Surface electromyograms (EMG) during test contractions (TCs) were studied to assess the muscle strain in simulated mushroom picking. Additionally, the duration of the TC for the effective assessment was investigated. Nine female subjects performed standardized shoulder abduction and a stooped posture for one minute as TCs. Each experiment consisted of a 60-min rest, three work periods (W1-W3), a 30-min rest, and two work periods (W4 and W5) separated by a 30-min rest period. The duration of each work period was about 20 min. A total of 18 TCs was performed between the work periods and every 10 minutes in the rest periods. EMGs were recorded from the trapezius, infraspinatus, deltoid, and erector spinae muscles. The amplitude of EMG (AEMG) and mean power frequency (MPF) of EMG were calculated. Each TC was divided equally into three parts. Ratings of perceived exertion (RPE) in the neck, shoulder and low-back were reported during TCs. The work increased RPE of all the parts. AEMG and RPE were increased and MPF was decreased by W1, W2 and W3 in the neck and shoulder muscles. MPF of the erector spinae was increased by the work. The results were not affected by the duration of TCs and the parts during the TCs. AEMG and MPF fluctuated before W1 although the changes of RPE were small. Averaging several TCs was recommended to get stable results from TCs. EMG changes and appropriate TC conditions were discussed in relation to the adaptation in fatiguing contractions.

**Key words:** real work; muscle fatigue; MPF; AEMG

**INTRODUCTION**

Surface EMG has been studied to evaluate muscle fatigue for more than fifty years. It is, however, still difficult to use EMG in an industrial setting. In former industrial EMG investigations, the amplitude and the frequency spectrum of EMG have most frequently been applied. Since the amplitude of EMG relates directly to the mechanical level of muscle contraction, it inevitably varies depending on jobs. The frequency spectrum is also influenced by the activity level although its change is less than that of the amplitude (Gander and Hudgins, 1985; Hagberg and Ericson, 1982). There are some methods to avoid the influence of the contraction level and other factors such as muscle length, motions, and electrode dislocation (Bazzy et al., 1986; Ohashi et al., 1985; Potvin, 1997; Saitou et al., 1996), which also influence EMG. A simple method is recording EMG during well defined activities (reference activities), e.g. holding or lifting a certain object or by maintaining a defined posture (e.g. Luttmann et al., 2000). Picking up the activities and posture, however, is sometimes troublesome. Even if muscle activity varies momentarily by motions and the posture...
depending on the job, the total muscle activity can be equal among the conditions with the same total job. Therefore, although EMG varies momentarily, the average EMG in muscle activities over a long duration is expected to be similar if the amount of activity is the same as far as muscle fatigue does not occur. To avoid the influence of changes in the activity level while interpreting the EMG from real work, it is recommended to use simultaneous analysis of both the spectra and amplitude as muscle fatigue indices (Luttmann et al., 1996).

If the real work contains large EMG changes in the activity level, the evaluation of muscle fatigue might be difficult, and therefore well defined test contractions (TCs) are worthwhile to be used (Hägg et al., 1987). Muscle-fatigue-related changes are shown during TCs in connection with industrial working operations (e.g. Bosch et al., 2006; Jørgensen et al., 1991; Meyer and Radwin, 2006). Although the test contraction seems to be a valuable method for the evaluation of muscle fatigue in real work, the conditions of the TC are not well studied. The contraction level and the duration of TCs are not standardized in the different studies. TCs which induce a considerable level of fatigue as a fatigue test cannot be performed frequently during work of a day (Jørgensen et al., 1991). Light contractions of short duration are desirable in order to minimize the load on the subject and the effects on the work caused by the TCs. On the other hand, light-to-moderate fatigue development by TCs has the possibility to emphasize and clarify the difference in the fatigue state during the TCs. If fatigue occurs during the TCs, the fatigue development will probably be larger in the later part of a long TC. Since longer EMG sampling durations generally result in more precise estimates of exposure (Fethke et al., 2006), longer recording during TCs has possibility to yield more stable results. Longer EMG samplings can be obtained by lengthening and repetition of the TCs.

The present study was part of an investigation aiming to assess the muscle strain during simulated mushroom picking by means of surface EMG. Muscle strain of the picking work was evaluated with EMG during the work in the previous study (Ohashi et al., 2008). The purposes of the present study were to 1) assess the muscle strain of the work based on EMG samplings during interposed test contractions and 2) investigate if the duration of the TC and the temporal placing of the EMG samplings within the test contraction affects the muscle strain assessment.

