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Danuta Roman-Liu^a, Tomasz Tokarski^a & Joanna Kamińska^a

^a Department of Ergonomics, Central Institute for Labour Protection, Warsaw, Poland

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Assessment of the Musculoskeletal Load of the Trapezius and Deltoid Muscles During Hand Activity

Danuta Roman-Liu
Tomasz Tokarski
Joanna Kamińska

Department of Ergonomics, Central Institute
for Labour Protection, Warsaw, Poland

The purpose of the study was to analyse the influence of the precision of a task on tension and fatigue of the trapezius and deltoid muscles. Ten young men took part in experiments. Different levels of force and different frequencies of pressing a button defined the precision of the task. Surface electromyography (EMG) was used. Muscle tension and fatigue were reflected by 2 parameters of the EMG signal: the Root Mean Square amplitude related to the maximum value and changes in the Median Power Frequency. The results showed that hand activities influence the descending part of the trapezius muscle and do not influence the deltoid muscle, and that the precision of work can influence the examined muscles of the arm and shoulder even during work in which only the hand is involved in a performed task.

electromyography muscle fatigue precision work hand activities

1. INTRODUCTION

Manipulation functions of the upper limbs are very broad. Usually the forearm and hand are involved in the manipulation function as the arm

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Correspondence and requests for reprints should be sent to Danuta Roman-Liu, Central Institute for Labour Protection, ul. Czerniakowska 16, 00-701 Warsaw, Poland. E-mail: <daliu@ciop.pl>.

supports the upper limb position. The area of the muscles involved in a performed task depends on the kind of task and usually the muscles involved experience a different pattern of muscle load. Some muscles are involved in the performed activities only, whereas others play a stabilising role. The muscles of the arm and shoulder usually support the upper limb in a defined position. Some researchers (Inman, Saunders, & Abbot, 1944; Kronberg, Nemeth, & Broström, 1990; Mathiassen & Winkel, 1990; Sporrang, Palmerud, & Herberts, 1995, 1996) studied the function of shoulder muscles. It is generally accepted that the role of the trapezius muscle is to support posture and that the deltoid muscle is one of the main drivers of the shoulder joint.

There is a great number of varying work tasks, associated with small movements and low forces, in which arm muscles work over a long period of time, very often with demands for high precision. A high rate of cumulative trauma disorders (Jensen, Nilsen, Hansen, & Westgaard, 1993; Silverstein, Fine, & Armstrong, 1986) is associated with work activities. The main physical risk factors are extreme posture, forceful exertion, and the repetition of movements as well as the duration of exertion and work-rest characteristics (Herberts, Kadefors, Andersson, & Petersen, 1981). Studies that concentrated on arm-neck region complaints and disorders connected with work (Chiang et al., 1993; Hagberg & Wegman, 1987; Stock, 1991; Veiersted & Westgaard, 1993) revealed that there was a high prevalence of musculoskeletal disorders in this region. During a given performed task, shoulder region muscles experience a different kind of tension, depending on the exposure to risk factors. There are suggestions that muscle tension of the upper limb is influenced not only by physical factors (Roman-Liu, Wittek, & Kędzior, 1996) but by psychosocial factors as well (Larsson, Larsson, Zhang, Cai, & Öberg, 1995; Lundberg et al., 1994). Psychological factors are connected with the character of the performed task, precision and pace of performed work, its complexity, attention-related activity as well as social factors (Arndt, 1987; Waersted, Björklund, & Westgaard, 1994; Waersted & Westgaard, 1996; Weber, Fussler, O'Hanlon, Gierer, & Grandjean, 1980; Westgaard & Björklund, 1987).

A few studies tackle the problem of whether the activity of the hand influences the activity of shoulder muscles. Aoki (1991) examined the influence of wrist movement on the activity of arm muscles (biceps brachii, brachialis, triceps brachii). The results showed that the activity patterns of arm muscles were associated with rapid wrist movements. Studies of Sporrang et al. (1995) investigated the influence of the precision of dentist work on shoulder muscles load. The studies did not reveal any influence of

hand activity (handgrip) on the trapezius muscle, and showed that there was influence on the middle deltoid muscle. Another study of those authors (Sporrong, Palmerud, Kadefors, & Herberts, 1998), whose aim was to analyse the influence of precision on the electromyography (EMG) of shoulder muscles, showed that light manual precision work increased shoulder muscle activity as revealed by EMG. Changes in muscle tension according to the precision of a task were recorded in all analysed shoulder muscles in all analysed upper limb locations.

