MUSCLE ACTIVITY DETECTION USING EMG ENVELOPE THRESHOLDING – COMPARISON OF VARIOUS APPROACHES

D. Špulák[1], R. Čmejla[1], P. Mikulíková[2], J. Bezoušková Paulů[2], B. Kračmar[2]

[1] Department of Circuit Theory, Faculty of Electrical Engineering,
Czech Technical University in Prague, Prague, Czech Republic

[2] Department of Outdoor Sports, Faculty of Physical Education and Sport,
Charles University in Prague, Prague, Czech Republic

Abstract

This paper is focused on various approaches to thresholding of electromyographic (EMG) envelope. We used multichannel surface electromyography to record and evaluate electrical activity of muscles during Nordic walking. Muscle activity detection was performed using thresholding of the EMG envelope. We compared thresholding related to the maximum of the corresponding movement cycle and thresholding related to the average of all maxima of several movement cycles. Our conclusion is that the results of both approaches are generally comparable when using the same threshold level. There are greater differences if the overall amplitude of the EMG envelope tends to change during the whole recording. In these cases, thresholding related to the maximum of the corresponding movement cycle should be preferred.

1. Introduction

Electromyography deals with recording and evaluating of electrical activity of contracting muscles. There are many applications of the EMG signal: in medicine, rehabilitation, sport, entertainment etc. Multichannel electromyography is an obvious method for muscle coordination assessment. In this case, the detection of muscle onset and cessation is necessary for creating muscle coordination patterns. These patterns are used in further research for various comparisons (e.g. differences in muscle coordination when the same subject performs different movements, when different subjects perform the same movement etc.).

There are many methods for muscle coordination detection. Excluding manual analysis of the raw EMG signal, other common methods use digitized EMG signal. There are some progressive methods such as Bayesian change-point analysis [1] or Kalman smoother [2], however, rather simple detections are much more popular. Commonly, the EMG envelope (i.e. the smoothed signal obtained through low-pass filtering of the full-wave rectified EMG signal) is used as it allows simple interpretation and relatively easy muscle onset and cessation detection using thresholding or more detailed curve shape analysis . For comparison of various methods, see for example [3] or [4].

When using thresholding of the EMG envelope, it is necessary to choose the threshold level. This is usually defined as a part of maximum of the EMG envelope in the respective channel. However, the maximum can be understood as the maximum measured during the maximum voluntary contraction test, the absolute maximum obtained during the whole recording, the maximum appearing in the corresponding movement cycle or the average of maxima of several movement cycles. In this paper, we compare results of the latter two methods.

2. Experiment

2.1. Measurement

Seven females (average age 30.5 years) and three males (average age 35 years) joined our research. All volunteers are Nordic walking instructors. As the test track, we used a grassy hillside having an inclination of 7°. All volunteers performed both uphill and downhill Nordic walking (i.e. walking with poles) and common walking (i.e. walking without poles).

