

Observations and Analysis of Long-Duration, Constant-Posture, Force-Varying, Fatiguing EMG

M.V. Bertolina¹, E.A. Clancy¹, D. Farina², and R. Merletti²

¹Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA 01609-2280

²Centro di Bioingegneria, Dip. Di Elettronica, Politecnico di Torino, C.so Duca degli Abruzzi 24, 10129, Torino, Italy

Abstract—In this paper, electromyographic (EMG) data from long-duration (30–90 minutes), constant-posture, force-varying, fatiguing contractions of the hand were analyzed for trends. Both time (EMG amplitude) and frequency domain (EMG mean power frequency) parameters were tracked. For these long-duration contractions, results found no consistent change in either parameter, even though all subjects continued contractions until exhaustion.

I. INTRODUCTION

EMG data from a long-duration, cyclic, hand-grip task were analyzed, both in the time and frequency domains. The hand-grip task is reminiscent of industrial tasks that have been known to lead to repetitive stress injuries. A more complete understanding of muscle physiology changes throughout the duration of such tasks might lead to better strategies for preventing repetitive stress injuries.

II. METHODS

A. Experimental Methods

The data acquired included EMG recordings, hand-grip force and perceived discomfort ratings. Three bipolar surface EMG electrode-amplifiers were applied to each subject. One electrode-amplifier was placed over the flexor digitorum superficialis (FDS), another immediately distal to the first (still over the FDS), and the third over the extensor carpi radialis (ECR). Subjects maintained a fixed posture while squeezing a hand grip dynamometer. Feedback was provided on a computer screen showing the subjects a target force level and their current force level. A 12 s varying force target pattern was repeated many times with interval breaks. The pattern consisted of 1 s rest, 4 s contraction “hill”, 1 s rest, 3 s contraction hill, 1 s rest, and 2 s contraction hill. The contraction hills were gradual increases and decreases of the target force level in the shape of a Gaussian function. At the end of every 5 minutes, this 12 s pattern was substituted with a constant force contraction. After each 15 minutes there was a 2 minute interruption, during which the subject completed a written discomfort survey. Then, the entire 15 minute pattern was repeated. Subjects self-selected to stop when they could no longer continue the contractions due to fatigue. Prior to the first 15 minute contraction interval, each subject’s maximum voluntary contraction (MVC) was measured and used to calibrate the peak force levels to either 40 or 50% MVC. Also, a discomfort survey was administered before the first 15 minute interval, and at five minute intervals after contractions ceased. EMG and hand-force data were recorded

during these constant posture, force-varying, fatiguing contractions for 30 to 90 minutes, (i.e., until the subject self-selected to stop). All physiologic data were recorded at 4096 Hz by a 16-bit A/D converter.

B. Methods of Analysis

Initially, the subject discomfort ratings were evaluated. Each subject’s ratings were plotted as a function of time into the experiment. Thereafter, the recorded EMG signals were analyzed. From each 12 s contraction cycle, a 500 ms data segment was extracted from the rising section of the 3 s hill contraction. Prior work (unpublished) showed this section of the contraction cycle provided the most repeatable time and frequency domain parameters. In the time domain, EMG amplitude was estimated from each 500 ms segment using the adaptive whitening algorithm of [1]. Because the contractions were constrained to be cyclic and constant posture, conventional methods for estimating the mean power (MNPF) frequency were appropriate [2]. Thus, MNPF (the frequency domain parameter) was estimated from the squared modulus of the discrete Fourier transform of each 500 ms segment. In this way a time-series of EMG amplitude estimates, and separately MNPF estimates, was generated from each subject’s 30 to 90 minute recordings. Successive time-series parameter values were typically separated in time by 12 s.

Cross-covariance coefficients at zero lag were computed among all paired combinations of each subject’s three EMG signals, separately for EMG amplitude and MNPF; and also between EMG amplitude and MNPF within each electrode site. Next, time trend plots of the time and frequency domain parameters were generated. To identify time trends, the least-squares best-fit line was fit to the parameter values for each 15 minute contraction interval. A series of sign tests [3] were performed using the slopes of the best fit lines. (Each slope was considered either positive or negative.) The sign test asks the probability of getting k or more positives in n independent trials. The null hypothesis was rejected for $p \leq 0.01$.