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, BMI: 21.6(18.6-23.9)) volunteered as subjects after their informed consent was obtained. They had not performed mushroom picking work before the experiment, and they did not have any physical problem relating to the experiment.

Test contractions

A stooped posture and a bilateral arm abduction with a light horizontal flexion in upright standing (Fig. 1) were used as a test contraction (TC) for the trunk extensors and the shoulder abductors, respectively. The duration of each TC was one minute. In the stooped posture, the stretched arms were kept vertical downward and the trunk was stooped until the metacarpophalangeal joint touched the edge of a desk 0.70m above the floor level. The feet were parallel and the tip of the feet was positioned 0.18m or 0.25m, for small and tall persons, respectively, in front of the vertical projection of the desk edge on the floor. The subjects were requested to look at a certain point in front of them with the head maintained in a vertical position.

In the shoulder abduction posture, the upper arms were abducted horizontally and rotated outward with the elbow flexed until the tips of the index fingers touched the upper edge of the ears. A board was placed parallel to the frontal plane of the subjects. A bar of 0.10m length was attached perpendicular to the center of the board at a height equal to the vertical floor - acromion distance. The TC posture was defined by the elbows and the upper part of the sternum (manubrium) touching the
board and the bar, respectively. The stooping posture was always performed prior to the shoulder abduction.

The TCs were practiced before the experiment. The practice was continued until a stable amplitude and MPF of EMG were observed in several consecutive TCs separated by a rest of two min.

*Mushroom picking*

Mushroom picking was simulated in a mock-up laboratory model 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 with space of about 0.35m between them (Fig. 2). 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 picking two corks up by the dominant hand (right) and put them on a tray held by the other hand. The subjects were told to treat the corks as mushrooms. Some of the corks were marked by a 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 weight of the corks was almost equal to that of real mushrooms (approx. 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. The picked corks were replaced by an experimenter without disturbing the picking. A wide area condition and a near area condition were defined by the depth conditions of the picking areas. In the wide area condition, the picking areas were alternated between the depth conditions (near to the body and far from the body) every one-minute. In the near area condition, only the near area was used.

![Fig. 1. Postures of the test contractions. A stooped posture (left) and a bilateral arm abduction with a light horizontal flexion (right).](image)

In the stooped posture the metacarpophalangeal joint touched the edge of the box (a desk) and the distance between the box and the toe was kept constant. Subjects were requested to stare at a certain point. In the arm abduction the position was defined by the touches of the finger to the upper edge of the ear and the touches of the elbows and chest to the experimental apparatus.
Main procedure

The time schedule of the experiment is shown in Fig. 3. The experiment consisted of rest periods, five work periods (simulated mushroom picking) (W1-W5), and 18 TCs (TC1-TC18). The duration of each rest and each work period was 10 min and 20 min 15 s respectively. The sequence of the periods was six rests, three works (W1, W2, W3), three rests, one work (W4), three rests and one work (W5). The TCs were performed before the first rest, after W5, and between every rest and work periods. W4 was performed in the near area condition and the other works were performed in the wide area condition. The period prior to W1 is named pre-work (control) and the remaining period the main part. The average of the pre-work is used as the control.

Maximum voluntary contractions (MVC) for the elevators, ab- and adductors of the shoulder and the trunk extensors were determined prior to the practice of TCs.

Psychophysical ratings

Ratings of perceived exertion (RPE) of the neck, shoulder and low back were reported at 0 s, 30 s, and 60 s of each TC 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 at L4 to L5. The recordings were obtained bilaterally from the erector spinae and only on the right side from the other muscles. Disc electrodes (10 mm in diameter) were attached parallel to the muscle fibers with an interelectrode distance of...
about 25 mm. In the 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. The infraspinatus was identified by the outward rotation of the upper arm. In the 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 the fast Fourier transform method. The power spectrums were averaged for every 9.2 s. Amplitude (AEMG) was calculated as the square root of power between 3.9 and 386.7Hz. Mean power frequency (MPF) was calculated for the same frequency range. AEMG were calculated for every 512ms during MVC. The maximum AEMG was used as the maximum voluntary electric activity (MVE). AEMG was used as percent of MVE. AEMG and MPF were calculated from 4 seconds after the start of a TC for every 9.2 seconds six times in each TC. The six points of data were used in Fig. 5. The data were averaged for the first two, the middle two, and the last two data points, and they were also averaged for all of the six data points. The averaged data were called the start, middle, end and whole, respectively. The "analysis part of a TC" means these three segments and the whole of one TC.

