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THE ASSESSMENT OF MUSCLE STRAIN WITH SURFACE ELECTROMYOGRAMS DURING SIMULATED MUSHROOM PICKING

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Muscle strain was assessed with surface EMG during simulated mushroom picking. Nine female subjects performed five periods of work (W1-W5). The duration of each period was about 20 min. W1, W2 and W3 were separated by a short break of several minutes. W3, W4 and W5 were separated by a rest period of about 43 min. EMGs were recorded from the muscles of trapezius, infraspinatus, deltoid and erector spinae muscles. Amplitude of EMG (AEMG) and mean power frequency (MPF) of EMG were calculated every minute. Ratings of perceived exertion (RPE) were recorded for every 5 min. RPE increased during each work period and with the advance of W1-3. AEMG increased during some of the work periods in the trapezius and infraspinatus. AEMG decreased in a few of the work periods in the other muscles. MPF decreased during some of the work periods in the infraspinatus, deltoid and erector spinae. The increase of AEMG in the trapezius was interpreted as spare capacity for the work. The infraspinatus and deltoid were assessed to be more fatigued than the trapezius. The fatigue level of the erector spinae was low.
Key words: real work; dynamic contraction; muscle fatigue; rest; mean power frequency

INTRODUCTION

Mushroom farmers have a risk for pain and sick leave due to musculoskeletal disorders especially in their neck, shoulder or upper extremities (Hartman et al., 2006). The picking work is characterized by fast and repetitive movements of the upper extremities. The work is also often performed in a forward bent and rotated position of the trunk. The posture is caused mainly by the large width of the growth shelves and the short vertical distance between the shelves. Additionally the work is highly vision demanding since the maturity stage and size of mushrooms must be inspected concurrently with the picking task. In such working circumstances with inexpedient mechanical exposure, muscle fatigue may occur, and this may further cause musculoskeletal complaints (Jørgensen, 1997).

Surface EMG is a suitable method for the detection of muscular fatigue during field conditions as it is noninvasive (Hägg, 1991). The method gives direct information from the muscles and EMG can be recorded continuously without pain and interruption of the work. Numerous reports have shown increases in the amplitude and in the relative power in the lower frequencies of the surface EMG during sustained isometric contractions (e.g. Kogi and Hakamada, 1962; Krogh-Lund and Jørgensen, 1991).

However, the method does have several methodological drawbacks for applications relating to the working situation. The influence of muscle length and contraction level on the power spectrum as well as on the EMG amplitude is the most serious especially regarding low-level muscle contractions

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(Bazzy et al., 1986; Gander and Hudgins, 1985; Hagberg and Ericsson, 1982; Okada, 1987). Since muscle length and contraction level changes in daily activities, momentary EMG is difficult to apply for evaluation of muscle fatigue. To avoid these difficulties, EMG in real work should be analyzed either by separating the task in similar sequences regarding muscle activities and postures (Luttmann et al., 1996) or by using long averaging periods in long recordings. The latter method can be attained with the computer technology aiming to expand the storing possibilities of the data (PC cards) (Asterland et al. 1996; Hansson et al. 1997).

EMG measured during real work situations has already succeeded in showing development of muscle fatigue (Adalarasu and Balasubramanian, 2006; Lee et al., 2006; Lin et al., 2004; Jørgensen, 1997)). The EMG, however, was also reported not to detect the fatigue in spite of occurrence of significant fatigue sensation (EL Falou et al., 2003). Judgments of fatigue development from EMG are sometimes different between its amplitude and frequency spectrum (Hostens and Ramon, 2005). Even in static contractions and simple dynamic contractions of laboratory experiments, EMG was sometimes decided to be inappropriate for the index of fatigue especially in low-level contractions (Farina et al., 2003; van Dieën et al., 1996). Whether EMG during real work can assess muscle fatigue or not depends on the situation. The applicability of the EMG should be studied in various situations at the present stage.

