Changes in Relations between Surface Electromyogram and Fatigue Level by Repeating Fatiguing Static Contractions

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Changes in relations between surface electromyogram (EMG) and fatigue level estimated by fatigue sensation were studied during repeated fatiguing static contractions. Six male subjects performed elbow flexion of 13-15%MVC. Contractions were repeated 5 times (C1, C2, C3, C4, C5) with 5min intervals of rests. The contractions continued until the onset of fatigue sensation such as obvious pain or considerable tiredness. Bipolar surface EMGs were recorded from 6 synergists of elbow flexors. Mean amplitude (AEMG) and relative power spectrum (RPW) of EMG were calculated.

Partial correlation coefficients between time, AEMG, and RPW during each contraction were calculated. AEMG increased with time. EMG spectrum shifted towards lower frequencies with time. The correlations between AEMG and RPW were negative below 60Hz. AEMG and RPW were compared between C1 and C2-C5 being related with fatigue sensations. The changes in AEMG and EMG spectrum with the repeated contractions were similar to those with the development of fatigue. The increases in AEMG with the repeats were seen in most synergists in 4 subjects. Though EMG roughly reflected the fatigue during work, the changes of EMG were thought to include active adaptation to work.

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More than 30 years have passed since surface electromyogram (EMG) was reported to be useful as an objective index of muscle fatigue of static contractions (Kogi and Hakamada, 1962 ; Lippold et al., 1960). The relations between EMG and muscle fatigue during endurance work have been studied in many reports (Hagberg 1981 ; Petrofsky et al., 1982). Contractions continued till exhaustion in most of these reports. In actual work most contractions are stopped before fatigue develops into a serious state, and contractions are repeated with rests. The fatigue level at which contractions were felt to be stopped was studied in the work of sustaining a load with spontaneous alternations of the working arm (Ohashi and Sato, 1992). The working arm was

alternated before or when considerable tiredness or apparent pain occurred. Westgaard (1988) noted that an acceptable load cannot be determined without any relation to rest. Changes in fatigue must be investigated during the whole work with rests to evaluate load. Stable relations between EMG and fatigue level are necessary, when muscle fatigue is investigated during the actual works with EMG. I studied the relations between EMG of biceps brachii and fatigue sensations during repeated fatiguing contractions with 5 min rests between the contractions (Ohashi, 1988). Amplitude of EMG (AEMG) at the same fatigue sensation increased with repeated fatiguing contractions. Migrations of muscle activities among synergists can cause the increase in

AEMG. In the next experiment EMGs of plural synergists were investigated in the same experimental condition (Ohashi, 1989). The increase of AEMG was different among synergists. This difference seemed to cause the change in the relation between fatigue sensation and AEMG with repeated fatiguing contractions. However, this change in the relation was not explained completely. Central nervous system is thought to influence a surface EMG spectrum during a fatiguing contraction as well as peripheral factors such as conduction velocity of action potential (Zwarts et al., 1987). If central nervous system causes the changes in EMG with fatigue, the relations between EMG and other measurements connected with fatigue can vary according to conditions.

The purpose of this study is to elucidate that the relation between fatigue level and surface EMG changes with repeated contractions considering synergists. That is, I examine whether changes of EMG with repeated contractions can be explained by changes of fatigue level. Fatigue for physical work is defined as a decreased force generating capacity (Vøllestad and Sejersted, 1988). In this study I define fatigue as failure in muscle fiber contractility. However, fatigue levels were determined not by physiological and/or physical measurements but fatigue sensation in this study. It is not certain that the sensation reflects fatigue level exactly. The subjective sensation can vary with variation of its criterion. It is possible that surface EMG reflects fatigue more correctly than fatigue sensation. However, surface EMG was tested as a fatigue index with the fatigue sensation. To prevent misjudgement by using fatigue sensation as a reference, I set bias that made it difficult to obtain the result of the purpose of this study: increase in AEMG at the same fatigue sensation with repeated fatiguing contraction. That is, more fatigued sensations were used in the first contraction than those in the latter contractions. I hypothesized that fatigue level was not lighter if fatigue sensation was severer

than that of compared part.