Statistics

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

RESULTS

Fatigue sensation

The average RPE of each TC is shown in Fig. 4. The RPE from the neck and shoulder increased from W1 to W3, and it did not return to the pre-work level during the experiment. In the low-back, the RPE after the rest periods following W3 and W4 was reduced and was not always significantly higher compared to the control. The RPE increased even before the first working period (W1). The series of TCs (TC1-7) during the pre-work period affected RPE significantly.

Gross changes of EMG

Changes of AEMG and MPF are shown in Fig. 5. The results are presented in the same manner as in Fig. 4. Although the average AEMG of each TC changed and fluctuated before W1 (TC1-7), the changes in the neck and shoulder muscles after W1 were larger and related to the work periods. AEMG decreased slowly toward their pre-work levels during the following rests. In trapezius, however the recovery was not completed during the experiment. The AEMGs in the TCs from the trapezius immediately after the work periods were different mainly between W1-W4. In the infraspinatus and deltoid, statistical difference was only present in one case. No AEMG increases were observed in the erector spinae.

MPF from the shoulder and neck muscles decreased from W1 to W3 and increased slowly toward pre-work levels during the following rest periods. Statistically significant decreases from W1 to W3 were observed most often in the infraspinatus. The changes of the MPF from the erector spinae were not consistent. Although the MPF decreased with time during each TC, it increased in the TCs after the work periods compared with the level before the work period. In the shoulder and neck muscles, such complicated changes were also observed. In one subject, the infraspinatus MPF always increased during each TC although the average MPF of each TC decreased after W1 and W2. The deltoid MPF was considerably larger in the main part than in the control in one subject. The opposite directed changes were the main reason for the lack of statistical significance in the MPF changes compared to the control in the deltoid muscle.
Fig. 4. The changes of RPE. W1, W, W3, W4 and W5 indicate that the graph below the respective letters corresponds to the test contraction just after the simulated mushroom picking rounds: work1, 2, 3, 4 and 5. '-' symbolize that the average RPE is significantly lower in the test contraction just below the symbol compared to the control, which is the average RPE of the first seven test contractions. The symbol '+' indicates significantly larger cases (p<0.05). The horizontal bars above the graphs indicate significant difference in the RPE between the work indicated at the tips of the bars (p<0.05).

Rank correlations were tested between the whole part of EMG and RPE (Table 1). Changes from the control for each subject were used for the calculation. AEMG correlated positively in the trapezius. MPF correlated negatively in most shoulder and neck muscles. The correlations of the left erector spinae were opposite to those from the shoulder and neck muscles.

Effects of the temporal placing of the EMG samplings within the TC.

Statistically different cases between the pre-work level and the main part were counted and summarized in Figs. 6 and 7. The comparisons were tested for all analysis part of TC, that is the start, middle, end and whole part of each TC. The numbers by the subtraction of the significantly decreased
The changes of AEMG (upper graphs) and MPF (lower graphs). The interval of data in each TC was 9.2s and each TC contains six points (55.2s in the total analysis duration). The symbols and the horizontal bars above the graphs indicate the significantly different cases as in Fig. 4.

Table 1. Rank correlations between EMG and RPE. Significances of correlations between whole part of EMG and RPE.

<table>
<thead>
<tr>
<th>RPE</th>
<th>Muscle</th>
<th>AEMG</th>
<th>MPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>Trapezius</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Infraspinatus</td>
<td>.</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Deltoid</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Trapezius</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Infraspinatus</td>
<td>.</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Deltoid</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Low-back</td>
<td>Erector spinae (R)</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>Erector spinae (L)</td>
<td>-</td>
<td>+</td>
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</tbody>
</table>

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

case count from the significantly increased one are shown. Figure 6 was arranged for the comparison among the analysis parts of a TC. Large similarity of calculated fatigue indices within each of the shoulder and neck muscles investigated was demonstrated. Figure 7 shows the variation among the pre-work part without respect to the analysis part of a TC. The results of all analysis parts of a TC were averaged. Large variations were seen among the TCs of the pre-work part.
Differences in the changes of RPE and EMG

RPE showed a fatigue level developed during the work periods and did not return to the pre-work level during the experiment. In the shoulder and neck muscles, AEMG and MPF also changed roughly relating to the works and rests. Some of them did not return to the pre-work level during the experiment in the average. These changes of EMG resembled to those of RPE. Statistically significant cases of the differences between W1-W3, however, were much less in EMG than in RPE, which is in concert with the results by Jørgensen (1997). Rank correlations between EMG and RPE were not significant in some conditions. All together EMG showed weaker fatigue development than in the case of RPE. One reason for this might be that the fatigue expressed as perceived exertion also occurs in other tissues than in the skeletal muscles e.g. tendons and joints.

