Fatigue Sensation and Surface Electromyogram during Sustained Shoulder Flexion with Spontaneous Alternations of Working Arm

Junya Ohashi and Haruhiko Sato
Department of Ergonomics, Kyushu Institute for Design Research

Sustained contractions were compared between with (AW) and without (NAW) spontaneous alternations of working arm to investigate the fatigue level at which the contraction is felt to be stopped. Subjects maintained an upper limb in the horizontally flexed position at 5%, 10%, 15% and 20% of maximum voluntary contraction strength (MVC). Contractions were continued until they felt exhausted or 45min. had passed. Fatigue level was evaluated with 4 levels of fatigue sensations and surface electromyogram (EMG) of the deltoid. Mean amplitude (AEMG) and relative power in 8-40Hz (RPLF) of EMG were calculated. The following results were obtained. Fatigue level was lower in AW than in NAW for the same amount of work done by one arm. As AEMG often decreased with time, fatigue was estimated by relating AEMG to RPLF. At 20% MVC in AW the alternation interval decreased and the muscle fatigued with repeated contractions though the fatigue level was not severe. Contraction was felt to be stopped when the first fatigue sensation occurred. But it was not necessary to stop the contraction until considerable tiredness or apparent pain occurred.


Key words: Fatigue sensation, Electromyogram, Sustained contraction

Although machines have replaced human in many kinds of work, low level static contractions are seen in assembly work (Bjelle et al., 1981), building works (Malmqvist et al., 1981) and even in writing (Sakurai and Miwa, 1975). The prolonged static contractions sometimes causes disorders (Suurkuula and Hägg, 1987). The static contractions have been studied from the view point of the relation between contraction levels and endurance time (Björkstén and Jonsson, 1977 ; Monod and Scherrer, 1965 ; Moritani et al., 1981). Since the work is not continued till exhaustion in actual work, we showed the relations between contraction levels and the times at the onset of fatigue sensations (Sato and Ohashi, 1988). But it is not known at what level of fatigue works are stopped in the actual work. In some experiments we asked subjects to report when they wanted to stop work. But they often missed the report since the criteria of stopping work was dependent on the reward for continuing work. Tanii et al. (1972) studied 30min. static works with and without spontaneous alternation of working arms. They showed the level of fatigue sensations the arm was altered at. But the expressions of fatigue sensations were different between Tanii and our previous experiment (Ohashi et al., 1987; Sato and Ohashi, 1988; we call this experiment our previous experiment in this report.). The effects of contraction levels have not been examined yet.

In this report we studied the relations between the alternation of working arm, fatigue sensations and fatigue by comparing the fatigue sensations, work time and surface EMG between the experiments with and without permitting the alternations of working arms like Tanii et al. (1972).

METHOD
Subjects were seven males. They were asked to
hold their arm in the horizontally flexed position as their work. Contraction levels were set at 5%, 10%, 15% and 20% of maximum voluntary contraction strength (MVC). Weights were hung at the distal part of the upper arm. At 5 and 10% MVC the arm was sometimes pulled up by weights for the compensation of weight of the arm (Fig. 1). MVC was measured at the point where the weight was hung with the strain gauge dynamometer for the right arm (Table 1). The experiments consisted of two types of work. They were requested to hold the position either with or without spontaneous alterna-
tions of working arm until they felt exhausted or 45min. had passed. In this report, the work with the alternation of the arm is called AW and the work without the alternation is called NAW. The weight was transferred by the subject in AW. In NAW subjects were requested to report fatigue sensations of the following.

“DARUI” (feeling of tiredness)
“KANARI DARUI” (feeling of considerable tiredness)
“ITAI” (feeling of pain)
“KANARI ITAI” (feeling of intensive pain)
“DARUI” was used as a general term meaning the first fatigue sensation without pain. In AW subjects started to hold the position at the right arm and changed the working side freely. In all AW conditions, subjects could endure the work for 45min. In this report ‘each AW’ and ‘contraction’ in AW mean a sustained contraction between successive alternations of the working arm. ‘Whole AW’ means a series of contractions with alternations till 45 min. had passed. Intervals of experiments were longer than a day. The order of experiment conditions were set to be counterbalanced among subjects. Bipolar surface electromyograms were recorded from the middle part of deltoid on the FM tape recorder. EMG was converted from analogue to digital at 1024Hz. Mean amplitude of EMG (AEMG) was calculated as the mean value of absolute amplitude. EMG power spectrum was obtained with FFT method. Relative power in 8-40Hz to power in 8-400Hz of EMG (RPLF) was calculated. Interval of analysis was chosen from 2, 4, 8 and 16sec. according to the endurance time of the work. Paired-t-test and correlation coefficient were used for statistical analysis. The level of significance was chosen at p < 0.05.