METHODS

Subjects were 6 males (subject A-F, age 22-25years). They sat on a chair of a multipurpose muscle strength measuring apparatus (Takei Kiki Kougyo 1281). Static contractions of the elbow flexors were performed against a load hung from the right wrist with the forearm horizontal and semi-pronated at 90 degrees of elbow angle. An elbow support was set at the back of the elbow to prevent shoulder extension. The contraction level was set at 13-15% of maximum voluntary contraction (MVC) considering the weight of the forearm. The work consisted of 5 repeats of the contraction with intervals of 5min rests. These contractions are called C1, C2, C3, C4, and C5 from the start of the work. The contractions in C1-C4 were continued until the point of 50sec or 0sec after the onset of fatigue sensation such as obvious pain or considerable tiredness in the upper arm. When fatigue sensation in the upper arm was not obvious, severe fatigue sensations in the other parts were used. In C5 the contractions were continued as long as subjects could endure. The part of C5 corresponding the shortest contraction time among C1-C4 was called C5a. Contraction time was limited to 5min in C2-C4. Total time of contractions in a work was limited to 45min by the limitation of the length of recording tape. Fatigue sensations were asked to be reported freely. Fatigue level at the start of each contraction was also reported being compared with that of the last contraction. MVCs at the wrist were measured with strain gauge dynamometer. MVCs ranged between 235N and 340N with its mean of 292N.

Bipolar surface EMGs were led from 6 muscles: extensor carpi radialis longus (ECRL), pronator teres (PT), brachioradialis (BRR), brachialis (BR), short head (BBS) and long head (BBL) of biceps brachii. The disc electrodes were 10mm in diameter and the centers of two electrodes were about 25mm apart. The electrodes for EMG of BR were

positioned at the lateral part of the upper arm. EMG was sampled at 1024Hz. Mean amplitude of EMG (AEMG) was calculated as the mean value of absolute amplitude. AEMGs were used as relative value to AEMG from 1/20 to 1/10 of C1. EMG power spectrum was calculated by FFT method. Relative powers to the total power in 8-400Hz were obtained for every 4Hz in the range of 8-80Hz, for every 8Hz in the range of 88-120Hz, and for 124-200Hz and 204-400Hz. The spectra and AEMGs were obtained continuously for the analysis time of 8sec. Sum of the relative powers below and equal to 40Hz was used as an index of EMG slowing and was called RPWL40.

Wilcoxon matched-pairs signed-ranks test and simple and partial correlation coefficient were used for statistical analysis. The level of significance was chosen at $p < 0.05$.

EMG spectra were sometimes considerably different between subjects as been reported (Sato, 1976). The interindividual differences obscure tendencies of EMGs during work, which are the main subject in this study. In order to manifest the changes during work, all values were used as the deviations from their mean values for each subject to even out the differences in the means among subjects, when correlation coefficients were calculated. The degree

of freedom that this offset operation for the mean uses is 1 for each mean (subject).

Though fatigue levels were estimated by fatigue sensations in this study, the fatigue sensations were not used as a variable in the correlation analysis. The contractions in this experiment caused fatigue. Fatigue would develop roughly with contracting time, though fatigue level of a muscle sometimes lighten during a contraction depending on its synergist's help. I used contracting time as the parameter that included the factor of fatigue level.

RESULTS

Endurance time and fatigue sensation

Table 1 shows contraction times. The endurance times in C5 were about twice the length of the contraction times in C1. I decided that C1 of subject E ended at lighter fatigue sensation than that of other subjects, because his contraction time was about twice the length of those of other subjects. Fatigue sensations at the start of C2-C5 and at the end of C2-C4 lightened a little with the repeat of contractions in subject E and developed in other subjects. Fatigue sensations at the end of C2, however, developed in subject E from that of C1, but lightened in subject A, B, and C.