Sporrong et al. (1998) studied how the precision of a task influences shoulder muscles. The study showed that the precision of a performed task was an important factor that influenced musculoskeletal load. Higher precision put higher demands concerning stabilisation and caused higher stress. This implies that precision seen through muscle load can be considered in two aspects. First, higher precision of a task requires accuracy of movements, which means more stabilisation of the upper extremity and higher muscle tension. The second factor is higher muscular tension depending on the stress factor, that is difficulty and complexity of task. Studies performed by Milerad and Ericson (1994) showed that the degree of precision of a performed task influenced the tension of the trapezius muscle, but not of the deltoid muscle.

There are hand activities where muscles of the glenohumeral joint are expected to be loaded with constant load (stabilising function) like muscles of the forearm with intermittent load depending on the performed task. The question is if static intermittent load of the hand can influence the load of the muscles of the arm and shoulder, whose main task is to keep the upper limb in a defined position.

The purpose of the study was to analyse the influence of the precision of work, depending on the pattern of hand activity, on tension and fatigue of the descending part of the trapezius muscle and the middle part of the deltoid one.

2. METHODOLOGY

2.1. Participants

Ten young, right-hand dominant men aged 20–29 (average: 22.7) were recruited from the male students of the Academy of Physical Education in Warsaw, Poland. Body height was from 166 to 188 cm (average: 178) and body mass from 66 to 82 kg (average: 73.1). Participants were right-handed and had no history of muscle pain. Before the experiments informal consent was obtained.

2.2. Variants of Experiments

To analyse how changes in the character of a performed task influence muscle activities, 16 variants of experiments were performed. The task was to press a button with an imposed frequency of repetition and level of force. To introduce an element of precision, force was at low levels (from 7 up to 20% F_{\max}). The level of force and the frequency of pressing the button characterised the precision of the performed task. Experiments were performed for four different levels of force (7, 11, 15, and 20% F_{\max}). For each of those force series, experiments for three different frequencies and constant force exertion were performed. Experiment variants were marked with two letters: an uppercase letter (A, B, C, and D) described the force level and a lowercase letter (a, b, c, and d) described the frequency of repetitions. According to Mathiassen (1993) repetitive work can be characterised by the following parameters: CT—cycle time, EP—duration of exercise period, PP—duration of pause period, EPL—exercise period load. A characteristic of the variants of experiments in relation to those parameters is presented in Table 1.

TABLE 1. Characteristics of Experiment Variants

Experiment Variant	CT (s)	EP (s)	PP (s)	EPL (% F_{\max})
Aa	120	60	60	7
Ab	30	15	15	7
Ac	12	6	6	7
Ad		constant		7
Ba	120	60	60	11
Bb	30	15	15	11
Bc	12	6	6	11
Bd		constant		11
Ca	120	60	60	15
Cb	30	15	15	15
Cc	12	6	6	15
Cd		constant		15
Da	120	60	60	20
Db	30	15	15	20
Dc	12	6	6	20
Dd		constant		20

Notes. CT—cycle time, EP—duration of exercise period, PP—duration of pause period, EPL—exercise period load, F_{\max} —maximum force.

2.3. Methods

Bipolar electromyography is a well established method for evaluating muscular load: It has been used in studies of various occupations to estimate muscle loads during tasks involving upper limbs. In performed experiments the EMG signal from the two main muscles of the shoulder girdle and arm were registered. The descending part of the trapezius and the middle part of deltoid muscle were examined. The anatomical location of the muscles was done by feel as the participant put them to isometric tension.

EMG measurements were performed during isometric muscle contractions. A MESPEC 3000 (Mega Electronics, Finland) muscle tester and an IBM computer were used to measure and store data. The EMG signal was registered though MS-OOS (Medicates, Denmark) surface electrodes. Skin was appropriately prepared so as to bring skin resistance below 2 k Ω . Pre-amplifiers mounted immediately next to the electrodes permitted registration of the nonartefact signal. The EMG signal was sampled through a 12-bit A/D converter with a sampling rate of 1000 Hz. The EMG signal was calculated for 0.5-s segments. The filter band was between 4 and 1500 Hz.

To ensure consistent electrode placement for each test session, the participants' skin was marked around the electrodes.

