouble group (LT)

[b] Muscles on the left side are weaker compared to those on the right side

Anthropometry and work station design

Average body height of the sewing-machine operators was 165 (range 155–176) cm, sitting height was 87 (range 81–94) cm, chair seat to acromion was 58 (range 54–62) cm, and upper arm length was 33 (range 28–37) cm. Working table height was 79 (range 74–83) cm, chair height was 56 (range 52–66) cm, the thickness of the working table was 5 (range 4–7.5) cm and the height of the foot support was 8 (range 6–11) cm. By combining the data above, it can be calculated that

1. Average working height was 2 cm less than average elbow height and

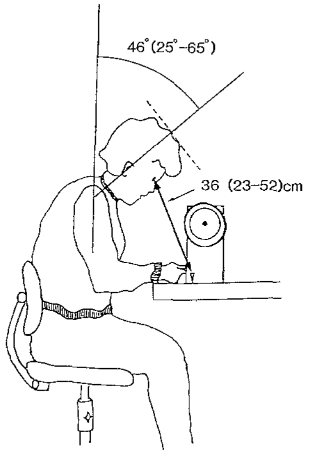

Fig. 1. Neck angle and distance from eyes to needle during sewing

2. Distance from chair seat to the underside of the working table was 24 cm. In addition, positive and significant correlations were found between body height and height of the table ($r=0.6$; $y=0.26x+29$) and between body height and chair height ($r=0.5$; $y=0.46x-26$). The neck angle in relation to vertical and the visual distance from eyes to needle is shown in Fig. 1.

Response to sewing work

During sewing-machine work, mean loads ($P=0.5$) in the left and right trapezius muscles were 16% and 14% EMG_{max}, respectively. The static contraction level ($P=0.1$) in the left and right trapezius muscle was 9% EMG_{max}. The peak loads ($P=0.9$) were 25% and 21% EMG_{max} for the left and right trapezius muscles, respectively. The mean, static and peak load in the infraspinatus muscle during sewing were 9%, 4%, and 20% EMG_{max}, respectively (Fig. 2). The APDF from the infraspinatus muscle during sewing was based on only 4 operators. They were therefore considered to be additional measurements. No changes of the static, mean and peak loads were seen in any of the muscles investigated during the working day. No differences were found in any of the periods analysed between HT and LT.

During the 10-min period, including sewing and additional kinds of operations, the mean load was similar to the mean load during sewing, while the static load decreased from 9% to 8% EMG_{max} in the left trapezius muscle and from 9% to 7% EMG_{max} in the right trapezius muscle. Furthermore, the peak load increased from 25% to 29% EMG_{max} in the left trapezius muscle and from 21% to 23% EMG_{max} in the right trapezius muscle.

A typical example of an APDF curve calculated from the EMG recording during sewing is shown in Fig. 3A. The shape of the APDF profile during sewing and during the static test contraction (Fig. 3B) was similar, although the operators moved their arms when performing the tasks. A completely different APDF profile was found during dynamic contractions of the shoulder muscles performing rhythmic arm movements (Fig. 3C).