Table 1 Duration of each contraction and onset time of fatigue sensation used for the comparisons between C1 and C2-C5

(min' sec'')

Subj.	Duration of contraction					Onset time of fatigue sensation used for the comparison between C1 and C2-C5				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
A	10' 50"	5' 0"	4' 0"	5' 0"	20' 0"	8' 20"	3' 30"	2' 23"	0' 53"	0' 30"
B	11' 0"	5' 0"	5' 0"	5' 0"	17' 0"	8' 43"	2' 47"	2' 14"	1' 14"	2' 7"
C	8' 50"	4' 0"	4' 0"	4' 0"	19' 20"	8' 10"	2' 5"	1' 50"	1' 53"	1' 27"
D	9' 50"	5' 0"	5' 0"	5' 0"	19' 45"	7' 56"	2' 40"	2' 36"	2' 6"	←
E	20' 50"	5' 0"	5' 0"	5' 0"	9' 10"	18' 9"	→	1' 57"	→	1' 46"
F	7' 50"	5' 0"	5' 0"	4' 0"	22' 50"	7' 35"	2' 14"	1' 52"	1' 34"	1' 28"
mean	9' 40"	4' 48"	4' 36"	4' 36"	19' 47"	8' 9"	2' 39"	2' 11"	1' 32"	1' 32"

Means were calculated eliminating data of subject E.

Symbols '→' and '←' show that the next and last value were used because appropriate fatigue sensation was not reported.

Changes of EMG during each contraction

Examples of AEMG and RPWL40 during work are shown in Fig 1. Subjects often clenched their fist with increase in the effort for work due to fatigue. This clenching largely increased the AEMGs of ECRL. Correlation coefficients between AEMG and contracting time were calculated for C1, C5 and C2-4 for each subject (Table 2). Eighty-three percentages of the correlations were positively significant. Correlation coefficients between relative power and time were also calculated for each frequency for C1, C5 and C2-4 (Fig 2). The positive correlations were shown mainly below 30Hz, and the correlations were negative between 30 and 60Hz. Correlation coefficients between AEMG and relative power were also calculated. The correlations for each frequency were similar to those between relative

Table 2 Significance of the correlation between time and AEMG. Values are number for C1, C2-C4, C5, and percentage for mean.

	r<0.	NS.	r>0.
C1	0	6	30
C2-4	2	7	27
C5	2	1	33
mean (%)	4	13	83

r : correlation coefficient
($p < 0.05$)

NS. : not significant

power and time. This similarity in correlations was derived from the positive correlation between time and AEMG. Partial correlation coefficients were calculated between contracting time, relative power and AEMG to clarify these relations (Fig 2). The correlations between relative power and time were positive below 30Hz and negative above 60Hz. The

Fig. 1 Examples of changes in AEMG(upper) and RPWL40(lower) during the repeated contractions.

Fig. 2 Simple and partial correlation coefficients of time and AEMG to relative power for each frequency. The values at dotted lines parallel to the frequency axis are significant borders of correlations at $p=0.01$. Thin solid lines and circles represent C1, thin dotted lines and '+' represent C2-4, and thick solid lines and 'x' represent C5. Results for 124-200Hz are positioned 160Hz. Results for 204-400Hz are plotted by the symbols.

correlations between relative power and AEMG were negative below 60Hz and positive above the frequency, though the significances were different between muscles. However, the correlations were positive in 8 and 12Hz in some cases.

Changes of EMG with the repeat of contractions; Comparisons between nearly equal fatigue levels

AEMGs and RPWL40s increased during contractions and returned during rests in many cases. However, these returns were not complete. Averages of AEMGs and RPWL40s for each contraction sometimes increased with the repeat of contractions. Whether these increases were caused by the increase in fatigue was investigated. Since these increases with the repeat were large between C1 and

C2 and were small after C2, AEMGs and RPWL40s were compared between C1 and C2-C5 being related with fatigue sensations. AEMGs were compared with Wilcoxon test. Relative powers were compared with correlation coefficients between relative power and repeat number of the contraction. The correlation coefficients were calculated as simple correlation and partial correlation with the factors of contracting time and AEMG.

The compared parts were chosen with care that fatigue level in C1 didn't become lighter than that in C2-C5. Obvious fatigue sensations such as pain and considerable tiredness were used in C1. The used fatigue sensations in C2-C5 were lighter ones than those in C1: slight pain and tiredness, for example. The onset times of used fatigue sensations are

shown in Table 1. The compared parts were just after the fatigue sensation in C1 and just before the fatigue sensation in C2-C5. The lengths of the parts were the first quarter of time from the fatigue sensation to the end of C1 and the last quarter of time from the start of C2-C5 to the fatigue sensation. These compared parts related with fatigue sensations are called CPRFS. C2-C5 were not distinguished and the data were pooled for the comparison of AEMGs. Used values as the repeat number of contractions were 0 for C1 and 1 for C2-C5 in the calculation of the correlation coefficients between the repeat number and relative power. AEMGs of PT, BR, BBS and BBL were significantly larger in C2-C5 than in C1. The correlation coefficients were calculated for each frequency (Fig 3). Relative powers in C1 were smaller in the low frequencies and larger in the high frequencies than those in C2-C5, though the frequencies with significant difference were a few particularly in BBS and BBL. Though relative power in low frequencies was larger in C2-5 than those in C1, relative power in 8 and 12Hz was significantly larger in C1 than those in C2-C5.

