On the inter- and intra-subject variability of the electromyographic signal in isometric contractions

R. Correa Araujo, M. Duarte and A. Carlos Amadio [1]

Abstract

The objective of the present study was to evaluate the variability of the surface EMG signal of the same muscle in healthy subjects, because of lack of reproducibility of the EMG signal for the same subject and muscle in different trials of maximal isometric voluntary contraction. The results showed an EMG coefficient of variability of 21.61%, indicating that this variability must be considered in experiments with an inappropriate condition for normalization procedures, such as EMG biofeedback in rehabilitation sessions, or normalization procedures by the maximal isometric voluntary contraction.

Key-words: Electromyography – Biomechanics – Isometric contractions.

Introduction

The signal of electromyography (EMG) during human movement has been extensively studied considering that the EMG signal presents a potential relationship with the intensity of muscle force (1) and can be related to the possible commands from the central nervous system (2). A great problem in the analysis of the EMG signal and its interpretation is related to the comparison of the EMG amplitude from different acquisitions for different subjects, muscles, or trials. This problem rises from the many uncontrollable sources of variability at the acquisition and processing level (3).

In order to decrease this variability, the normalization of the EMG signal is a common process in the EMG literature, resulting in less variability in the comparison of intra- and inter-subject signals (4). Many different normalization procedures have been proposed. Winter (5) discussed three normalization procedures of the EMG signal: a) normalization by the average of the entire EMG signal; b) normalization by the peak of the EMG signal; and c) normalization by a value of a maximum voluntary isometric contraction (MVIC) of the respective muscle.

The reproducibility of the EMG signal as a function of different normalization procedures has been studied by many authors (6-11). The great majority has used the coefficient of variability (CV), as proposed by Yang & Winter (11) and Winter (5), as a reference index.

The objective of the present study was to evaluate the variability of the surface EMG signal of the same muscle in healthy subjects. We particularly addressed the question of lack of reproducibility of the EMG signal for the same subject and muscle in different trials of MVIC. By doing so, we intend to quantify the variability of the EMG signal in very well controlled experiments – the minimum possible variability in surface EMG – which can be referred to as the baseline of the variability in such signal. This variability in surface EMG has not been quantified but offers a better understanding of the different sources of variability and is important to ascertain the limits of reproducibility in experiments measuring surface EMG.

[1] Laboratory of Biomechanics, School of Physical Education and Sports, University of São Paulo, Brazil.

Methods

Nine voluntary healthy adult volunteers participated in the study (age: 27 ± 3 years; height: 176 ± 10 cm, and mass: 76.4 ± 16 kg).

Two experiments were performed in order to study the inter- and intra-variability of the electromyographic signal in isometric contractions. For each subject we recorded 6 acquisitions of the EMG signal of the m. tibialis anterior (TA) for the right and the left leg. In the first experiment, we performed the six recordings on the right TA and then the six recordings on the left TA. In the second experiment, the same procedure was used but now the acquisitions were alternated between the right (R) and left (L) leg since the placement of the electrodes is a source of signal variability and in order to avoid the error propagation of the electrode placement across trials. To avoid any variability due to the characteristics of the electrodes, only one electrode (an active electrode) was used in these two experiments and for each experiment there were 108 acquisitions (2 legs $\times 6$ trials $\times 9$ subjects).

The EMG signal was acquired by a bipolar differential active electrode (Bagnoli-2, Delsys Inc.) with the two elements made of silver and with measuring 1-mm height $\times 2$-mm thickness $\times 10$-mm width at a distance of 10 mm center-to-center from each other. The electrode had a pre-amplification of 10 and was connected to an amplifier with a gain of 100 (CMRR $>$ 80 dB) and bandpass filtered in the region of 20-400 Hz (Bagnoli-2, Delsys Inc.). The acquisitions were performed using an A/D board (12 bits) with a sampling frequency of 1,000 Hz interfaced to an IBM PC computer, according to the current literature (12, 13).

The m. tibialis anterior was selected because it is a large muscle (minimizing in this way the presence of cross talk). Besides, the localization of the motor point is easy (approximately 4 cm below the tuberosity of the tibia and 1 cm lateral to the crest of the tibia), minimizing in this way the variation of the signal due to the placement of the electrodes. In this study, the proximal electrode was placed over the motor point and the distal electrode was placed distally on the muscle belly, and they were oriented parallel to the longitudinal axis of the muscle.