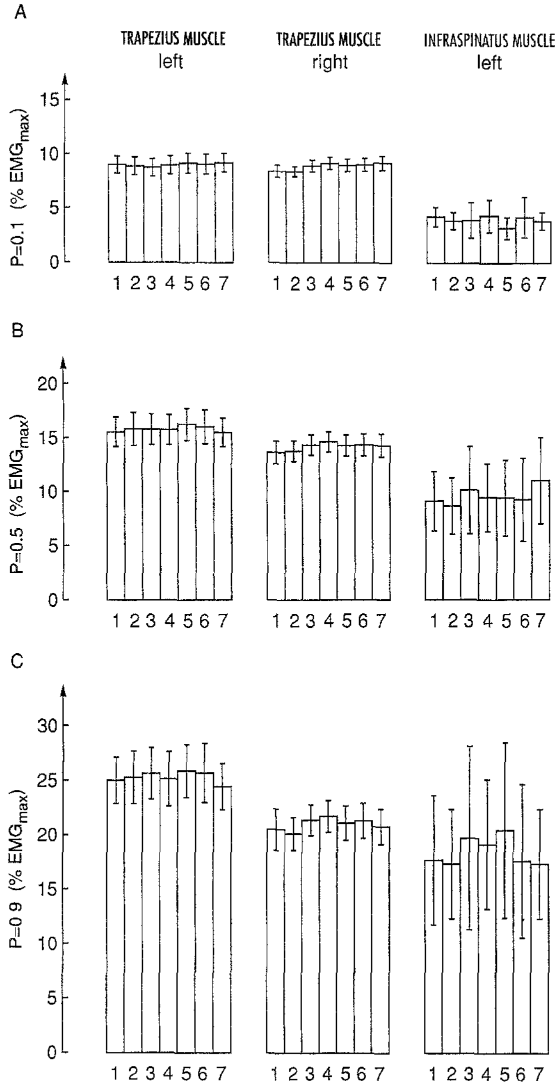

Fig. 2. Average values of amplitude probability distribution functions (APDF) from left trapezius muscle ($n=17$), right trapezius muscle ($n=21$) and left infraspinatus muscle ($n=4$) from seven periods of work at the sewing-machines. *Each bar* (numbered 1–7) represents one work period. (**A**) shows the static load ($P=0.1$), (**B**) the mean load ($P=0.5$) and (**C**) the peak load ($P=0.9$). *Vertical error bars* are SEM. % EMG_{max}, Percentage maximal electromyogram

A weak, but significant correlation was seen between the mean load and the maximal shoulder elevation strength (left trapezius muscle, $r=0.5$; $y=27.30-0.03x$ and right trapezius muscle, $r=0.6$; $y=24.50-0.02x$), whereas the static load was independent of the maximal shoulder muscle strength. No differences were found between the two groups of workers (Fig. 4).

Systolic blood pressure was 128 (range 105–170) mmHg [17.1 (range 14.0–22.7) kPa], diastolic blood pressure 85 (65–100) mmHg [11.3 (range 8.7–13.3) kPa] and heart rate averaged 86 (range 68–108) beats·min^{-1}. Blood pressure and heart rate remained

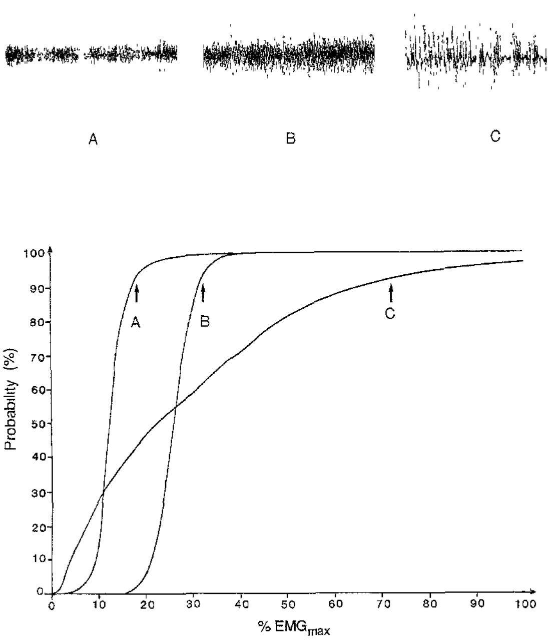

Fig. 3. The APDF calculated from a typical *EMG* recording (trapezius muscle) during sewing (**A**), during the static test contraction (**B**), and dynamic contractions (**C**). The APDF profile during sewing shows the static characteristics of sewing-machine work. Definitions as in Fig. 2