The purpose of the study was to investigate how EMG during work can assess muscle strain in simulated work of mushroom picking. Real work includes rest and variation of load related to the situation. Work strain must be assessed with them and the experiment was consequently programmed to include them. Test contractions, which are predefined to record EMG of intended muscles in a comparable state, have been used to evaluate the muscle strain with EMG in real work (Hägg et al, 1987). Although they were used in this experiment, results of them will be reported in another paper. This paper focuses on EMG during the intended work.

METHODS

Subjects

Nine healthy women (eight Nordic students and one Oriental) (age: 25(21-36) years, stature: 1.69(1.57-1.80) m, body mass: 62(47-73) kg) volunteered as subjects after their informed consent was obtained. They had not performed mushroom picking work before the experiment. They did not have any physical problem relating to the experiment.

Mushroom picking

Mushroom picking was simulated in a laboratory with short columnar corks of two sizes, 5.5 cm and 2 cm of diameter, on beds of rice placed on a shelf of 2.00 m in width and 0.70 m in depth. The picking area was covered by another shelf. The inter-shelf distance was 0.35 m between them (Figure 1). These conditions were decided to simulate the real work situations. The height of the shelf was individually adjusted to the elbow height of the standing subject. Each picking cycle consisted of

Fig. 1. The experimental setup and a scene of the mushroom picking.

picking two corks up by the dominant hand (right) and put them on a tray held by the other hand. Subjects were told to treat the corks as mushrooms. Some of the corks were marked by tape as a sign of picking prohibition, which simulated too small or too mature mushrooms. The picking rate was maintained with a metronome and set to 20 picking cycles per minute. When the tray was filled with the corks, it was replaced by an empty one and the picking was continued. The picked corks were replaced by an experimenter without disturbing the picking. The weight of the corks was almost equal to that of real mushrooms (app 10 g) and the picking rate was decided to be equal to that of real work conditions. Prior to the experiment, the subjects practiced the picking work until they mastered the pace.

The shelf was divided equally into eight areas (0.5 x 0.35 m): four for the width and two for the depth. After all of the non-marked corks were picked up in an area, the subjects moved to the laterally adjacent area. The direction of the moving was reversed when the terminal area of the shelf was finished. A wide area condition and a near area condition were defined by the depth conditions of the picking area. In the wide area condition, the picking areas were alternated between the depth conditions, which were near to the body and far from the body, for every one minute. In the near area condition, only the near area was used.

Main protocol

The time schedule of the experiment is shown in Figure 2. The experiment consisted of two rest periods and five work periods (simulated mushroom picking, W1-W5). The sequence was W1, W2, W3, rest, W4, rest, and W5. The duration of the work period and the rest period was 20 min 15 s and about 43 min, respectively. W4 was performed in the near area condition and the remaining works were performed in the wide area condition. The low workload in W4 and the rests were included to study whether EMG can reflect the difference of load and recovery in the rest periods.

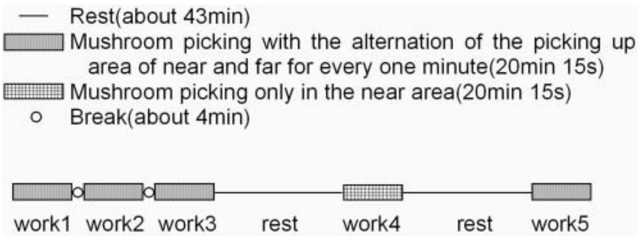

Fig. 2. Time schedule of the experiment. "Rest" and " Break" include the test contractions.

The time schedule was programmed to be able to study test contractions. The purpose made the time schedule somewhat complicated. A set of test contractions was performed between all the periods by keeping a standardized stooped posture and a bilateral arm abduction for a minute, respectively. The test contractions were also performed twice during each rest period with an interval of ten minutes. A break of about 4 min was needed to complete the test contractions between W1, W2 and W3. A 60-minute work was divided to W1, W2 and W3 to study the test contractions. The rest of about 43 min was composed of the quiet rest of 30 min and the total of four times test contractions during, before, and after the rest. Although the test contraction might induce light to moderate fatigue, their effects are not considered here.