The studied task was the MVIC induced by protocols of manual testing of muscle function (14): the subjects were instructed to perform a movement of dorsal flexion and inversion of the foot against a strong manual resistance from the investigator. The EMG measurement was performed when the foot segment was at the end of its physiological range of movement for this task. Each trial consisted of holding this task for about 3 s with a resting interval of 1 min between trials. Fatigue was not an issue in this protocol.

The root mean square (RMS) value of a 500 ms period of the EMG curve where the signal presented maximum amplitude was calculated for each trial. A CV was employed to estimate the variability of the RMS value across trials, given by:

$$CV = \frac{\sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} sd_i^2}}{\frac{1}{N} \cdot \sum_{i=1}^{N} |\bar{X}|} \times 100\%$$

where N is the number of RMS values being compared, and sd and X are the standard deviation and the mean of these values.

Due to the reduced sample size and non-normality of the data, the non-parametric Wilcoxon test for paired sample was employed with a p-value of 0.05 for the significance test (15).

Results

Figure 1 presents the CVs for each subject and for the right and left sides. Figure 1A shows the results for experiment 1 where the 6 trials for one side were recorded in sequence maintaining the electrode in the same place. There was an $18 \pm 8\%$ (range of 8 to 34%) variation of the CV in relation to the side of recording, and there was no statistical difference between sides. When the leg of electrode placement was alternated between acquisitions a $23.8 \pm 9\%$ (range of 11 to 46%) variation of the CV was observed, as illustrated in Figure 1B. There was no statistical difference between sides.

Figure 2 compares conditions I and II, i.e. maintaining the electrode in the same place and alternating it between acquisitions, respectively. This figure shows that there was no statistical difference between conditions and therefore it is

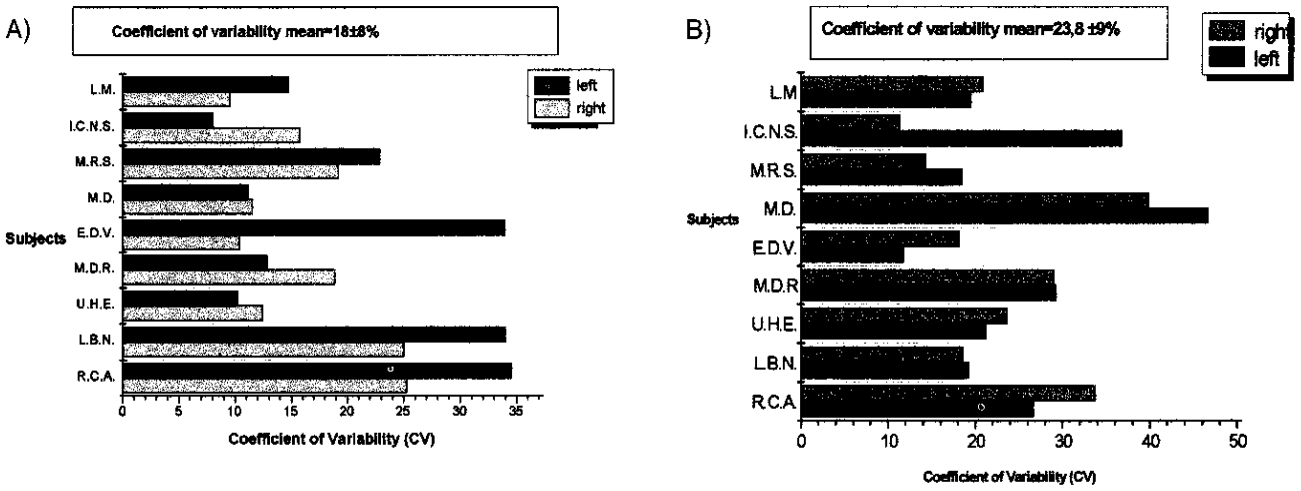

Fig. 1. – Coefficient of variability of the RMS values of the EMG signal of six trials from the right (R) and left L) m. tibialis anterior during MVIC. A) Trials for one side were recorded in sequence maintaining the electrode in the same place. B) Trials in which the leg of electrode placement was alternated between acquisitions.