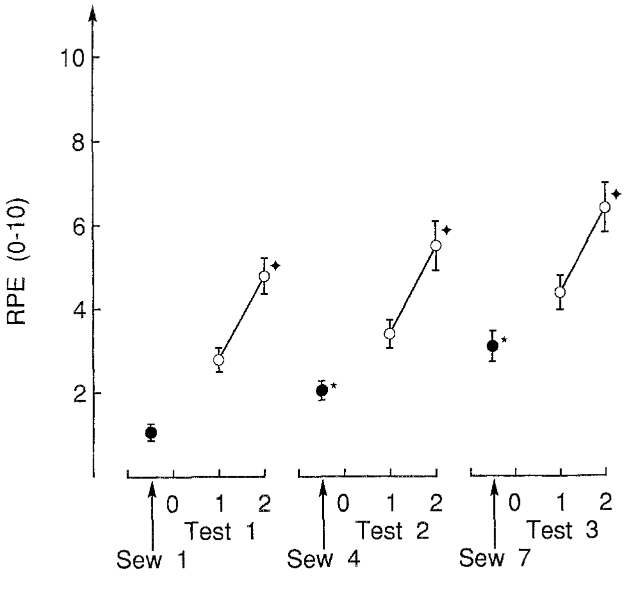

Fig. 5. Rating of perceived exertion (*RPE*) in the shoulder/neck region. *Filled symbols* are average values during sewing period 1, 4, and 7. *Small asterisks* denote changes in relation to initial values (Sew 1). The *open symbols* are average values during test contractions at 1 min and 2 min. *Large asterisks* denote changes during the tests. *Vertical bars* are SEM

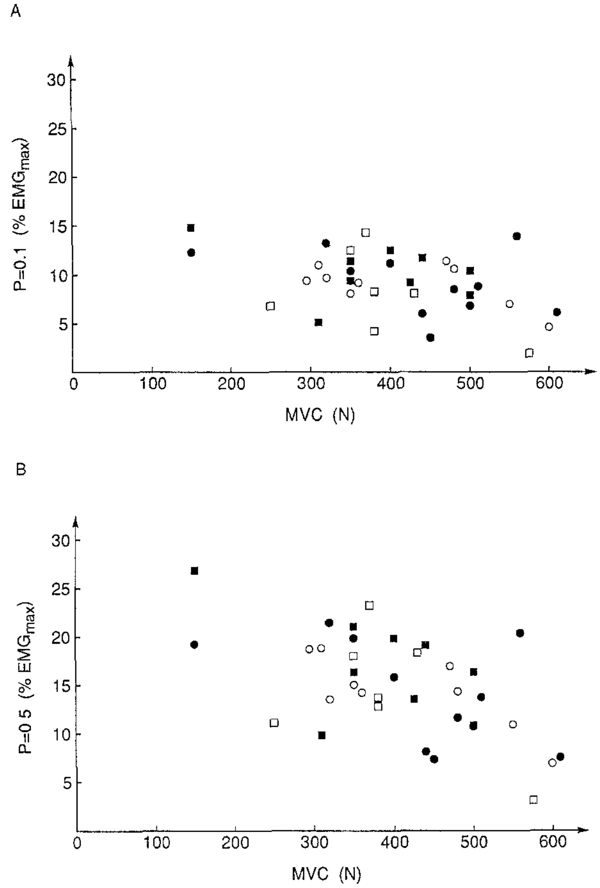

Fig. 4. The electromyogram (EMG) recorded from left (*square symbols*) and right (*round symbols*) trapezius muscle in relation to maximal shoulder elevation strength. *Open and filled symbols* represent low trouble group and high trouble group, respectively. (**A**) Static load. (**B**) Mean load

unchanged during the working day. Also, EMG_{max} amplitudes measured in the morning and at the end of the working day were unchanged.