The number of muscles whose AEMGs during CPRFS were smaller in C2-C5 than in C1 is shown for each subject in Table 3, because migrations of

Table 3 Number of muscles whose AEMGs in C2-C5 were smaller than those in C1.

Subj.	C2	C3	C4	C5
A	1	1	1	1
B	1	1	1	1
C	2	0	0	0
D	2	0	0	0
E	3	5	5	5
F	3	2	3	2

activities among muscles can affect AEMG. The AEMGs were larger in C2-C5 than in C1 in most muscles for subjects A, B, C and D. This means that something besides the migrations between synergists increased the AEMGs in C2-C5 than those in C1.

Changes of EMG with the repeat of contractions

Simple and partial correlation coefficients were calculated between contracting time, repeat number of the contraction, AEMG, and RPWL40 for last 56sec of each contraction. The correlation coefficients were calculated for C1-C5a and C2-C5a. Significances are shown in Table 4 for the simple correlations between the repeat number and AEMG and the partial correlations between the repeat number and RPWL40. Cases of positive correlations were more than those of negative ones in both the

Fig. 3 Simple and partial correlation coefficients between relative power and repeat number for each frequency. The values at dotted lines parallel to the frequency axis are significant borders of correlations at $p=0.05$. Results for 204-400Hz are plotted by open circles.

Table 4 Significances of simple correlations between AEMG and the repeat number of the contractions, and partial correlations between RPWL40 and the repeat number with the factors of time and AEMG.

Subj	Muscle												Muscle											
	AEMG						C2-C5a						RPWL40						C2-C5a					
	ECRL	PT	BRR	BR	BBS	BBL	ECRL	PT	BRR	BR	BBS	BBL	ECRL	PT	BRR	BR	BBS	BBL	ECRL	PT	BRR	BR	BBS	BBL
A	=	H	(+)	(+)	H	H	(-)	H	(+)	(-)	H	(+)	H	H	(-)	(+)	H	H	H	H	H	(+)	H	
B	=	(+)	(+)	=	H	(+)	=	(+)	(+)	=	H	(-)	(+)	H	(+)	(+)	(-)	(-)	(+)	(+)	(-)	(-)	=	(-)
C	H	H	H	H	H	H	(+)	H	(+)	(+)	(+)	(+)	(+)	(+)	H	(+)	H	H	(+)	(-)	(+)	(+)	(+)	(-)
D	(-)	H	H	H	H	H	H	H	(+)	(+)	H	H	H	H	H	H	(-)	H	(-)	H	H	H	(-)	H
E	=	=	=	=	H	(-)	(-)	=	(-)	(-)	H	(-)	=	(+)	(+)	H	(+)	H	=	(-)	(+)	(+)	H	(+)
F	H	(+)	(-)	H	H	(+)	H	(+)	(+)	H	(+)	(+)	H	(+)	(+)	H	H	H	(+)	(-)	(-)	H	H	(+)

H, (+) : The correlation is positive.

=, (-) : The correlation is negative.

H, = : The significance is $P < 0.01$.(+) , (-) : Not significant. $P > 0.05$.

correlation pairs. Subject B and subject E showed negative correlations in some muscles in both the correlation pairs. Positive cases were more in the correlations for C1-C5a than in those for C2-C5a in subject B, C, D and F. Subject A, B and C reported that the fatigue sensations at the end of the contraction were lighter in C2 than in C1, namely the changes in fatigue sensations at the end of C1-C2 were opposite to those of C2-C4. If AEMG and RPWL40 correlated not to the repeats of fatiguing contraction but only to fatigue sensation, the correlation coefficients of AEMG and RPWL40 to the repeats would have been lower in the case where the correlations were calculated for C1-C5a than in the case where those were calculated for C2-C5a. However, in subject B, C, D and F, the cases of the positive correlations of AEMG and RPWL40 to the repeats decreased when the correlation coefficients were calculated eliminating C1. This shows that the repeats of the fatiguing contractions affected EMG, namely the muscle activities, at the end of C2-C5.