Interpretation of the increase in MPF by work

Gross changes of EMG in the neck and shoulder muscles were easy to be interpreted as development of fatigue. MPF of the erector spinae, however, changed inconsistently. MPF increased after the work but decreased with time during a TC. There were a few analogous cases in other muscles. Deltoid MPFs at the start of a TC were higher after W1 than before W1 in six subjects. In four of them, however, the MPF at the end of the TC was lower after W1 than that before W1. The increases in higher frequency components were reported during low-level fatiguing contractions.
ASSESSMENT OF MUSCLE STRAIN WITH EMG OF TEST CONTRACTIONS

(Hagberg, 1981; Hägg, 1991), and can be caused by the recruitment of motor units with higher conduction velocity of the muscle action potential (MAPCV) (Arendt-Nielsen et al., 1989; Krogh-Lund and Jørgensen, 1991; Schulte et al., 2006a). Suzuki et al. (1990) reported that a previous contraction decreased the recruitment threshold of motor units in the following contraction. The motor units with higher recruitment threshold are expected to have higher MAPCV (Andreassen and Arendt-Nielsen, 1987). The work would activate the motor units with the higher MAPCV, and therefore many active motor units probably alternated during the work. If the zone of the motor endplates (innervation zone, IZ) is located between bipolar EMG electrodes, especially at the center of them, the EMG amplitude tends to be smaller and the EMG signal has a relatively large rate of high frequency components (Beck et al., 2008; Saitou et al., 1996). The recruitments of motor units in such a location do also increase MPF. Since IZs are scattered in the deltoid (Saitou et al., 2000), such recruitments may occur. In the erector spinae such recruitments also probably explain the MPF increase by the work since the MPF increase was not accompanied with an increase of RMS. Although the cause of the MPF increase is not determined, it is thought to be related with new recruitments of motor units. Thus considerable amount of active motor units must overlap between the target work and test contractions.

The adaptation to the work as the cause of EMG changes during fatiguing contractions

Significant EMG changes were reported even in light works with light fatigue (Jørgensen, 1997; Hostens and Ramon, 2005; Rosendal et al., 2004). The changes of EMG in the TCs also seem to relate fairly well to the work in this experiment although the relations between RPE and EMG were not high. On the other hand, MPF in trapezius was reported to be inappropriate as an estimator of muscle fatigue at low-level contractions since it did not decrease significantly even in endurance contractions, causing the occurrence of significant subjective fatigue (Gerdle et al., 1993; Hägg and Ojok, 1997; Öberg et al., 1994). The inconsistent relations between EMG and muscle fatigue suggest some factors affect EMG during fatiguing contraction in addition to changes in biochemical and/or bioelectric property of muscle fiber as muscle fatigue. We think adjustment of motor unit activities to fatiguing contraction is one of the factors as follows.

It was observed that substitutions of active motor units took place during low level contractions and tasks (Westad et al., 2003; Westgaard and De Luca, 1999). Moreover, it was speculated that the reason for the substitution was to protect motor units from excessive fatigue in sustained contractions (Westgaard and De Luca, 1999). The changes in the motor unit activities during fatiguing contractions occur possibly as an adaptation to the contractions, which to a certain degree might protect the muscles. Since the adaptation affects the surface EMG during fatiguing contractions, the EMG changes do not have to relate linearly to the fatigue level. In strong contractions, active motor units cannot alternate much since most motor units already are activated. Therefore, the possibility to change EMG more apparently in light contractions (Jørgensen, 1997; Hostens and Ramon, 2005; Rosendal et al., 2004) than moderate ones (Gerdle et al., 1993; Hägg and Ojok, 1997; Öberg et al., 1994) is present.