The RPE ratings increased during the working day for both groups of workers from 1 (range 0–4) (very weak) in the morning to 2 (range 1–4) (weak) just before lunch and finally to 3 (range 0–7) (moderate) at the end of the working day (Fig. 5). Also during each of the three test contractions, the RPE ratings increased. During test 1, RPE was 3 (range 1–5) after 1 min and 5 (range 1–10) (strong) after 2 min. During test 2 the corresponding values were 4 (range 0–7) (somewhat strong) and 6 (range 0–10) and during test 3, RPE were 5 (range 0–10) and 7 (range 0–10) (very strong).

Response to test contractions

The average relative load during the test contractions was 32% (20–47) MVC. Only 1 subject was unable to sustain the 2-kg load for 2 min. The relative load for this subject was 47% MVC.

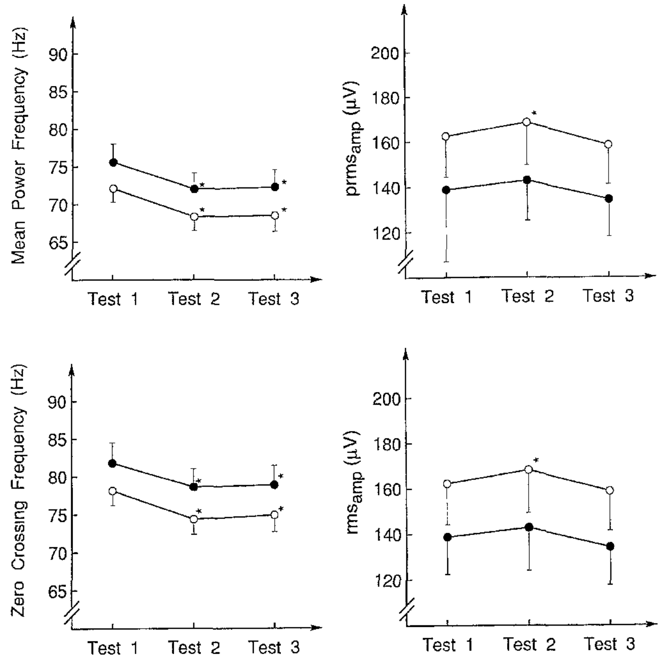

Fig. 6. The electromyogram (EMG) during the test contractions. *Open symbols* are right trapezius muscle ($n=19$) and *filled symbols* are left trapezius muscle ($n=19$). *Asterisks* denotes changes in relation to initial values. *Vertical bars* are SEM. rms_{amp}, Root mean square amplitude; prms_{amp}, power root mean square amplitude

Figure 6 shows that EMG signs of muscle fatigue developed during the working day in the trapezius muscle. Thus, the average MPF and ZF calculated from each of the three test contractions decreased from test 1 to test 2 and remained unchanged from test 2 to test 3 for both the left and right trapezius muscles. In all three tests MPF and ZF of both the left and right trapezius muscle were highly correlated (Table 3). In addition, in the right trapezius muscle the amplitude (prms_{amp} and rms_{amp}) increased from test 1 to test 2 and remained unchanged from test 2 to test 3 (Fig. 6). No differences in the EMG results were seen between the two groups of workers.

Discussion

Some EMG signs of muscle fatigue developed in the left and right side of the trapezius muscles of the operators during the working day. This was found in spite of the anthropometric data and maximal muscle strengths being within normal range (Asmussen and Heebøll-Nielsen 1962; Kilbom and Persson 1985; Nicolaisen and Jørgensen 1985; Grandjean 1986).

By comparing the test contractions during the day it is, however, remarkable that the frequency content of the power spectrum was shifted towards lower frequencies during the morning, while it remained unchanged during the afternoon. A similar MPF pattern during the working day has been found in the triceps brachii muscle during 7 h of monotonous intermittent work at a mean work load of 14% MVC and in the low back muscles of bricklayers (Jørgensen et al. 1988, 1991). The RPE scores during sewing work, as well as the test contractions, increased during the working day, supporting the findings of EMG signs of muscle fatigue.