2.4. Experimental Layout

Experiments were conducted in a room with constant temperature 23–25 °C. The examined participants were right-handed, however, to make the task more complicated the left limb was chosen to be active in experiments. The level of force and frequency of force exertion were the variables.

As changes in upper limb position and external load can be expected to affect EMG activity, all experiments were conducted in the sitting position with the same upper limb and spine location. The spine was straight, the right upper limb was supported on the table, the left upper limb was in the position chosen for the experiment. The location of the left upper limb was defined as follows: The arm was in the frontal plane, perpendicular to the floor. The angle between the arm axis and the frontal plane was 45°. The forearm was parallel to the floor and the saggital plane. The participant performed the assigned task for 25 min. Dependence between the duration of exertion and force assigned by Romerth (Corlett, 1990) and the results of others were taken into consideration when establishing the duration of experiments (Dien, Toussaint, Thissen, & Ven, 1993).

The experimental stand consisted of a desk, a chair, a press button, and a video display unit (VDU), on which two lines were presented. The experimental task was to press the button with the defined by the experiment variant value of force (expressed as percentage of F_{\max}) and frequency of pressing the button. Pressing the button was triggered by sound, which lasted for a time dependent on the experiment variant. Keeping the required constant force for the duration of the exercise demanded eye control of the force level. This was accomplished by two lines on the screen. One of them was at a level adjusted as the level of the force for a given variant of the experiment. The other line reflected the level of the pressing force the participant exerted on the button. The participant's task was to keep those two lines together. Such an experimental setting demanded from the participant a precision of the performed task that correlated with the conditions of the experimental variant (frequency of pressing the button and force level).

2.5. Analysis

The analysis of the EMG signal was based on software supplied with the ME 3000p (Mega Electronics, Finland) equipment, which was used for measuring and registering the signal. Two parameters of the EMG signal were analysed: the normalised integrated EMG amplitude and the fatigue index. The EMG signals were full wave rectified and averaged within windows that were 512 samples in length.

Analysed were averaged integrated EMG amplitude (IEMG) calculated from the raw EMG signal registered during the exercise period in the second cycle or—for variants marked d—in the first minute of the experiment. Normalisation was made against a maximum isometric contraction.

The fatigue process was monitored during the 25-min experiment by calculating the Median Power Frequency (MPF) parameter from samples registered during the exercise period. During muscle fatigue the content of the power spectrum shifts toward lower frequencies (Kadefors, Kaiser, & Petersen, 1968; Lindström, Magnusson, & Petersen, (1970). This phenomenon can be quantitatively described by changes in MPF. MPF was calculated for each exercise period. The fatigue index is the parameter that reflects changes in Median Power Frequency during the experiment expressed by the slope of regression line of MPF in time.

Analysed were differences in values of the aforementioned EMG parameters between groups of variants differentiated according to the frequency of repetitions and according to values of the external force. The aim of such

analysis was to find out which of those factors of precision influence muscle load to a higher degree.

For statistical analysis, Statistica (StatSoft) software was used. The analysis of differences between groups of variants was conducted by a non-parametric Wilcoxon test. Differences with $p < .05$ were considered as statistically significant.

3. RESULTS

Figure 1 shows mean values, standard deviation, and standard error of a normalised IEMG signal for groups of variants analysed according to the frequency of repetitions.

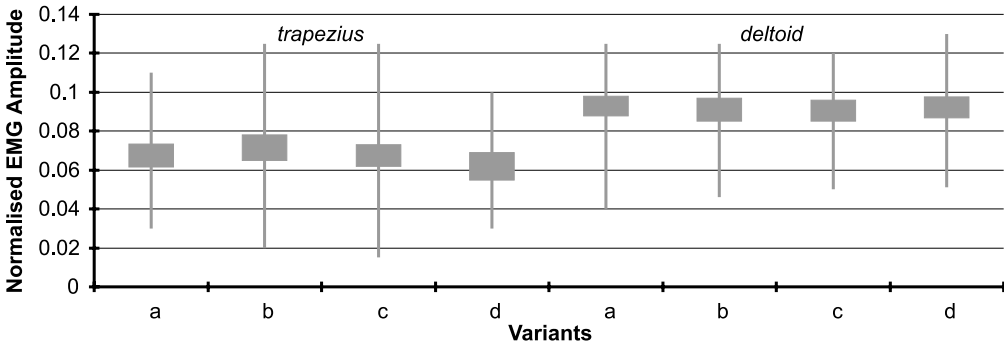


Figure 1. Mean values, standard deviation, and standard error for a normalised IEMG amplitude depending on the frequency of repetitions. Notes. a, b, c, d—groups of variants with the same frequency of repetitions.