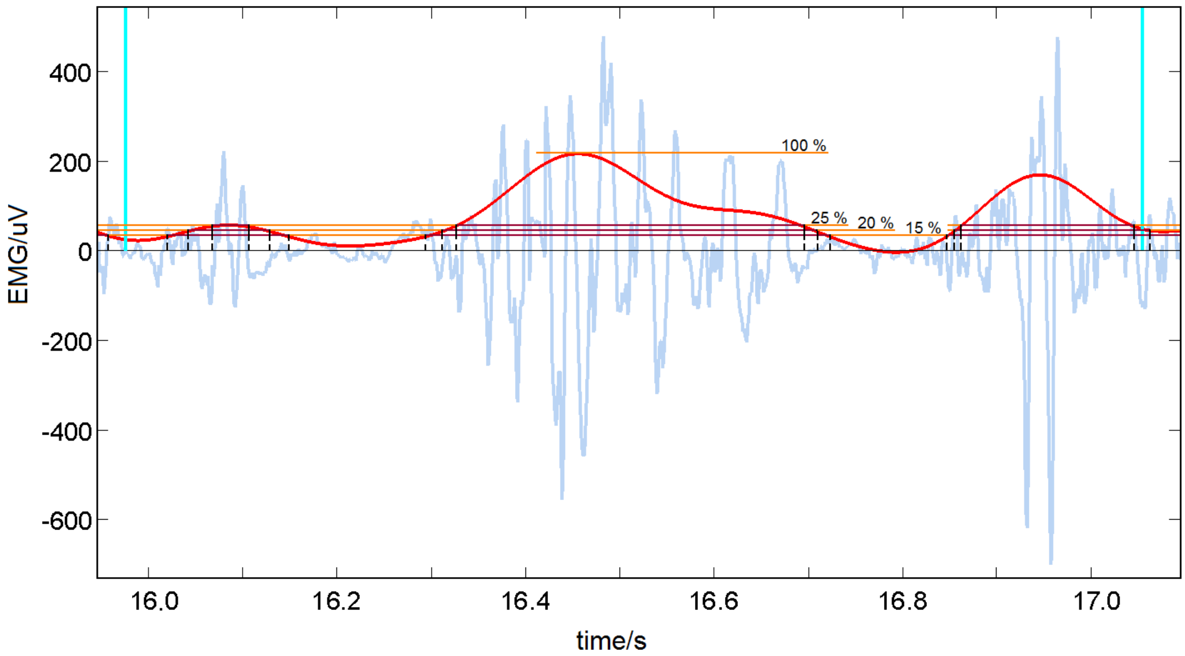

Fig. 1: EMG signal (pale blue), its envelope (red) and threshold levels (15 %, 20 % and 25 %) related to the maximum of the movement cycle (bordered by turquoise vertical lines). Note different lengths of intervals marked when using different threshold levels.

For EMG recording, the portable 16-channel recording system ME 6000 (Mega Electronics Ltd., Finland) was utilized. We used surface Ag/AgCl electrodes (H92SG, 48x34 mm, Kendall). The electrodes were placed on muscles mentioned in both tables 1 a 2 according to the SENIAM requirements. The sampling rate was 1 kHz. The walking was simultaneously recorded by a video camera in order to allow further movement analysis.

As mentioned, only results related to the Nordic walking uphill are presented in this paper. However, the purpose of the whole measurement is to provide new information about muscle

Tab. 1: Average duration of muscle activity

	Threshold					
	(% of resp. max.)	*(% of aver. max.)*	*(% of resp. max.)*	*(% of aver. max.)*	*(% of resp. max.)*	*(% of aver. max.)*
Muscle	*15*	*15*	*20*	*20*	*25*	*25*
Biceps brachii muscle-R	86.7	86.6	79.5	79.2	72.4	72.0
Triceps brachii muscle-R	57.9	57.3	53.4	52.9	49.6	49.2
Latissimus dorsi muscle-R	63.9	63.3	53.1	51.8	45.3	44.2
Pectoralis major muscle-R	92.9	93.2	86.0	85.8	77.7	76.8
Trapezius muscle medius-R	75.8	75.8	66.2	65.4	57.1	55.6
Serratus anterior muscle-R	89.6	89.5	82.4	82.0	74.5	73.6
Biceps brachii muscle-L	83.3	80.6	73.1	70.0	64.2	61.0
Triceps brachii muscle-L	54.8	54.7	49.7	49.2	45.4	45.1
Latissimus dorsi muscle-L	62.3	61.8	52.7	52.1	45.1	44.3
Pectoralis major muscle-L	80.7	81.1	69.9	69.3	60.8	59.8
Trapezius muscle medius-L	82.2	82.0	74.3	73.8	65.7	64.7
Serratus anterior muscle-L	78.4	76.4	68.2	65.7	***59.6***	***56.6***
Deltoid muscle - antherior part-R	90.5	89.7	84.0	83.0	77.5	76.4
Deltoid muscle - posterior part-R	74.6	74.1	68.6	68.0	64.3	63.5
Trapezius muscle-R	86.2	86.0	79.0	78.4	73.0	72.3
Gluteus medius muscle-R	88.6	88.7	84.4	84.2	80.8	80.5