Psychophysical ratings

Ratings of perceived exertion (RPE) of the neck, shoulder and low back were reported every five minutes during the work period according to Borg's CR-10 scale (Borg, 1982). The ratings were used to evaluate the fatigue sensation of the above-mentioned body regions.

EMG

Surface bipolar EMGs were recorded from the descending part of trapezius, lower part of infraspinatus, middle part of deltoid and erector spinae. The recordings were obtained bilaterally from erector spinae and only in the right side from the other muscles. The disc electrodes were 10 mm in diameter and were attached parallel to the muscle fiber with electrode cream. The distance between the centers of electrodes was about 25 mm. In trapezius, one electrode was placed at the middle point between the seventh cervical spine and the acromion. The other electrode was placed medially to this. Infraspinatus was identified by the outward rotation of the upper arm. In deltoid, the electrodes were placed at the center of the muscle and on the distal part. The erector spinae electrodes were placed on L4 and L5 levels 3 cm lateral to the spine. EMGs were amplified and recorded on a magneto optical disk at a rate of 1 kHz.

Power spectrums were calculated for every 256 ms by fast Fourier transform method. If the rate of the power below 8 Hz exceeded 2% of the power between 3.9 and 386.7 Hz, the results were not used. The criterion was decided by experiences to eliminate EMG including ECG and fluctuation of base line caused by motion. The power spectra were averaged between 10.0 s and 58.1 s of the one-minute picking work for each picking area in the wide area condition, and for every 118.8 s in the near area condition. AEMG was calculated as the square root of power between 3.9 and 386.7 Hz and was converted into a percentage of the maximum voluntary electric activity (MVE) described below. Mean power frequency (MPF) was calculated for the same frequency range.

Maximum voluntary contractions (MVC) were performed for shoulder elevation and shoulder abduction in a sitting posture after electrodes were attached. MVCs of trunk extension were performed in an upright position (Jørgensen, 1997). AEMG was calculated for every 512ms. The maximum AEMG was used as MVE.

Left EMG of one subject was not used because of measurement trouble.

Joint angle

The angles of the right shoulder joint and low-back were measured with goniometers (Biometrics Ltd XM180). The shoulder horizontal flexion, the shoulder abduction and the body flexion were determined. The shoulder abduction was measured as a dip at the shoulder. The measurement, however, failed in some cases by connector troubles. The values sometimes fluctuated in a control posture of simple standing. The angle data were used subsidiarily from these problems. They were used to show the working posture roughly. The expression of 'all subjects' in angle data does not mean exactly all subjects of the experiment. It only means all conditions where the joint angle data were valid.

Statistics

The Wilcoxon matched-pairs signed-ranks test and Kendall rank correlation were used for the statistical test. The significance level was set at $p < 0.05$.

RESULTS

Fatigue sensation and posture

RPE in the three body regions increased during the work periods (Figure 3). The average of the maximum RPE of each subject during the work was 3.2 in the neck, 3.9 in the shoulder, and 2.5 in the low back. Average RPE of each work period were compared with that of the remaining work periods. The statistically significant cases are indicated in the figure. Average RPE of each work increased from W1 to W3 and decreased from W3 to W4. In the shoulder, the average RPE was smaller in W4 than in W2, W3 and W5. The RPE at the start of W2, W4 and W5 were almost the same. These results show that the self-rated work load in shoulder was smaller for the near area condition than for the wide area condition. Although these relations between W4 and the other work