RESULTS

In NAW the onset time of each fatigue sensation usually became longer with the lowering of the contraction level (Table 2). The onset times were

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**Table 1** Age and maximum voluntary contraction strength (MVC) for each subject

<table>
<thead>
<tr>
<th>subj.</th>
<th>age (yrs.)</th>
<th>MVC(N)</th>
<th>right</th>
<th>left</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>23</td>
<td>250</td>
<td>224</td>
<td></td>
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<tr>
<td>B</td>
<td>24</td>
<td>257</td>
<td>225</td>
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<td>C</td>
<td>25</td>
<td>262</td>
<td>242</td>
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<td>D</td>
<td>25</td>
<td>247</td>
<td>222</td>
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<tr>
<td>E</td>
<td>26</td>
<td>268</td>
<td>254</td>
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<tr>
<td>F</td>
<td>26</td>
<td>204</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>28</td>
<td>282</td>
<td>232</td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>25</td>
<td>253</td>
<td>229</td>
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</table>
irregular in relation to the contraction level in 3 cases. At 10% MVC in NAW only one subject could not endure the work for 45min.

The changes of AEMG, RPLF and alternation interval were shown in Fig. 2. Whole AWs were divided into 7 parts for each side for the statistical comparison; first contraction and six-divided contractions (section 1–6) for the rest. AWs that had less than 7 contractions for one side were not analyzed. The number of AW that had contractions more than 7 times for one side were 2, 6, 12, 14 for 5, 10, 15, 20% MVC AW, respectively. As the analyzed cases at 5% MVC AW were few, the results for 5% MVC AW are not shown in Fig. 2. The alternation interval and RPLF were shown by the difference from the value at the first contraction. AEMG was shown by the ratio to the value at the first contraction. RPLF and AEMG were analyzed for three parts: data at the start, end and the mean of each AW. The circles above the graphs represent significant differences between 7 parts of contractions. The decrease in alternation interval at 20% MVC was apparent in some cases. The alternation intervals at 10% MVC were longer at the first contraction than at the later contractions though the differences were not significant because of a large variance. At 20% MVC in AW, the alternation intervals of the 1st contraction were significantly longer in the right arm than in the left arm, which started the contractions after the right arm.

Alternation intervals were related with the onset time of fatigue sensations for each subject in Fig. 3. The points above the identical line means that alternation interval was shorter than the onset time of fatigue sensation. Time range was limited to 10min. to show the details. The alternation intervals were shown for the shortest, first and second contraction of the right arm. At the first contraction, alternation intervals varied beyond the range between the onset time of tiredness and pain. At the second contraction, most alternation intervals ranged between the onset time of tiredness and pain. The shortest alternation intervals were shorter than the onset time of tiredness in 68% of the cases. In the 1st and shortest contraction, the ratio of alternation time relative to the onset time of tiredness was longer at 20% MVC than at 10 and 15% MVC except for 1 case and 6 cases in which the onset times of tiredness were irregular in relation to the contraction level. Alternation intervals were shorter than the onset time of tiredness in 8 cases in the 1st contraction. In 4 of 8 cases, the longest alternation interval in whole AW was longer than the onset time of tiredness. In 1 of 8 cases, contraction was repeated once and the alternation time of the left arm was 2.5 times of the onset time of tiredness. In 2 of 8 cases, the subject was the identical and his onset time of fatigue sensation was irregular; onset times of tiredness were 92,166 and 49sec. at 10, 15 and 20% MVC and no report of fatigue sensation at 5% MVC. The shortest alternation time was fairly longer than the onset time of considerable tiredness for one subject at 10% MVC where the number of alternation was 3 for each side (about 8min. of alternation intervals in Fig. 3).