The sign tests, performed separately for the time and frequency domain parameters, used the following data groupings: (i) all of the completed 15 min intervals for all of the subjects, (ii) all of the completed 15 min intervals for all of the subjects, but separate tests for each muscle recording site, (iii) only the first 15 min interval from each subject, and (iv) only the last 15 min interval from each subject. Two additional sign tests were performed (for both time and frequency domain parameters), comparing (v) the mean parameter value from the first 15 minute time period to the

mean parameter value from the last completed time period, and (vi) the corresponding slopes to determine if their sign agreed or not.

III. RESULTS

From the discomfort surveys, it was found that each subject's discomfort increased until they self-selected to stop contracting. Discomfort values decreased in time after the contractions ceased. These trends were found in all subjects, but in varying relative amounts. Thus, muscles were subjectively fatigued by this experimental paradigm.

Table 1 shows the cross-covariance coefficient comparison results. The coefficients from the two FDS recording sites were highly related, which agrees with the expected result that one FDS EMG would be a delayed copy of the other. The other coefficients were low indicating those pairs of EMG were not very related linearly.

Table 2 shows the sign test results for case ν as listed above in "Methods of Analysis". The last row indicates that the ECR MNPF had greater mean value in the last 15 min interval than the first 15 min interval most of the time. Since the other comparisons in Table 2 had a greater than 19% chance of occurring randomly, their differences are not statistically different.

TABLE 1
CROSS-COVARIANCES COEFFICIENTS AMONG THE EMG SIGNALS

Sub. Code	Coefficients of time domain signals:			Coefficients of frequency domain signals:		
	FDSP FDS	FDSP ECR	FDS ECR	FDSP FDS	FDSP ECR	FDS ECR
1	0.670	-0.049	0.298	0.428	0.308	0.393
3	0.875	-0.145	-0.164	0.321	0.239	0.304
4	0.956	0.607	0.546	0.377	-0.096	-0.109
5	0.549	0.369	0.644	-0.581	-0.356	0.401
6	0.809	-0.062	-0.047	0.087	-0.026	0.210
7	0.812	0.796	0.678	0.329	-0.129	-0.031
11	0.264	-0.397	-0.117	0.378	-0.070	-0.085
13	0.947	0.259	0.196	0.280	0.001	0.028
18	0.979	0.545	0.492	0.507	-0.129	0.013
19	0.325	-0.323	0.031	0.265	0.030	0.225
21	0.917	0.276	0.243	0.484	0.014	0.174
22	0.827	0.381	0.315	0.642	0.360	0.367
mean	0.744	0.188	0.260	0.293	0.012	0.158
std	0.244	0.380	0.292	0.308	0.204	0.188

TABLE 2
SIGN TEST COMPARING THE MEAN VALUES OF THE FIRST AND LAST TIME PERIODS

Muscle	Domain	Probability	k	n
FDSP	Amplitude	.38721	6	12
FDS	Amplitude	.38721	6	12
ECR	Amplitude	.19385	8	12
FDSP	MNPF	.19385	8	12
FDS	MNPF	.38721	7	12
ECR	MNPF	.0031738	2	12

All remaining sign tests ("Methods of Analysis" cases $i-iv$ and vi) did not produce any statistically significant differences. Most results showed a greater than 10% chance of occurring randomly.

IV. DISCUSSION

While recent literature [4] suggests there is not a linear relation between EMG amplitude and MNPF, a common observation for short-duration muscle fatigue exercises is that as fatigue occurs EMG amplitude increases and frequency domain content shifts to lower frequencies. If this trend had occurred it would have shown up in the results presented in Table 2. However this pattern was not observed; all except the ECR frequency domain trends had a high probability of occurring randomly (19-38%). For the long-duration exercises analyzed here, we did not find the trends classically observed in short-duration fatiguing tasks. Others have reported a similar lack of the classic fatigue trends in long-duration contractions (c.f., [5]). McLean et al. [5] suggest that the muscle motor units may be rotating in and out of use over these long-term exercises. All of the subjects in our study perceived fatigue, but the EMG indications for it were not consistently manifested. This result might suggest that electrical and mechanical processes of muscles are not fully coupled and/or that recovery of these processes may occur at different rates.

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