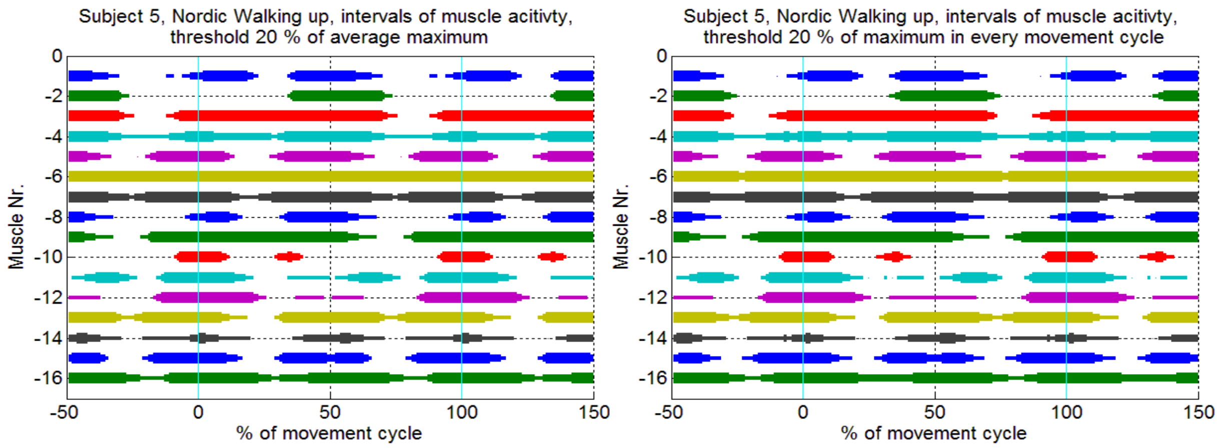

Fig. 2: Intervals of muscle activity within a movement cycle computed by thresholding of the EMG envelope. Left: the threshold 20 % was related to the average of all maxima from several cycles. Right: the threshold 20 % was always related to the maximum of the respective movement cycle. Note that the activity detection was performed in several movement cycles and the width of the lines corresponds with the probability of muscle activation in the particular part of movement cycle. The muscle numbers 1 to 16 stand for: 1-Biceps brachii muscle – right (R), 2-Triceps brachii muscle – R, 3-Latissimus dorsi muscle – R, 4-Pectoralis major muscle – R, 5-Trapezius muscle medius – R, 6-Serratus anterior muscle – R, 7-Deltoid muscle – antherior part – R, 8-Deltoid muscle – posterior part – R, 9-Trapezius muscle – R, 10-Gluteus medius muscle – R, 11-Biceps brachii muscle – left (L),12-Triceps brachii muscle – L, 13-Latissimus dorsi muscle – L, 14-Pectoralis major muscle – L, 15-Trapezius muscle medius – L, 16-Serratus anterior muscle – L

coordination. These findings will be used in physiotherapy, sport training improvement, for movement coordination correction, correction of muscle imbalance etc.

2.2. Signal Processing

Signals were processed in MATLAB. The raw EMG signal was full-wave rectified and low-pass filtered (FIR, order 501, cut-off frequency 5,2 Hz, stop-band rejection –55 dB). Obtained EMG

Tab. 2: Average number of muscle activity intervals detected within a movement cycle