Differences of increases in AEMG between muscles

Ratios of increases in AEMG were compared among the muscles. The ratios were calculated as follows.

(A) : CPRFS of C2-C5a relative to that of C1

(B) : the last one fifth of C1 relative to the first one fifth of C1

(C) : the last one fifth of C5 relative to the first one fifth of C1

The orders of muscles for these ratios were as follows from large to small.

(A) BBS > BBL > PT > BR > BRR > ECRL

(B) ECRL > BBS > BBL > PT > BRR > BR

(C) ECRL > BBS > PT > BBL > BRR > BR

These differences were significant in following conditions.

(A) BBS > BBL > PT, BR, BBR, ECRL

(B) ECRL, BBS, BBL > BR ; ECRL > BBL

(C) ECRL > BRR, BR ; BBS > PT ;

BBL > BR

In these three comparisons of AEMGs the difference in fatigue level was the smallest in A and the largest in C. The ratios in the forearm muscles tended to be large when the difference in fatigue level was large. The orders of these ratios were not changed among the upper arm muscles and among the forearm muscles except for the large changes of ECRL.

DISCUSSION

As Fig 1 shows, averages of AEMG for each contraction increased with the repeat of the contractions more largely between C1 and C2 than between C2 and C5, and the differences between C1 and other contractions were tested statistically. The differences among C2-C5 were not tested, because the differences were often obscure and I think that

fatigue sensation is not appropriate for the comparison of small differences. I use the differences between C1 and other contractions as the effects of the repeat of fatiguing contractions in this discussion.

Interpretation of changes of EMG with the repeat of contractions

The ratios of increases in AEMG in forearm muscles became larger relative to those in the upper arm muscles when the ratios were calculated between the conditions which were largely different in fatigue level. These differences in changes of increase ratios of AEMG between muscles would be explained as follows. Biceps brachii contracts stronger in the supinated position of the forearm than in the semipronated position, since biceps brachii supinates the forearm. The activities of motor units in biceps brachii were different between in elbow flexion and in forearm pronation. Some motor units in the medial part of BBL did not be recruited at elbow flexion (Ter Haar Romeny et al., 1984). BBS is positioned on the medial side of BBL. Activities of BBS in subject F were sometimes silent. The activities of BBL and BBS were expected to be small at the start of C1. But the activities of BBL and BBS increased with time. Since the activities of BBL and BBS supinate the forearm, pronators of ECRL and PT must be activated to cancel the effects of BBL and BBS. Clenching ones fist, which were sometimes seen at the fatigued state, also increase the AEMGs of ECRL. Five subjects reported that the first fatigue sensations were occurred in forearm. Semipronation of the forearm would increase the load for the forearm muscles, and the forearm muscles might be easier to be fatigued. These disadvantages in forearm muscles can explain the large increase ratios in ECRL and PT at fatigued state. Since BRR also positions the forearm in the semipronated position, the increase ratio of AEMG in BR might be smaller than that in BRR at the fatigue state.

Though the relations of increase ratios between muscles at fatigued state (compared condition B and C) were different from those calculated for CPRFS (condition A), these differences were attributed to the difference in fatigue level. I think that the manner of the increase in AEMG was not different essentially whether the increase occurred by the repeats of fatiguing contractions or by muscle fatigue.

From the correlation coefficient between time, AEMG and relative power (Fig 2), the changes in relative power were interpreted as follows. Relative power above 60Hz correlated positively with AEMG. This correlation would be caused by recruitment of motor units (MUs) with fast conduction velocity of action potential (Arendt-Nielsen et al., 1989; Ohashi, 1993). The correlations of relative power to AEMG in 30-60Hz were opposite to those above 60Hz. I think that relative power migrated between these 2 frequency bands by the same origin. Namely, the changes in relative power above 30Hz would be caused by the recruitment of MUs. The effects of recruitment of MUs can be excluded from the correlations between relative power and contracting time to some extent by calculating the correlations as partial correlations using the factor of AEMG, since AEMG reflects recruitment of MUs. The partial correlations between relative power and time showed a simple slowing pattern, positive correlations below 40Hz and negative correlations above 40Hz. Ohashi (1993) showed that relative power in low frequencies increased during fatiguing contraction without increase in duration of each wave, which is affected by conduction velocity of action potential. I think that these positive partial correlations below 40Hz were slowing induced by fatigue. Though these relations between the correlations and the frequencies were obscure in BBS and BBL, these obscure relations would be caused by the recruitment of MU which is shown by large increase in AEMG. Using partial correlations would not be enough to exclude the influence of the

recruitment in BBS and BBL.