Table 3. Correlation coefficients (ρ) between mean power frequency and zero crossing frequency during test contractions

	Trapezius muscle (left)	Trapezius muscle (right)
Test 1	$\rho=0.94$	$\rho=0.92$
Test 2	$\rho=0.95$	$\rho=0.97$
Test 3	$\rho=0.97$	$\rho=0.97$

The physiological mechanisms behind the EMG changes during fatiguing contractions are still a matter of debate. The possible explanations have included synchronization of the active motor units and changed motor unit recruitment patterns (Person and Kudina 1972; De Luca and Forrest 1973a, b; Broman 1977; Lippold 1981; Maton 1981; Kato et al. 1981). Another factor is a decrease in muscle fibre conduction velocity due to changes in shape of motor unit action potentials. It has been suggested that the main reason for the MPF decrease is a decreasing muscle fibre conduction velocity (Lindström et al. 1970, 1977). However, results from recent studies question the significance of conduction velocity decreases at low contraction levels (Zwarts and Arendt-Nielsen 1988; Krogh-Lund and Jørgensen 1991). Therefore, conduction velocity decreases may not be of significance for the signs of EMG fatigue resulting from sewing-machine work.

It has been suggested that not only MPF but also ZF rate can be used as an index of muscle fatigue. In this study, simultaneous calculations of the MPF and ZF rate illustrated a high degree of covariation between the two parameters and thus comparison of studies where these two different methods have been used separately are possible.

In this study the static load in the trapezius muscle was approximately twice the level which, according to previous recommendations, should not be exceeded during an 8-h working day (Jonsson 1978). Over the last 10 years, some studies have indicated that even a limit of 2–5% MVC is too high, and that maximally 1% MVC is acceptable, while others have suggested that even no static load at all is acceptable if sustained for hours (Aarås 1987; Westgaard 1988).

The variations in muscle activity, indicating the degree of dynamic muscle activity, have been measured as the difference between peak and static muscle load (Sundelin and Hagberg 1992). A difference of 27% for the trapezius muscle has been found in a standardized repetitive work simulation task where small cylinders were grasped and then released through a hole in the table (Sundelin and Hagberg 1992). In the present study, an even smaller variation of 12% and 14% for the right and left trapezius muscle, respectively, was found. When the additional operations were being performed, the variation in muscle activity increased to 16% for the right and 21% for the left trapezius muscle, indicating a more dynamic muscle activity pattern. However, it has been shown that the EMG signs of muscle fatigue develop similarly during continuous dynamic contractions without any rest periods and during sustained static contraction at similar contraction level. In contrast to this, intermittent contractions have been shown to be less fatiguing than sustained static contractions (Björkstén and Jonsson 1977; Jensen and Sjøgaard 1988). It is therefore suggested that rest periods without muscle activity in the trapezius muscle are of importance in preventing the development of muscle fatigue during industrial sewing.

In the present study the static, mean and peak load in trapezius muscle remained unchanged during the working day. In accordance with this, the duration of the work cycles was similar in the morning and in the afternoon, indicating that the work intensity was constant during the day, as measured on a subgroup of 10 sewing-machine operators.

Elevation of the arms and stabilization of the shoulder region imposed a static shoulder muscle load during work. It is noteworthy that the static load during sewing was independent of muscle strength. This would indicate that not only the body posture but also other factors are of significance for the static muscle load during industrial sewing. It has previously been demonstrated that muscle tension in the trapezius muscle may be provoked by nonpostural loads, such as accuracy, increased speed of work, and stress (Westgaard and Bjørklund 1987; Wærsted et al. 1987). It is, therefore, likely that the static load as measured during industrial sewing was caused by a combination of a working posture with elevated arms and additional demands, such as high precision, visual and mental demands.