Table 2 Time at the onset of fatigue sensations

<table>
<thead>
<tr>
<th>fatigue sensations</th>
<th>contraction level (%MVC)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>DARUI</td>
<td>- (3'21&quot;)</td>
<td>4'48&quot; (1'32&quot;-11'9&quot;)</td>
<td>2'17&quot; (1'2&quot;-3'32&quot;)</td>
<td>1'9&quot; (44&quot;-1'29&quot;)</td>
<td></td>
</tr>
<tr>
<td>&quot;KANARI DARUI&quot;</td>
<td>- (4'57&quot;)</td>
<td>5'46&quot; (2'59&quot;-10'33&quot;)</td>
<td>3'12&quot; (1'51&quot;-4'32&quot;)</td>
<td>1'45&quot; (1'13&quot;-2'2&quot;)</td>
<td></td>
</tr>
<tr>
<td>&quot;ITAI&quot;</td>
<td>- (8'33&quot;)</td>
<td>11'23&quot; (4'26&quot;-19'11&quot;)</td>
<td>4'23&quot; (2'14&quot;-6'57&quot;)</td>
<td>2'33&quot; (2'4&quot;-3'13&quot;)</td>
<td></td>
</tr>
<tr>
<td>&quot;KANARI ITAI&quot;</td>
<td>- (-)</td>
<td>- (8'33&quot;-)</td>
<td>6'5&quot; (4'1&quot;-8'10&quot;)</td>
<td>3'36&quot; (3'2&quot;-4'23&quot;)</td>
<td></td>
</tr>
<tr>
<td>exhaustion</td>
<td>- (-)</td>
<td>- (35'40&quot;-)</td>
<td>16'15&quot; (4'52&quot;-25'48&quot;)</td>
<td>5'35&quot; (4'28&quot;-9'39&quot;)</td>
<td></td>
</tr>
</tbody>
</table>
The changes of AEMG and RPLF during NAW are shown in Fig. 4. The changes of AEMG at 5% MVC were different between subjects. At other contraction levels AEMG was constant or decreased in the early part of the work and then apparently increased in many cases. RPLF often increased with time. At 10 and 15% MVC the increases of RPLF were larger in the early part of the work when the AEMG was constant or decreased.

Correlation coefficients of RPLF and AEMG to the time during each AW were calculated. The percentage of the significant coefficients was summarized for each subject. They were averaged for subjects in Table 3. RPLF tended to increase and AEMG tended to decrease during each AW.

AEMG increased with the alternations at 15 and 20% MVC. The increases at 20% MVC were larger than that at 15% MVC (Fig. 2). Mean RPLF of each AW tended to increase with the alternations at 10 and 15% MVC though it was not significant. At 20% MVC mean and end RPLF decreased with the alternations in some cases. RPLF at the start of first contraction tended to be smaller than that of the later contractions. The tendency was significant in some cases at 20% MVC.

DISCUSSION

The shoulder abduction was the most fatigable work in seven work positions (flexion and extension of elbow, knee and ankle joint, and shoulder abduction) in our previous studies and shoulder work often become a problem (Hagberg, 1982; Wiker, 1989). As the relation between endurance time and contraction levels had been examined in shoulder abduction, we chose the shoulder flexion in this study.

We recorded EMG from the middle part of the deltoid, the same position as in the previous study. The middle part of deltoid acts weaklier at holding arm in the horizontally flexed position than in the horizontally abducted position (Ringelberg, 1985). Though the anterior part of deltoid works stronger
Fig. 3 Relation between alternation intervals and the onset times of fatigue sensations. The bottom and top of vertical line point the onset time of tiredness and pain, respectively. The symbol on the vertical line represents the onset time of considerable tiredness and the contraction level. Dotted line is identical line. Time range was limited to 10min. The symbols at 10min of the onset times of fatigue sensation mean the existence of data above 10min.

than the middle part of deltoid at the latter position, the middle part of deltoid also acts during shoulder flexion at an angle in this study (Ito, 1980; Oliveira et al., 1988). EMG in this experiment showed changes that resemble the changes induced by fatigue (Fig. 4). Hagberg (1981) showed that EMG of both the anterior and middle part of deltoid changed during static works of shoulder flexion and abduction. In his study the number of cases where significant changes were seen in EMG was little different between abductions and flexions if EMG was led from the same position of the muscles. We believe that the changes of EMG in this study showed the fatigue induced by work though cautions are need to interpret the changes of EMG as follows.

AEMG of the middle part of the deltoid was reported to show decreases (Hagberg, 1981) or not monotonous changes (Ohashi et al., 1987) during fatiguing static contractions. In this experiment many AEMGs decreased at the early part of NAW. Many AEMGs also decreased during each AW and increased with the repeats of AW. Fatigue can not be evaluated by RPLF without AEMG, since the increases of contraction level increase the higher frequency component of EMG (Gander and Hudgins, 1985; Moritani and Muro, 1987; Ohashi et al., 1986). For example the changes of AEMG and RPLF in subject B at 5% MVC might be caused only by changes of contraction level (Fig. 4). The evaluation of fatigue by EMG is possible only when AEMG and/or RPLF increases with the not decreasing state of RPLF and/or AEMG. Large increases of RPLF at the early part of the NAW must be related to the decrease or constancy of AEMG at the part.