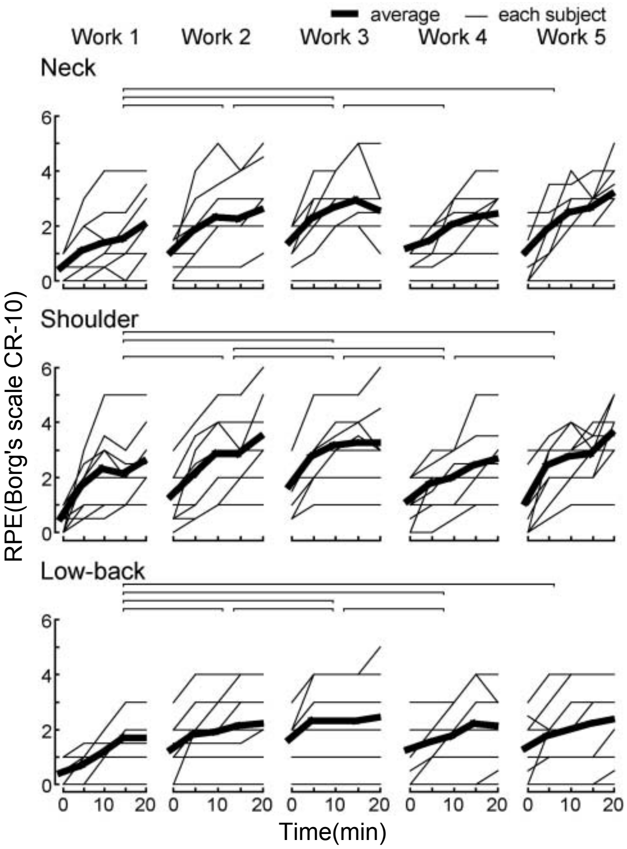

Fig. 3. The changes of RPE during simulated mushroom picking. In Work4, only the nearest half of the mushroom shelf was used. The horizontal bars above the graphs indicate the significant difference in average RPE of each work between the work periods indicated at the tips of the bars. $p<0.05$ ($n = 9$).

periods were also seen in the neck, the difference was only statistically significant for W3. RPE of W5 did not return to the level of W1 in all positions.

The shoulder abduction was larger in the far area picking than in the near area picking in all subjects. The shoulder flexion on the horizontal plane was larger in the near area picking than in the far one in four subjects. The horizontal flexion was not different in four subjects. These indicate the trunk faced the picking shelf perpendicularly rather than parallel in the far area picking to extend the picking arm as in Figure 1. The trunk bended more in the far area picking than in the near area picking except for one subject. The shoulder abduction decreased during W1, W2, W3 and W4 in the near area picking and during W1 in the far area picking. The trunk bending decreased during W1 and W5 in the far area picking. The shoulder abduction was larger during W1 than during W2 in the both area conditions and during W3 than during W5 in the far area picking. The trunk bending was larger during W1 than during W2 and W3 in the far area picking.

EMG during the work

Changes in EMG during the work are shown in Figure 4. Amplitude of EMG (AEMG) increased in some work conditions in the trapezius and infraspinatus.

Average AEMG of each work period appeared to increase from W1 to W3 and W5 in the trapezius. AEMG was statistically smaller in W1 than in W2 and W5. Statistically significant differ-