Relative power below 60Hz increased and that above 60Hz decreased with the repeat of the contractions. These changes of relative power show that changes of MUs activities with the repeat contained those occurred with fatigue. These changes of relative power also show that conduction velocity of newly recruited MUs was slower than that of MUs already active. But simple correlation coefficients show quicking of EMG with the repeat in BBS where AEMGs increased largely. Therefore this recruitment of MUs with slow conduction velocity was not dominant if recruitment of MUs was large. Though EMG spectrum showed slowing with the repeat, relative power below 12Hz decreased with the repeat. Tremor increases with a fatiguing contraction, and main frequency of tremor is below 12Hz (Lippold, 1981). Since the fatigue sensations at compared part were lighter in C2-C5 than in C1, smaller tremor in C2-C5 might resulted the smaller relative power below 12Hz. Though the changes of EMG spectrum with the repeat were not the same completely with the changes by fatigue, these changes with the repeat contained common changes which are caused by fatigue.

Origin of changes of EMG with the repeat of contractions

In the previous study only BBS was examined in the same experimental condition with this study. The results in the previous study are the same with the results of BBS in this study. In both studies the reliability of the fatigue sensation is important, because the compared parts were determined by the fatigue sensations. Care was taken to prevent the error by using subjective sensation. Fatigue levels were estimated not only by single word but also by relations with other fatigue sensations. For the determination of the compared parts, I set the deviation that makes it difficult to obtain this and previous results. That is, used fatigue sensations were lighter in C2-C5 than in C1, and the compared parts

were before the fatigue sensations in C2-C5 and after the fatigue sensation in C1. The results of this study will not be caused by fluctuation of fatigue sensations.

The increases of AEMG with the repeat of fatiguing contractions were similar to that with fatigue. Though migrations of muscle activities are thought to cause these increases with the repeat, these increases were not attributed only to the migrations among synergists (Lippold et al., 1960 ; Sjøgaard et al., 1986). The activities might migrate between deep and surface MUs in a muscle. The migrations between deep and surface MUs are not thought to occur in lightly fatigued state because MUs with low recruitment threshold are non-fatigable (Stephens and Usherwood, 1977), and deep MUs have low thresholds (Clamann, 1970 ; Kossev et al., 1991). Migrations of activities were observed among synergists in 5%MVC contractions (Sjøgaard et al., 1986). Person (1974) reported that contraction manner changed recruitment order of MUs, and noted that this substitution of MUs prevents fatigue during prolonged contraction. Relative increase in role of surface MUs can increase AEMG. Contractions in my experiment induced fatigue. Lightening load of each MU by recruiting many MUs before development of fatigue will be a better strategy for prolonged contractions than recruiting MUs after development of fatigue. In Fig 1 AEMG in biceps brachii of subject A increased steeply at the start of contractions and then the increases in AEMG became small in C2-C5. In other muscles average AEMGs of C2-C4 were almost equal to that at the end of C1, and increases in the AEMGs were obscure during each contraction of C2-C4. AEMGs in BBS and ECRL of subject A decreased steeply at the start of C1. Decreases in AEMG, MU discharge frequency, and number of active MUs at the start of a contraction were also reported (Kamo and Morimoto, 1990 ; Ohashi and Sato, 1992). Grimby and Hannerz (1968) reported that the recruitment order of MUs sometimes changed after a fairly longlast-