The muscles with disorders are reported to show smaller changes in myoelectric activities such as the amplitude and frequency spectrum of surface EMG, MAPCV, and the discharge rate (Kallenberg et al., 2007; Öberg et al., 1992; Schulte et al., 2006a, b). This relation can be explained easily if the cause of the EMG changes is thought as adaptation to the fatiguing contractions as follows. Small EMG changes suggest small adaptation to the contractions. The small adaptation can lead to small and insufficient protection of the muscle and sometimes cause muscle disorders. Therefore, people with muscle disorders might show the smaller EMG changes during the fatiguing contractions.

The adaptation, which relates to substitution and protection of active motor units, is worthwhile to be thought as a cause of EMG changes during fatiguing contractions in addition to the biochemical impairment of muscle fibers although the mechanism is not certain.
EMG changes related with the substitutions of active motor units among TCs and during a TC

The substitutions of motor unit activities can be attained by changing the recruitment order of motor units. The change of the recruitment order is usually difficult if the task is completely the same (DeBakker et al., 1983; Jones et al., 1993) since the recruitment order is basically defined by the size principle (Henneman, 1981). The change of the recruitment order, however, can sometimes be attained by a small modification of the task (Person, 1974). If a requested task is easy for a subject, it can be managed with some modification such as force generation and a posture without any alternation in the appearance of the task, i.e., the subject has the possibility to perform the task with certain flexibility. The change of the recruitment order might sometimes occur among the TCs in this experiment because the contraction level was low, the posture was natural and simple, and reproduction of exactly the same posture was difficult. The recruitment order, however, would not change easily during a TC because the posture was tried to be kept constant.

These suppositions can explain some observations such as MPF decrement by the work without the decrement during each TC and the fluctuation of MPF and AEMG among the TCs before W1 without related changes of RPE (Figs. 5 and 7). The lengthening of the analysis duration did not yield any improvement in the average sensitivity of fatigue detection. The averaging of the repeated TCs, however, is important since the EMG variation is large among the trials.

Additionally we suggest that the above mentioned condition, that is easiness of fluctuations of EMG, also affects the fatigue-related changes of EMG. It may be appropriate if CNS modifies the motor unit activities during fatiguing contractions. If an intended work task, however, must be performed by few synergists and in a fixed recruitment order, the motor unit activities may not change even in a fatigued state. Motor unit activities may change more easily relating to the fatigue state under easy contractions where various modifications of motor unit activities are allowed to perform an intended work task. Since the TCs of the present experiment consisted of easy contractions, EMG of the shoulder and neck muscles could change relating to the work. On the other hand, the easy contractions also allow changes of motor unit activities not related to the fatigue state, which is phrased as fluctuations. Thus EMG of TCs by easy contractions must be used by taking their fluctuation in consideration.

Assessment of the muscle strain

Management of fatiguing contractions, a kind of adaptation to the work, may be different among individuals in some degree. If some of the EMG changes related with fatiguing work are caused as adaptation, there is no wonder if the changes relative to fatigue changes are different among subjects. Large EMG fluctuations among TCs as well as among subjects also must influence statistical tests significantly. The cases of statistically significant difference were less in the deltoid than in the trapezius and infraspinatus because of large fluctuations of a few subjects in the deltoid (3.2). If the large fluctuations are related to the IZs (4.2), they will depend on the distribution of the IZs, which is different among muscles (Saitou et al., 2000). Furthermore, the large fluctuations might be one of the EMG properties in easy contractions (4.4). Therefore the degree of the muscle strain should not be determined by the number of the statistically different cases if the sample size is small. We suggest that EMG during each single test contraction only can show roughly whether the muscle strain should be considered as a critical factor or not. In conclusion, the work of the experiment was determined fatigue inducible both for the neck and shoulder muscles although the difference of the effect level between the muscles was not determinable. The strain of the low back muscles was uncertain since the fluctuations were too large.

Recommendation and notice for the use of test contractions

Surface EMG during test contractions has the possibility to evaluate muscle strain. Low-level and easy performable contractions may be suited for the test contractions. Repeated contractions are more effective for improvement of the reliability of test contractions than extended contractions. It must be noted that EMG does not change linearly to the fatigue level of the muscle although it
changes relating to work. Since the changes of the fluctuations and the inter-individual difference are often large, the changes should be investigated with additional assessments of the muscle strain such as rate of perceived fatigue (RPE) and muscle performance.

REFERENCES