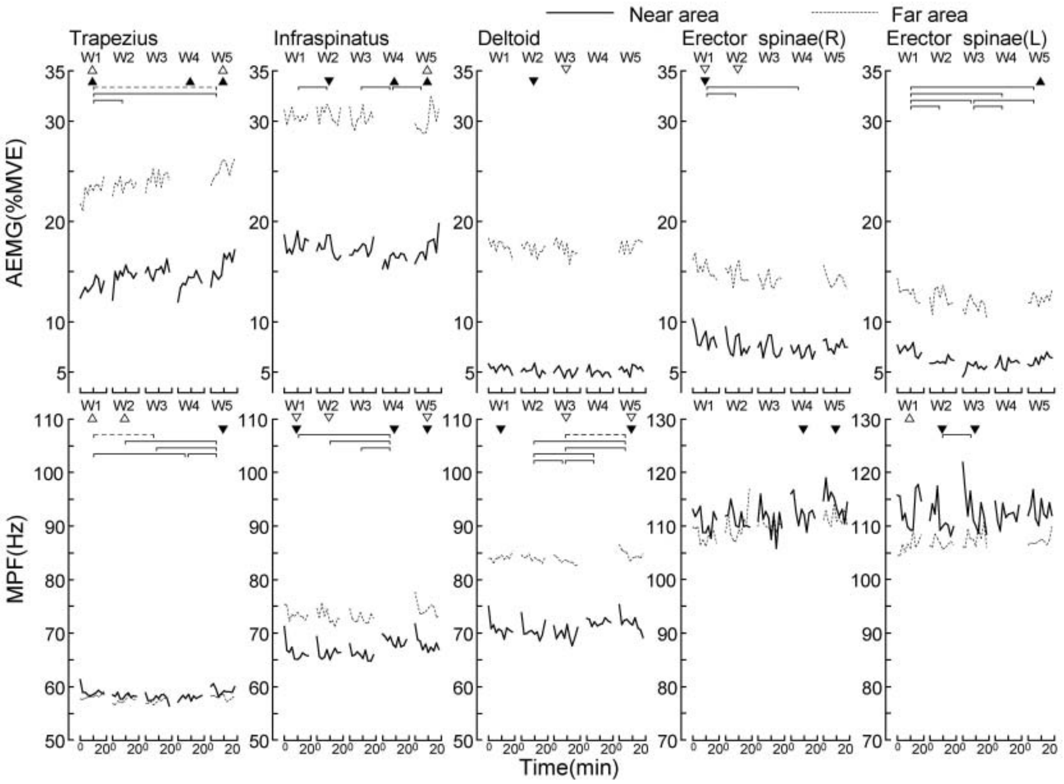

Fig. 4. The average changes of AEMG (%MVE) (upper graphs) and MPF (Hz) (lower graphs) from five muscles during simulated mushroom picking in the average of all subjects (n = 9). The horizontal bars above the graphs indicate the significantly different cases in the same manner of Figure 3. Upward and upside-down triangles symbolize increases and decreases over time, respectively. Results from the picking in the near half of the mushroom shelf were represented in solid lines, solid horizontal bars and filled triangles. Results from that in the far half of it were represented in dotted lines, dotted horizontal bars and open triangles.

ences in AEMGs between the work periods were also seen in the infraspinatus and erector spinae. Most of these differences especially in the erector spinae, however, were not increases but decreases. AEMG was significantly larger in the far area work than in the near area work in all the neck and shoulder muscles. Although the difference between the picking areas was not significant in the erector spinae, p-value was .0506 and .0687 for the right and the left side, respectively. AEMG of the infraspinatus was significantly smaller in W4 than in W3 and W5.

Average MPF of each work period changed little between W1 and W3 in the neck and shoulder muscles. The following cases were statistically significant in MPF.

1) MPF was higher in W4 than in W2 and W3 in the near area picking (infraspinatus, deltoid).
2) MPF was higher in W5 than in W2 and W3 in the near area picking (trapezius, deltoid).
3) MPF was lower in the near area work than in the far area picking (deltoid).
4) MPF decreased during each work period in more than half of the work periods (infraspinatus)
5) MPF was lower in W3 than in W1 in the far area picking (trapezius) and than in W2 in the near area picking (deltoid).

MPF of erector spinae decreased during two work periods in each side in the near area picking. Average MPF in the near area picking, however, increased from W2 to W3 in the left.

Relations between EMG and fatigue sensations

Rank correlations were tested between EMG and RPE (Table 1). The correlations were calculated after the data were transferred to deviations from the averages of each subject. The correlations of AEMG were significantly positive in the trapezius and infraspinatus and negative in the right erector spinae. The correlations of MPF were significantly negative in the infraspinatus and deltoid.

Table 1. Rank correlations between EMG and RPE (rate of perceived excertion) .

RPE	Muscle	Picking area	AEMG	MPF
Neck	Trapezius	near	+	.
		far	+	.
	Infraspinatus	near	+	–
		far	.	–
	Deltoid	near	.	–
		far	.	.
Shoulder	Trapezius	near	+	.
		far	+	.
	Infraspinatus	near	+	–
		far	.	–
	Deltoid	near	.	–
		far	.	–
Low-back	Erector spinae (R)	near	–	.
		far	–	.
	Erector spinae (L)	near	.	.
		far	.	.