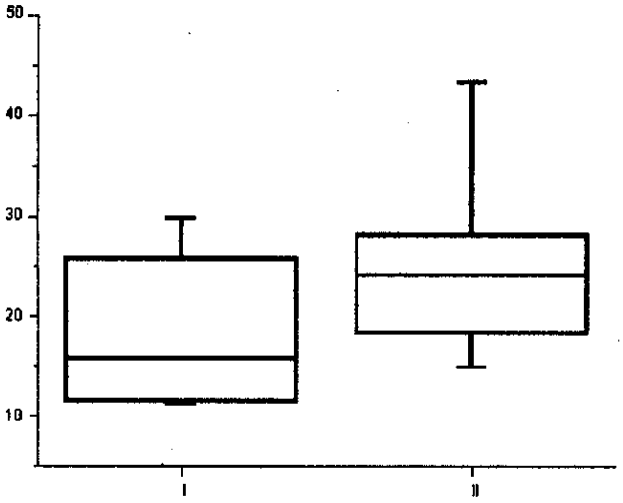

Fig. 2. – Graph showing the coefficient of variability (median and confidence interval) of the EMG signal registered during maximal isometric voluntary contractions in two different conditions. In condition I the electrodes were in the same place for all acquisitions, and in condition II the electrodes were alternated between the left and right side for each acquisition.

possible to confirm that the CV (17.46 and 25.76) average is 21.61, considering 95% confidence interval.

Discussion

The variability of the EMG signal was very high. For example, if one records an EMG signal with 100 mV RMS, and then another acquisition if performed, it is possible to measure an EMG signal with 120 mV RMS, even if nothing has changed. Some explanations of this high variability concerning factors in the generation and recording of the signal deserve to be addressed.

In relation to the signal recording, isometric contractions were studied because of the higher reproducibility of this task as compared to the isotonic contractions (2). The subjects were asked to develop a maximum force and, although the force was not monitored in these experiments, we expected little influence of the force at maximum effort on the EMG amplitude. In a previous experiment (16), we found that the amplitude of the EMG signal stabilizes at about 46 ± 13% of the maximum force. On the other hand, one must consider that force training could alter the level of maximum force. But even in this situation, the values could be questioned because the level of sub-maximal force is extremely variable, changing with the arousal level and the circadian rhythm, among other factors (16).

A possible source of variability is represented by the small alterations in the placement of the electrode by the experimenter. Here we used the technique of localizing the motor point using surface electrostimulation. The point located on the skin could not represent exactly the same motor point from trial to trial due to sliding of the skin in relation to the muscle. Despite this problem, the

placement of the electrode on the muscle motor point seems to be the most reliable technique because it is experimentally determined for each subject and is not based on general reference tables. Anyway, our findings showed no statistical difference between the two experiments, demonstrating that EMG variability is not due to the placement of the electrodes.

Gamet et al. (17) studied the reproducibility of spectral parameters of the EMG signal during dynamic exercise on a cycloergometer and pointed out that two factors can be considered in the reproducibility of the EMG signal:

a) extrinsic factors mainly related to the techniques of recording, such as type and location of the electrodes, type of detection, and electrical quality of the electrodes;
b) intrinsic factors mainly related to the physiological events, such as changes in the motor unit recruitment, increasing temperature, and particularly, metabolic and ionic changes, which affects the frequency content of the EMG signal.

Changes in temperature are unlikely to have played a role in our experiments because of the short time of the task and large interval between trials.

Nevertheless, if the reported mean variability of 21.61% is also applicable to other muscles, one must consider such error in the comparison of different acquisitions. In this sense, the reported mean coefficient of variation expresses a limitation of the surface EMG when one analyzes the signal amplitude. We were not able to identify a single cause for this high CV; rather we suggest that the summation of all factors discussed earlier can explain such occurrence.

Only when using the normalization procedures discussed earlier, does it seem reasonable to perform comparisons of the EMG signal between acquisitions. However, the present results show that even using a procedure normalizing by the MVIC value, one must consider an error of 21.61%.

However, it is not always possible to use normalization procedures. An interesting example is the use of EMG biofeedback, where such error should also be considered. In general, when the EMG signal of a subject with a motor deficit is acquired, the subject is instructed to perform contractions to increase the activity of a muscle group, by visualizing in terms of percentile of the maximum activity for a specific level of sensitivity of the equipment in that acquisition. Training is performed to increase the EMG activity visualized on the equipment. For example, the subject can obtain 70% of EMG activity in relation to the scale, and then be oriented to perform movements to obtain an EMG activity exceeding that level. Despite the unquestionable benefits that training can provide for the rehabilitation of subjects, an 10 or 20% in EMG activity from one day to the other should be a source of concern. This increase may not result from the evolution of the subject but rather from the variability of the surface EMG signal. In this case it does not make sense to normalize the data of two treatment sessions because the normalization would mask the difference in the EMG amplitude being monitored.