	Threshold					
	(% of resp. max.)	*(% of aver. max.)*	*(% of resp. max.)*	*(% of aver. max.)*	*(% of resp. max.)*	*(% of aver. max.)*
Muscle	*15*	*15*	*20*	*20*	*25*	*25*
Biceps brachii muscle-R	1.25	1.29	1.59	1.63	1.83	1.87
Triceps brachii muscle-R	1.36	1.35	1.36	1.34	1.33	1.35
Latissimus dorsi muscle-R	1.58	1.61	1.61	1.62	1.57	1.54
Pectoralis major muscle-R	0.91	0.95	***1.37***	***1.49***	***1.75***	***1.89***
Trapezius muscle medius-R	1.60	1.61	***1.83***	***1.93***	1.88	1.92
Serratus anterior muscle-R	***0.96***	***1.02***	1.42	1.44	1.75	1.83
Biceps brachii muscle-L	***1.58***	***1.77***	***1.95***	***2.06***	2.17	2.18
Triceps brachii muscle-L	1.27	1.24	1.23	1.24	***1.28***	***1.21***
Latissimus dorsi muscle-L	1.84	1.80	1.75	1.73	1.69	1.69
Pectoralis major muscle-L	1.93	1.95	2.09	2.18	***2.11***	***2.22***
Trapezius muscle medius-L	1.48	1.54	1.78	1.84	2.06	2.13
Serratus anterior muscle-L	1.85	1.95	2.11	2.17	2.24	2.25
Deltoid muscle - antherior part-R	***0.99***	***1.06***	1.26	1.31	1.49	1.54
Deltoid muscle - posterior part-R	1.08	1.09	1.00	1.01	0.92	0.89
Trapezius muscle-R	1.14	1.19	***1.26***	***1.35***	1.27	1.31
Gluteus medius muscle-R	0.71	0.73	0.81	0.84	0.87	0.89

envelope was segmented according to several movement cycles (double-steps) and thresholding was performed in every channel.

As threshold levels, we used 15 %, 20 % and 25 % of value defined as (1) maximum of corresponding movement cycle and (2) average of maxima of all movement cycles in respective channel. Parts exceeding the threshold level were marked as intervals of muscle activation. For evaluation, we computed the average duration of muscle activity and the number of muscle activity intervals within a movement cycle. See Fig. 1 and 2 for explanation.

3. Results

As mentioned, we computed the average duration of muscle activity and the number of muscle activity intervals within a movement cycle. For overall comparison, we averaged results from all participants and placed them into the Tables 1 and 2. Tables present results of various threshold levels (15 %, 20 % and 25 %) related to the maximum of the corresponding movement cycle and to the average maximum. The arrangement of data allows easy comparison; moreover, pairs of results with difference greater than 5 % are highlighted.

4. Discussion

As expected, the duration of muscle activity marked decreases with increasing threshold level. However, there is no clear dependence between the threshold level and the number of muscle activity intervals detected. When increasing the level, some relative maxima stay below this level, causing decrease of the number of detected intervals. Nevertheless, more relative minima can appear below this level, too. This means that some larger intervals of activity get split, increasing the number of intervals detected.

The comparison of results obtained by both definitions of reference level is more interesting. Generally, the results are comparable, meaning that the differences are usually below 5 %. Greater difference appears usually if the EMG amplitude tends to change during the whole recording (because of varying physical effort, changing quality of the skin-to-electrode contact etc.). In these cases, thresholding related to the maximum of the corresponding movement cycle seems to provide more reliable results.

We do not recommend to use thresholding related to the absolute maximum of the recording or to the maximum measured during the maximum voluntary contraction test: this test is very time consuming and obtained EMG amplitude is unreliable as the quality of the skin-to-electrode contact often changes during the time. Utilization of the absolute maximum is also unreliable because this can be an outlaying value produced by a random strong contraction or by some recording error.

5. Conclusions

When thresholding the EMG envelope, it is possible to use thresholding related to the average of maxima appearing in several movement cycles or thresholding related to the maximum of the corresponding movement cycle. As we found out, both methods provide generally comparable results. Greater differences appear especially if the EMG envelope does not appear to be periodic, i.e. when the overall amplitude of the EMG signal (and the EMG envelope) appear to change during the whole recording. In these cases, thresholding related to the maximum of the corresponding movement cycle should be preferred.

References

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Daniel Špulák, ČVUT FEL, K13131, Technická 2, 166 27 Praha 6 – Dejvice, Česká republika, daniel.spulak@gmail.com