+: positive correlation ($p < 0.05$)
-: negative correlation ($p < 0.05$)

DISCUSSION

Character of the work

The work of the experiment was controlled to be equal to real work in its pace and amount on the average. The RPE was largely different among subjects. The maximum RPE for each subject ranged from 2 to 6. Sustained contraction was stopped between the occurrence of apparent fatigue sensation and the occurrence of considerable tiredness or apparent pain (Ohashi and Sato, 1992). The fatigue sensation in their experiment would correspond to the RPE of 2 to 4 in our experiment. The average of the maximum RPE in the shoulder was higher than that of industrial sewing-machine operators in real work (Jensen et al., 1993) and almost equal to the RPE in the low back of bricklayers (Jørgensen et al., 1991). Considering the short duration of the work in the experiment compared with real work, the mushroom picking work was considered to be strenuous for the shoulder and low back muscles.

Using corks must decrease the muscle strain of the picking work since subjects could handle them easily with less care than mushrooms. The difference of weight between corks and mushrooms was not an important factor since the weight is negligible compared with the weight of the upper limb. Continuous contractions were more fatigable than intermittent ones (Björkstén and Jonsson, 1977; Ohashi and Sato, 1992). The picking rate in the work was once per 3 seconds. If the arm was moved slowly and very short time was used to put the cork on the tray, some of the muscles must work almost continuously. The differences in the familiarity and strategy for the picking work could make the differences in fatigability. The changes of posture mainly in the early periods of work suggest subjects were not well accustomed to the work at the start of W1. Low familiarity with the work and forced constant working pace would increase the fatigability.

RPE increased while advancing from W1 to W3. During the following 43-minute rest, RPE decreased a little, but did not return to the initial (start of W1) level. In W4, workspace was limited to the near area to the body. Although AEMG was higher in the far work area than in the near area, the differences of RPE between W4 and the others were not apparent in the neck and low back. A subject reported that the neck was fatigued more easily in W4 because she was always looking at a small limited area.

EMG

AEMG decreases and MPF increases were sometimes seen during the work periods. These changes are opposite to the common findings during fatiguing contractions (e.g. Kogi and Hakamada, 1962; Krogh-Lund and Jørgensen, 1991). It is reasonable for animals to intend to perform requested work at the minimal cost. The opposite EMG changes were possible to be a way for the preferable management of the work. Even in this laboratory experimental work, where a picking pace were controlled and EMG parameters were averaged for long duration for each picking area, the common EMG changes could not be sometimes extracted under apparent increases in RPE. Various modes of EMG changes should be considered to assess muscle strain in real work situations. In the following paragraphs, an attempt is made to relate the EMG changes to the muscle strain estimated by RPE and experimental conditions.

Amplitude of EMG

An increase in the EMG amplitude is usually interpreted as development of muscle fatigue if the contraction level is kept constant. In our experiment, however, subjects could modify the posture and motion for the work to some degree and this modification might change the EMG amplitude. The shoulder abduction and the trunk bending decreased in the early work periods, i.e. the subjects might change their posture to decrease their strain. Trapezius AEMG increased during some work periods and with the repetitions of the work. In deltoid, AEMG did not increase and even decreased during a far area picking although the fatigue ratings were the largest in the shoulder. One may speculate if the decrease in AEMG of the deltoid was caused by migration of the muscle activity (Sjøgaard et al., 1986; Ohashi, 1995) as an attempt to decrease its strain.

The decrease in AEMG, of course, does not always relate to fatiguing contractions. In the right erector spinae, AEMG decreased during the work although RPE was low in the low back. Additionally the AEMG of the left erector spinae also decreased with the repetitions of the work from W1 to W3 in the near area picking. AEMG in the erector spinae was the lowest in this condition. The decrease of the erector spinae AEMG in the low activity situation may not probably be caused by migration of the strain to the synergists. We suppose that adaptation to the work increased the efficiency of the motion and posture, and therefore decreased the muscle activity. In a low activity condition, a muscle might often be activated ineffectively since it can easily increase its activity. The adaptation can decrease AEMG easily in such a case. Since the adaptation, which includes modification of the work, is more important in a high load condition than in a low one, the decrease in AEMG of the right elector spinae during the work was also reasonable. The decrease in the trunk bending in the early work periods might also be one of the adaptations to the work, and contribute to the decrease in AEMG. When subjects were not accustomed to the work, the adaptation may be easily obtained.