The present work station dimensions and anthropometric data were evaluated in relation to recommended dimensions in work place design (Grandjean 1986). The distance from elbow to work table is recommended to be a few centimetres for sedentary work. In the present study, this distance was 2 cm. Also, work table and chair height, distance from chair seat to the top of and underside of working table were in accordance with the recommended guidelines. Furthermore, at an individual level, fitting the work station dimensions to the worker's anthropometry is of importance. In the present study a significant relationship was found between body height and height of the working table and between body height and chair height. Thus, the results show that the work stations were adjusted to the sewing-machine operators. This was also supported by direct observation of the work stations. It would therefore seem unlikely that any design improvements for the work stations could further reduce the static shoulder muscle load to any great extent. However, the average neck inclination of 46° was much larger than that recommended (Andersson et al. 1983; Grandjean 1986) and close to the maximal range of flexion motion in the cervical spine (Bennett et al. 1963; Lind et al. 1989). The posture of the cervical spine has been shown to be related to the load on the neck and shoulder muscles (Schüldt et al. 1987; Hagberg and Hagberg 1989). Biomechanical calculations have shown that an inclination of 46° as measured in this study corresponds to 15%–20% of the maximal neck extension strength (Hagberg and Hagberg 1989). This may be of significance for the development of muscle fatigue and neck disorders since the position of the head is maintained for hours.

Although the shoulder muscle strength of the operators was within normal range, the present investigation showed that HT was slightly but significantly weaker than LT. It has previously been shown by Kvarnström (1983), that workers with shoulder/neck troubles in the manufacturing industry had a lower shoulder muscle strength compared to healthy workers. The question is, then, whether a low shoulder muscle strength increases the risk for developing shoulder/neck troubles or if, on the contrary, work related shoulder/neck troubles may result in a lowered shoulder muscle strength. A prospective study has shown that a high shoulder muscle strength does not prevent the development of work related shoulder/neck troubles in the electronics industry (Kilbom and Persson 1985; Kilbom 1988). Furthermore, it has been shown that shoulder muscle strength capability does not affect the fatigue or discomfort perceived during longterm manual performance tasks where strength demands are low (Wiker et al. 1990). Based on these findings it is likely that the development of shoulder/neck troubles results in a decreasing shoulder muscle strength, which may be due to acute pain reflex inhibition and/or more chronic morphological changes in the soft tissue (Hargens et al. 1981; Lindman et al. 1991).

A history of shoulder/neck troubles for more than 7 days within the last 12 months was not reflected in the surface EMG recorded from the trapezius muscle. The cause may be the small differences with respect to shoulder/neck troubles between the two groups of subjects in this study. Therefore, this study does not rule out the possibility that acute and/or more severe symptoms may change the surface EMG relative to a group without such symptoms as has been indicated by Suurküla and Hägg 1987.

In conclusion, repetitive precision work, such as operating sewing-machines, imposes a high static load on shoulder muscles and EMG signs of muscle fatigue develop during the work day, although the present study would indicate that the work stations were adjusted to each individual. Furthermore, the static load was independent of muscle strength, indicating that factors other than working posture are of significance for the static load. Prevention of work-related musculoskeletal disorders call for work-organizational changes in the jobs, which would ensure more variation in working movements and thus distribute the load over more muscles during the working day.

References

Aarås A (1987) Postural load and the development of musculoskeletal illness. Thesis, Institute of Work Physiology, Oslo

Andersson G, Bjurvall M, Bolinder E, Frykman G, Jonsson B, Kilbom Å, Lagerlöv E, Michaelsson G, Nyström Å, Olbe G, Roslund J, Rydell N, Sundell L, Westerholm P (1983) Model for evaluation of work related neck and shoulder disorders. Lakartidningen 80:3186–3189

Asmussen E, Heebøll-Nielsen K (1962) Isometric muscle strength in relation to age in men and women. Ergonomics 5:167–169

Bennett JG, Bergmanis LE, Carpenter JK, Skowlund HV (1963) Range of motion of the neck. J Am Phys Ther Assoc 43:45–47

Björkstén M, Jonsson B (1977) Endurance limit of force in long-term intermittent static contractions. Scand J Work Environ Health 3:23–27