Fatigue level during whole AW

Both mean RPLF and AEMG of each AW at 15% MVC AW increased significantly though such cases occurred under only in three conditions of comparison (Fig. 2). Thus we think the fatigue levels increased with repeated contraction. At 20% MVC AW, RPLF and AEMG at the start of the first contraction were smaller than those of the other contractions. This means that the rest by alternating arm was not sufficient for the recovery from the fatigue at 20% MVC. Though fatigue levels must be higher at 20% MVC AW than at 10 and 15% MVC AW, some mean and end RPLF of each AW decreased with repeated contractions. We think these decreases of RPLF were caused by a large increase in contraction level, which was shown by increase of AEMG. If the increase in AEMG at 20% MVC AW was mainly caused by fatigue at the muscle part where EMG was recorded, RPLF might not decrease to a large extent. AEMG changed between the repeated fatiguing static contractions and the change was thought to be caused by the participation of synergists (Ohashi, 1989). The increase in
Fig. 4 Changes of EMG during NAW. The points at the onset of fatigue sensations are indicated by triangle (tiredness) and circle (pain).

### Table 3

Percentage in the significant correlation coefficient ($r$) of AEMG and RPLF to the time during each AW (%)

<table>
<thead>
<tr>
<th>contraction level (%MVC)</th>
<th>AEMG</th>
<th>RPLF</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$r&lt;0$</td>
<td>$r&gt;0$</td>
</tr>
<tr>
<td>S. NS. NS. S. S. S. S.</td>
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<td>5</td>
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<td>37</td>
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<tr>
<td>20</td>
<td>40</td>
<td>22</td>
</tr>
<tr>
<td>S.: $p&lt;0.05$, NS.: $p&lt;0.05$</td>
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</table>

AEMG with the repetition of contractions at 20% MVC was thought to be caused mainly by increased contraction level to compensate the fatigue of synergistic parts. From the above we reckon the increase in AEMG with repeated contractions means an increase in the fatigue of the whole muscles. Fatigue would be increased with the repetition of contractions at 15 and 20% MVC. A significant decrease in the alternation time at 20% MVC (Fig 2) also shows the progress of fatigue with the repeat of AW.

### Relations between alternation and fatigue sensations

Most alternation intervals were shorter than the onset time of pain. This agrees with the results of Tani et al. (1972) in which working arms in overhead work were alternated at the early stage of fatigue before the onset of pain. Subjects usually noticed some extent of local fatigue sensation before the alternation in their study. In this experiment some alternation times were shorter than the onset time of tiredness. This can not mean that the alternation occurred before the onset of any fatigue sensation as light fatigue sensation was difficult to feel. A few irregular orders of fatigue sensation time in relation with contraction level show the difficulty. As AW and NAW were experimented on different days, difference in condition of subjects could affect the time at the report of light fatigue sensation. We believe that the subjects might feel to
stop the contraction at the onset of light fatigue sensation which was sometimes difficult to recognize as the fatigue sensation.

Alternation intervals were longer than the onset time of tiredness in many cases and even longer than the onset time of pain in a few cases. The alternation intervals relative to the onset time of tiredness were longer at 20% MVC than at other contraction levels. Light fatigue sensations would become ambiguous by the effort for the work at high contraction levels. This could change the relations between the fatigue sensation and the alternation. The differences of mean alternation intervals were less than 5sec. between 15% MVC and 20% MVC in the latter half of the whole AW in 4 of 14 cases. EMG and alternation intervals showed the progress of fatigue by repeated AW at 20% MVC. Therefore subjects seemed to prefer to be patient with severer fatigue sensation rather than to alternate the working arm more frequently at stronger contraction level. The strategy for the whole work would result in some long alternation intervals in other contraction levels and the difference of alternation intervals between right and left in the first contraction at 20% MVC.

These could be concluded as follows. Contraction is felt to be stopped when the first fatigue sensation has occurred. But it is not necessary to stop the contraction until considerable tiredness or apparent pain occur.

Difference of fatigability between AW and NAW

The amount of work (product of time and contraction level) for one arm at 20% MVC AW was equal to that at 10% MVC NAW. At 10% MVC NAW one subject could not endure for 45min. and 5 of the other 6 subjects reported intense pain. In 20% MVC AW the fatigue sensation at the end of each AW was lighter than the pain. Therefore the physiological load was lightened by changing the continuous contractions to intermittent contractions. This result agrees with the reports in which continuous works were compared with intermittent works (Björkstén and Jonsson, 1977; Hagberg, 1981; Monod and Scherrer, 1965).

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大谷 純也
Junya OHAISHI

〒815 福岡市南区塩原4-9-1 九州芸術工科大学人間工学教室
Department of Ergonomics, Kyushu Institute for Design Research
4-9-1 Shiobaru, Minami-ku, Fukuoka, 815 Japan