Generally the AEMG was larger in the far area picking than in the near area picking (Figure 4). AEMG of infraspinatus was smaller in W4 than in W3 and W5. Although the smaller AEMG cannot directly show smaller fatigue development in W4 due to the preceding rest period, it might suggest an increase in the spare capacity for the work, which means remaining ability of muscle force generation here, in the synergist.

MPF

The rate of higher frequency components of surface EMG power spectrum is larger in stronger contraction level than in weaker one (Gander and Hudgins, 1985; Hagberg and Ericson, 1982). A larger rate of higher frequency components of surface EMG is also reported in shorter muscle length than in longer (Bazzy et al., 1986; Okada, 1987). Both stronger contraction level and shorter muscle length could contribute to the lower MPF of the deltoid in the far area picking than in the near area picking. The difference in muscle length between the near and the far area picking will be the largest in the deltoid among the shoulder and neck muscles studied. Although AEMG was larger, MPF was often lower if the muscles were expected to be lengthened, e.g. the erector spinae. This muscle was expected to be longer in the far area picking than the near one by bending the low back. Thus the left and right erector spinae MPF was lower in the far area picking than in the near one in 13 of 15 cases (subject x side) where the AEMG was larger in the far area picking than in the near one. Moreover, the finding was the most pronounced in the left erector spinae, which was more lengthened in the far area picking than in the right erector spinae by bending for extending the right arm for the picking. The right trapezius was probably lengthened by inclining the head to the left to keep it away from the upper shelf edge. The trapezius MPF was lower in the far area picking than in the near one in 6 of 8 cases where the AEMG was larger in the far area picking. Thus the muscle length might affect the difference of MPF between the near and far area picking more than the contraction level did.

Generally, the MPF fluctuated during the work periods and its trend was not clear. Although MPF of infraspinatus decreased during the work periods, it was not constant. MPF even increased in the trapezius in the far area condition. MPF was significantly different only in two comparisons between W1, W2 and W3 in the shoulder and neck muscles although RPE developed with the repetitions of the work from W1 to W3. MPF was correlated to RPE in two muscles. The relations, however, were gross ones.

In the left and right erector spinae, MPF decreased only in four of the 18 working periods studied. The MPF changes coincide with the insignificant MPF changes of the erector spinae muscles (Jørgensen, 1997). The average RPE of the low back was smaller than that of the neck and the shoulder although it was not statistically significant. One reason for the fatigue resistance in the erector spinae muscles is the large number of slow twitch muscle fibers (Jørgensen et al., 1993). Fatigue state of low back was not though to fluctuate much. MPF, however, fluctuated much in the erector spinae. Fatigue seemed to affect MPF less than other factors. Although fatigue state could not be determined with MPF, it was supposed to be low or moderate.

Assessment of the work with EMG

The muscle strain caused by the work was assessed with EMG as follows. The significantly higher MPF in W4 than in the remaining work periods shows that the smaller workload affected muscle fatigue to a lesser degree in W4 than in the other work periods. The infraspinatus and deltoid showed such relations of MPF. Correlations between MPF and RPE were significant in the muscles. Existence of the correlation suggests that an activity level was relatively higher in these muscles than in the synergists, e.g. the trapezius. And consequently it is supposed that the infraspinatus and deltoid were more fatigued than the trapezius. AEMG was increased but MPF did not show development of fatigue in the trapezius. One might speculate that the trapezius increased its activity, AEMG, to compensate for the decreased strength in the fatigued synergists. The spare capacity, remaining ability of muscle force generation, for the work might be larger in the trapezius than in the other muscles. No signs of fatigue development was present in EMG in the erector spinae.

The assessments of the muscle strain by EMG were in concert with RPE. Although EMG provides precious information about the state of muscles, little information can be certain if there is no data in addition to EMG. Muscle strain is affected by certain factors in real work situations, e.g. duration, rest, posture, blood flow, and muscle disorder. Therefore, the integration of several kinds of information is needed to assess the work-related muscle strain, and surface EMG during work can be used as available information.

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