Values of normalised IEMG for the deltoid muscle are higher than for the trapezius muscle, which means that muscular tension in the deltoid muscle was higher. For the trapezius muscle the d group of variants shows a lower value of amplitude than other groups of variants, which means that pressing the button with constant force resulted in a lower amplitude of the registered EMG signal (lower muscle tension). The only statistically significant differences are between the b and d groups of variants. For the deltoid muscle the normalised IEMG amplitudes have very similar values in all analysed groups of variants and there are no statistically significant differences.

Figure 2 presents mean values, standard deviation, and standard error for the normalised IEMG for the trapezius and the deltoid muscles for groups of variants analysed according to the external force.

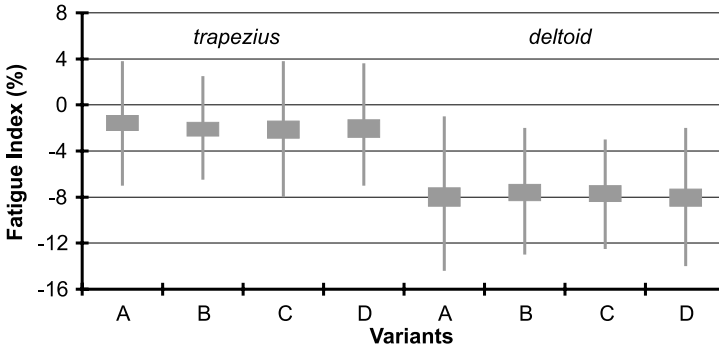


Figure 2. Mean values, standard deviation, and standard error for a normalised IEMG amplitude depending on the external force. Notes. A, B, C, D—groups of variants with the same external force.

In the trapezius muscle a strong declining tendency of the normalised IEMG dependent on the increasing force of pressing has been shown. In the deltoid muscle values of normalised IEMG are on the same level for each group of variants.

A statistically significant difference between variants occurs for the trapezius muscle between groups of variants marked D and A as well as D and B. For the deltoid muscle there are no differences between variants differentiated according to the force of pressing the button.

Figure 3 presents mean values from 10 participants, standard deviation, and standard error for the fatigue index for variants a, b, c, and d for the descending part of the trapezius muscle and the middle part of the deltoid muscle analysed according to the frequency of repetitions.

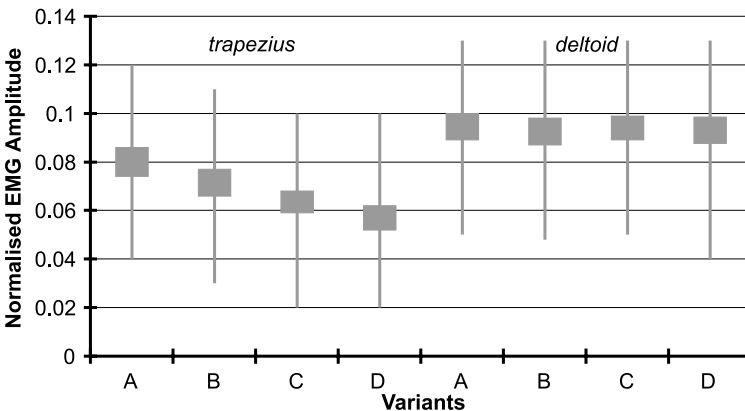


Figure 3. Mean values, standard deviation, and standard error for the fatigue index depending on the frequency of repetitions. Notes. a, b, c, d—groups of variants with the same frequency of repetitions.

Mean values show that much higher changes in median power frequency during the experiment occurred in the deltoid muscle than in the trapezius muscle. For the trapezius muscle the lowest changes are for the group of variants marked b, the highest for the group marked d. However, the differences between the groups of variants are not statistically significant. Values of the fatigue index for the deltoid muscle are on a similar level for all groups of variants, that is about 8%. All values of the parameter for the trapezius muscle are very small—about 2%. According to Öberg, Sandsjö, and Kadefors (1990) fatigue in muscles accrues when changes are at about 8%. That means that only in the deltoid muscle can it be supposed that there was fatigue.