A suggestion to the investigators who normalize by the MVIC would be to normalize by the peak amplitude of the M-wave because the electrical stimulus can be well controlled, which is not the case in the MVIC.

Summing up, this source of variability on the surface EMG signal must be considered either when normalization procedures are applied or not in order to avoid misinterpretations.

References

1. HERZOG, W., GUIMARÃES, A.C. and ZHANG, Y.T.: EMG. In: Nigg, B.M. and Herzog, W. (eds.), *Biomechanics of the musculo-skeletal system*. John Wiley & Sons, New York, 308-33, 1994.
2. BASMAJIAN, J.V. and DE LUCA, C.J.: EMG signal amplitude and force. In: Basmajian, J.V. and De Luca, C.J. (eds.), *Muscle alive*. Williams & Wilkins, Baltimore, 187-200, 1985.
3. LOEB, G.E. and GANS, C.: *Electromyography for experimentalists*. University Chicago Press, Chicago, 1986.
4. KASHIWAGI, K., TANAKA, M., KAWAZOE, T., FURUICHI, K. and TAKADA, H.: Effect of amplitude normalization on surface EMG linear envelopes of masticatory muscles during gum chewing. *J. Osaka Dental Univ.*, 29: 19-28, 1995.
5. WINTER, D.A.: *The biomechanics and motor control of human gait: normal, elderly and pathological*, 2nd ed. University of Waterloo Press, Waterloo, 1991.
6. ARSENAULT, A.B., WINTER, D.A. and MARTENIUK, R.G.: Is there a "normal" profile of EMG activity in gait? *Med. Biol. Engng. Comp.*, 24: 337-43, 1986.

7. GOLLHOUFER, A., HORTSMANN, G. A., SCHMIDTBLEICHER, D. and SCHÖNTHAL, D: Reproducibility of electromyographic patterns in stretch-shortening type contractions. *Eur. J. Appl. Physiol.*, 60: 7-14, 1990.
8. KABADA, M. P., RAMAKRISHNAN, M., WOOTETEN, J., GAINEY, J., GORTON, G. and COCHRAN, G. V. B.: Repeatability of kinematic, kinetic and electromyographic data in normal adult gait. *J. Orthop. Res.*, 07: 849-60, 1989.
9. KNUTSON, L. M., SODERBERG, G. L., BALLANTYNE, B. T. and CLARKE, W. R.: A study of various normalization procedures for within day electromyographic data. *J. Electromyogr. Kinesiol.*, 4: 47-59, 1994.
10. WINTER, D. A. and YACK, H. J.: EMG profiles during normal human walking: stride-to-stride and inter-subject variability. *Electroencephal. Clin. Neurophysiol.*, 67: 402-11, 1987.
11. YANG, J. F and WINTER, D. A.: Electromyographic amplitude normalization methods: improving their sensitivity as diagnostic tools in gait analysis. *Arch. Phys. Med. Rehab.*, 65: 517-21, 1984.
12. SAMESHIMA, K.: Princípios gerais de aquisição e processamento de sinais biológicos. *Jornal de Pneumologia*, 13: 50-61, 1987.
13. TREPMAN, E., GELLMAN, R. E., SOLOMON, R., MURTHY, K. R., MICHELI, L. J. and DE LUCA, C. J.: Electromyographic analysis of standing posture and demiplie in ballet and modern dancers. *Med. Sci. Sports Exerc.*, 26: 771-82, 1994.
14. KENDALL, F. P. and MCCREARY, E. K.: *Muscles testing and functions*, 3rd ed. Williams & Wilkins, Baltimore, 1983.
15. CONOVER, W. J.: *Practical nonparametric statistics*. John Wiley & Sons, New York, 1971.
16. ARAUJO, R. C.: *Utilization of the Electromyography in the Biomechanical Analysis of the Human Movement* (doctoral dissertation). School of Physical Education and Sports, University of São Paulo, São Paulo, 1998.
17. GAMET, D., DUCHÊNE, J. and GOUBEL, F.: Reproducibility of kinetics of electromyogram spectrum parameters during dynamic exercises. *Eur. J. Appl. Physiol.*, 74: 504-10, 1996.

Address reprint requests to:
Rubens Correa Araujo
Av. Mello Moraes, 65
Universidade de São Paulo
Cidade Universitaria
05508-900 – São Paulo – Brasil
Tel./Fax +55 (11) 818-3184