Blåder S, Barck-Holst U, Danielsson S, Ferhm E, Kalpamaa M, Leijon M, Lindh M, Markhede G (1991) Neck and shoulder complaints among sewing-machine operators. A study concerning frequency, symptomatology and dysfunction. Appl Ergon 22:251–257

Borg GAV (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14:377–381

Broman H (1977) An investigation of the influence of a sustained contraction on the succession of action potentials from a single motor unit. Electromyogr Clin Neurophysiol 17:341–358

Christensen H (1986) Muscle activity and fatigue in the shoulder muscles of assembly-plant employees. Scand J Work Environ Health 12:582–587

Conover WJ (1980) Practical nonparametric statistics, 2nd edn. Wiley, New York

De Luca CJ, Forrest WJ (1973a) Probability distribution function of the inter-pulse intervals of single motor unit action potentials during isometric contractions. In: New developments in electromyography and clinical neurophysiology, Desmedt JE (ed) Karger, Basel, pp 638–647

De Luca CJ, Forrest WJ (1973b) Some properties of motor unit action potential trains recorded during constant force isometric contractions in man. Kybernetik 12:160–168

Grandjean E (1986) Fitting the task to the man. An ergonomic approach. Taylor Francis, London

Hagberg M, Hagberg C (1989) Risks and prevention of musculoskeletal disorders among dentists. In: Brune DK, Edling C (eds) Occupational hazards among health professionals. CRC Press, Boca Raton, Fla., pp 323–332

Hargens AR, Schmidt DA, Evans KL, Gonsalves MR, Cologne JB, Garfin SR, Mubarak SJ, Hagan PL, Akeson WH (1981) Quantitation of skeletal-muscle necrosis in a model compartment syndrome. Bone Joint Surg (Am) 63-A:631–636

Jensen BR, Sjøgaard G (1988) Muscle fatigue during low-level isometric contractions with or without dynamic exercise (abstract). Acta Physiol Scand 134 [Suppl 575]:101–P47

Jonsson B (1978) Quantitative electromyographic evaluation of muscular load during work. Scand J Rehabil Med [Suppl 6]:69–74

Jonsson B (1982) Measurement and evaluation of local muscular strain in the shoulder during constrained work. J Hum Ergol 11:73–88

Jørgensen K, Fallentin N, Krogh-Lund C, Jensen BR (1988) Electromyography and fatigue during prolonged, low-level static contractions. Eur J Appl Physiol 57:316–321

Jørgensen K, Jensen B, Kato M (1991) Fatigue development in the lumbar paravertebral muscles of bricklayers during the working day. Int J Ind Ergom 8:237–245

Kadefors R (1978) Application of electromyography in ergonomics: new vistas. Scand J Rehabil Med 10:127–133

Kato M, Murakami S, Takahashi K, Hirayama H (1981) Motor unit activities during maintained voluntary muscle contraction at constant levels in man. Neurosci Lett 25:149–154

Kilbom Å (1988) Isometric strength and occupational muscle disorders. Eur J Appl Physiol 57:322–326

Kilbom Å, Persson J (1985) Low capacity of the shoulder muscles as a risk factor for occupational cervichobrachial disorders. In: Ergonomics International, Brown ID, Goldsmith R, Combes K, Sinclair MA (eds) Proceedings 9th Congress of International Ergonomics Association, Bournemouth, pp 553–555

Krogh-Lund C, Jørgensen K (1991) Changes in conduction velocity, median frequency, and root mean square-amplitude of the electromyogram during 25% maximal voluntary contraction of the triceps brachii muscle, to limit of endurance. Eur J Appl Physiol 63:60–69

Kuorinka I, Jonsson B, Kilbom Å, Vinterberg H, Biering-Sørensen F, Andersson G, Jørgensen K (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon 18:233–237

Kvarnström S (1983) Occurrence of musculoskeletal disorders in a manufacturing industry, with special attention to occupational shoulder disorders. Scand J Rehabil Med [Suppl 8]:1–114