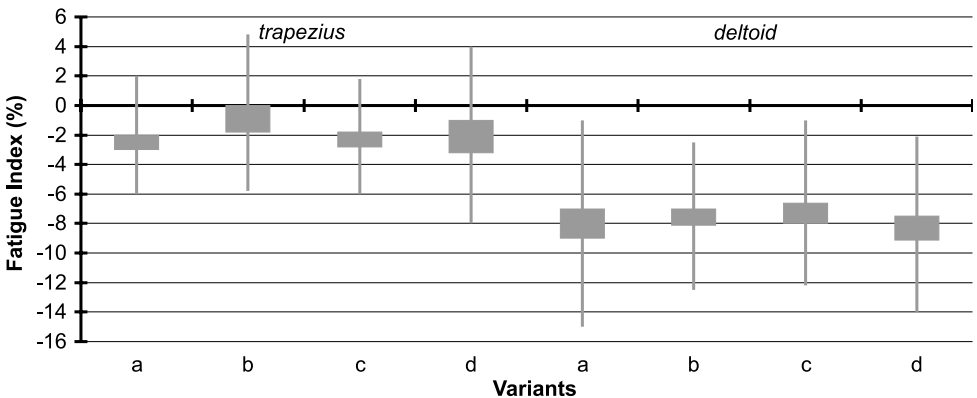


Figure 4. Mean values, standard deviation, and standard error for the fatigue index depending on the external force. Notes. A, B, C, D—groups of variants with the same external force.

Figure 4 presents mean values from 10 participants, standard deviation, and standard error for the fatigue index for the trapezius and deltoid muscles for the analysed groups of variants analysed according to external force. Values of the fatigue index are higher for the deltoid muscle than for the trapezius muscle. Like in the case of analysis according to the frequency of repetitions there is fatigue in the deltoid muscle only and it is on the same level for each group of variants. There is no fatigue in the trapezius muscle. There are no statistically significant differences between groups of variants either for the trapezius muscle or for the deltoid muscle.

4. DISCUSSION

In the performed study the examined muscles of the arm and shoulder (the middle part of the deltoid, the descending part of the trapezius muscles) sustained the upper limb in a defined position. Those muscles were to be loaded with a static constant load caused by sustaining the upper limb location. Therefore the fatigue process was to be noticed.

According to Öberg et al. (1990) it can be stated that a muscle is fatigued when there is a decrease in the fatigue index of at least 8%. In the present study there was a decrease in the fatigue index for all analysed groups of variants. However, the aforementioned phenomenon (the fatigue index of at least 8%) occurred only for the deltoid muscle. For the trapezius muscle the decrease in MPF was much lower, which means that there was no fatigue in this muscle. There were no statistically significant differences between the analysed groups of variants either for the trapezius or for the deltoid muscle, which suggests that work pace does not influence the fatigue of the analysed muscles.

However, there was fatigue in the deltoid muscle as opposed to the trapezius muscle. For the deltoid muscle there were no differences between groups of variants differentiated according to the frequency of repetitions or the external force in both parameters—normalised IEMG and the fatigue index. This can support the thesis that hand activities (pressing the button) do not influence the middle part of the deltoid muscle. The tension and fatigue in the deltoid muscle could have been caused by the position of the upper limb and by the time of maintaining the upper limb in the experimental position. It should be stressed that the tension level (normalised IEMG) in the deltoid muscle was not much higher than the tension in the trapezius muscle, as fatigue in the deltoid muscle was noticeably higher. Therefore a similar situation considering the fatigue could have been expected for the trapezius muscle. The main role of this muscle was to sustain the upper limb in the defined position. However, there was no fatigue in the descending part of the trapezius muscle. Lack of changes in the frequency of the power spectrum of the EMG signal for the trapezius muscle has also been reported by other authors (Gerdle, Henriksson-Larsen, Lorentzon, & Wretling, 1991; Hägg & Ojok, 1997; Hansson et al., 1992; Mathiassen, 1993). As for other muscles of the shoulder and limb changes showing muscular fatigue occur even at the level of 5–10% of Maximum Voluntary Contraction (MVC; Caffier, Heinecke, & Hinterthan, 1993; Hansson et al., 1992; Jørgensen, Fallentin, Krogh-Lund, & Jensen, 1988). Hägg and Ojok

(1997) showed no decrease in MPF at the load of 10–15% of MVC of the trapezius muscle and they questioned the use of EMG spectrum indices as indicators of fatigue at low load levels.