ing static contraction. The contraction time before this change in the recruitment order became shorter in the repeated contraction, when the order had changed in the last contraction. This change in the order resembles that of the change in AEMG in the early part of the repeated contractions in its time course. They also reported that the newly recruited MU whose recruitment order changed to the first discharged more regularly than the MU that was substituted for the newly recruited MU. MUs which discharge regularly (tonic MUs) are recruited at low force (Kato et al., 1981; Hannerz, 1974), and MUs recruited at low force are fatigue resistant (Stephens and Usherwood, 1977). From these relations, recruitment of tonic MUs is suitable for a prolonged contraction. However tonic MUs are expected to be recruited at first. These changes of recruitment order are considered as follows. Recruitment order of MUs changes when a muscle contracts for a different movement, such as abduction and flexion of the index finger by first dorsal interosseous muscle (Person, 1974; Desmedt and Godaux, 1981). I expect that high recruitment threshold of MUs for one motion decreases after a prolonged contraction, if the MUs is tonic type and works as a synergist. The changes of EMG spectrum with the repeat showed that MUs with slow conduction velocity, which suggests tonic MUs, were recruited by the repeats of fatiguing contraction. I think that tonic MUs whose recruitment threshold was high for the elbow flexion decreased the threshold after the prolonged contraction. Activities of biceps brachii especially BBS were expected to be low, because the forearm was semipronated. The larger increase in AEMG in BBS and BBL would be attributed to the low activities at the start of C1. However recruitment of tonic MUs would not increase AEMG, because MUs with low recruitment threshold are distributed in a deep part of a muscle. Ordinary recruitment of MUs also would occur. Since co-activation of pronators (ECRL and PT) and supinator (BBL and BBS) is not efficient,

recruitment of high threshold MUs would not be efficient and this unefficiency would increase AEMG.

The changes in frequency spectra of EMG were also large at the start of each contraction. Ohashi (1993) reported that EMG showed slowing at the early part of static contractions in 5%MVC contraction, though the slowing is usually little in such a low contraction level. Sato (1978) reported that slowing of EMG was observed in a non-fatiguing contraction of one arm, when the other arm was under a fatiguing contraction. The large increases in AEMGs of ECRL seemed to be attributed to clenching the fist with increase in effort. This suggests that the role of ECRL for the elbow flexion was light. Though fatigue level of ECRL is supposed to be light because of light load, slowing of EMG was observed in ECRL. EMG showed slowing by the repeat of the fatiguing contraction, though fatigue level was thought to be equal or lightened. I think these slowings of EMG at light fatigue state is not caused by failure in function in peripheral by fatigue. Latash (1988) mentioned that synchronization of MU spikes led EMG spectrum shift towards lower frequencies and that this synchronization was likely to play a compensatory role for insufficient force generation. Though it is not certain whether the synchronization or grouping in MU activity compensates failure in contraction performance, I think these changes in AEMG and EMG spectrum were active adaptation to the contraction rather than inevitable changes by failure in the contraction performance.

Effect of fatigue on EMG

Fig. 3 in Sjøgaard et al. (1988) shows that a static contraction at 15%MVC for 5min raised arterial and venous lactate levels, and that a rest for 3min was not sufficient for the recovery of the levels. Potassium release is thought to be a cause of fatigue in a low level static contraction, and its re-uptake is also slow (Sjøgaard, 1988). From these results the

fatigue in this experiment is thought to remain until the next contraction and to accumulate with the repeat of contractions. The accumulation of fatigue with the repeat of contractions was suggested by increases in AEMG and RPWL40 in the last 56sec of each contraction with the repeat of contractions. Though these increases in AEMG and RPWL40 were affected by the repeats of fatiguing contraction, I think these increases also reflected differences of fatigue level between subjects. The order of onset time of severe fatigue sensation in C5 was D, F, C, A and B (no report in subject E) from the earliest subject to the latest. The order of the development of fatigue sensation with the repeat was A, C, D, F, B and E from large to small. These orders suggest that development of fatigue level was small in subject B and E. It would be attributed to small development of fatigue that the rate of the negative correlation of AEMG and RPWL40 to the repeat was large in subject B and E. EMG at several minutes after a start of contraction would reflect fatigue level.

The results of this study show that caution is necessary to interpret surface EMG as a fatigue index, when fatiguing and recoveries are repeated in a work. If the changes in EMG are caused not only by fatigue but also by the adaptation to contractions, caution is also necessary to apply EMG in a work that does not contain a repeat of fatiguing. The origin of the changes in surface EMG must be known in order to interpret the changes in EMG during fatiguing contractions.

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