Kwatny E, Thomas DH, Kwatny HG (1970) An application of signal processing techniques to the study of myoelectric signals. IEEE Trans Biomed Eng BME-17:303–312

Lind B, Sihlbom H, Nordwall A, Malchau H (1989) Normal range of motion of the cervical spine. Arch Phys Med Rehabil 70:692–695

Lindman R, Hagberg M, Ängqvist K-A, Söderlund K, Hultman E, Thornell LE (1991) Changes in muscle morphology in chronic trapezius myalgia. Scand J Work Environ Health 17:347–355

Lindström L, Magnusson R, Petersén I (1970) Muscular fatigue and action potential conduction velocity changes studied with frequency analysis of EMG signals. Electromyography 4:341–356

Lindström L, Kadefors R, Petersén I (1977) An electromyographic index for localized muscle fatigue. J Appl Physiol Respir Environ Exerc Physiol 43:750–754

Lippold O (1981) The tremor in fatigue. Human muscle fatigue: physiological mechanisms. Ciba-Found-Symp 82:234–248

Maton B (1981) Human motor unit activity during the onset of muscle fatigue in submaximal isometric isotonic contraction. Eur J Appl Physiol 46:271–281

Nicolaisen T, Jørgensen K (1985) Trunk strength, back muscle endurance and low-back trouble. Scand J Rehabil Med 17:121–127

Person RS, Kudina LP (1972) Discharge frequency and discharge pattern of human motor units during voluntary contraction of muscle. Electroencephalogr Clin Neurophysiol 32:471–483

Pheasant S (1986) Bodyspace. Anthropometry, ergonomics and design. Taylor Francis, London

Schüldt K, Harms-Ringdahl K, Arborelius UP, Nemeth G (1987) Influence of sitting postures on neck and shoulder e.m.g. during arm-hand work movements. Clin Biomech 2:126–139

Sigholm G, Herberts P, Almström C, Kadefors R (1984) Electromyographic analysis of shoulder muscle load. J Orthop Res 1:379–386

Sjøgaard G, Simonsen EB, Jensen BR, Christiansen JU, Pedersen KS (1988) Physical workload and musculoskeletal disorders in sewing machine-operators (abstract). Proc Int Ergon Assoc 2:384–386

Sundelin G, Hagberg M (1992) Electromyographic signs of shoulder muscle fatigue on repetitive arm work paced by the methods-time measurement system. Scand J Work Environ Health 18:262–268

Suurküla J, Hägg GM (1987) Relations between shoulder/neck disorders and EMG zero crossing shifts in female assembly workers using the test contraction method. Ergonomics 30:1553–1564

Veiersted KB, Westgaard RH, Andersen P (1990) Pattern of muscle activity during stereotyped work and its relation to muscle pain. Int Arch Occup Environ Health 62:31–41

Viitasalo JHT, Komi PV (1975) Signal characteristics of EMG with special reference to reproducibility of measurements. Acta Physiol Scand 93:531–539

Westgaard RH (1988) Measurement and evaluation of postural load in occupational work situations. Eur J Appl Physiol 57:291–304

Westgaard RH, Bjørklund R (1987) Generation of muscle tension additional to postural muscle load. Ergonomics 30:911–923

Wiker SF, Chaffin DB, Langolf GD (1990) Shoulder postural fatigue and discomfort. A preliminary findings of no relationship with isometric strength capability in a light-weight manual assembly task. Int J Ind Ergon 5:133–146

Wærsted M, Bjørklund R, Westgaard RH (1987) Generation of muscle tension related to a demand of continuing attention. In: Knave B, Wideback P-G (eds) Work with display units. Elsevier Science, Amsterdam, pp 288–293

Zwarts MJ, Arendt-Nielsen L (1988) The influence of force and circulation on average muscle fibre conduction velocity during local muscle fatigue. Eur J Appl Physiol 58:278–283