Tension in the trapezius muscle is at a low level (low values of normalised IEMG). However, values of the normalised IEMG of the trapezius muscle are influenced by force level as well as by the frequency of repetitions. Lack of fatigue in the trapezius muscle can be caused by too low muscle tension (Hägg & Ojok, 1997) or by the influence of the intermittent character of hand activities as well as the ability to reduce EMG activity voluntarily in the trapezius muscle without changing the hand load or arm posture, which has been shown in Palmerud et al.'s (1995) study. This ability has not been detected in the middle part of the deltoid muscle. Palmerud, Sporrang, Herberts, and Kadefors (1998) showed that during relaxation of the descending part of the trapezius muscle while maintaining a specific arm posture, the load is distributed among other shoulder muscles. This means that there is a significant voluntary effect in the trapezius muscle and it is suggested that trapezius EMG measurements should not be uncritically relied on when estimating total shoulder load. This phenomenon could influence the fatigue index: Participants may involuntarily relax the load of the trapezius muscle as they feel tired. However, it is not very likely that this could have influenced the normalised IEMG signal registered in the present study, as amplitude was registered at the beginning of the experiments, when the participants were not tired.

Considering the physical factor as a cause of the muscle activity of the trapezius muscle there should be no differences between groups of variants differentiated according to the frequency of repetitions, as measurements were performed at the beginning of the experiment at the same moment for all variants. Therefore no differences in normalised IEMG should have occurred in analysis according to the frequency of movements.

The influence of the frequency of repetitions on the amplitude of the EMG signal can be explained by an additional psychosocial factor (precision of the performed task). Awareness of the time pressure and awaiting for the sound, which impose work pace, cause tension, which is illustrated by a higher trapezius muscle EMG amplitude. For variant d, where there is an on-going exercise period, this phenomenon does not occur. The amplitude of the EMG signal for the d group of variants is lower than for the other groups. There are statistically significant differences between groups of variants d and b. This suggests that variants with intermittent load cause higher tension for the trapezius muscle. This tension is probably caused by

the psychosocial factor, that is the participants' greater attention in variants with intermittent load (Waersted & Westgaard, 1996). For the deltoid muscle such a phenomenon does not occur.

The influence of the force level on the trapezius muscle is reflected in higher values of the normalised IEMG signal for lower force levels. Analysis according to external force revealed that for the trapezius muscle there is a noticeable declining tendency in the increasing force of pressing. The lower the level of force, the higher the precision of the performed task. In the experiments, the force level was 7–20% of MVC, that is, the task imposed the precision of work. The lower the level of force, the more precision demands, the more difficult the task and, as a consequence, the higher the tension of the trapezius muscle. Milerad and Ericson (1994) showed that the degree of precision of the performed task influenced the load of the trapezius muscle. However, it did not influence the deltoid muscle. A similar case is presented in our study.

The co-ordination pattern of shoulder muscles seems to be sensitive to mental loads (Waersted et al., 1994). The differences that occurred could have been caused by the complexity of the task and precision connected with imposed time sequences, which caused tension because the more complicated the task, the higher the tension (Waersted & Westgaard, 1996).

It has been proved that the trapezius muscle not only sustains the upper limb in the defined position but it is also sensitive to the complexity and difficulty of the task (Nakata, Hagner, & Jonsson, 1993; Waersted & Westgaard, 1996). A similar situation occurred in the present study in which the task consisted in maintaining the force of pushing at a given level (from 7 to 20% F_{\max}). Results showed that the higher the level of force, the lower the amplitude of the EMG signal registered from the trapezius muscle.

5. SUMMARY

1. Hand activities influence the descending part of the trapezius muscle and do not influence the middle part of the deltoid muscle.
2. The descending part of the trapezius muscle is sensitive to the complexity of task and the demanded attention whereas the middle part of the deltoid is not.
3. At low levels of force (up to 20% F_{\max}) of hand activities during a 25-min task there is no fatigue in the trapezius muscle, whereas the middle part of the deltoid muscle shows fatigue due to maintaining the upper limb in a selected position.

4. It can be concluded that even during work involving fingers only, some muscles of the arm and shoulder can be influenced by that work, not only by sustaining the upper limb in a given position.

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