Evaluation of sternocleidomastoid muscle activity by electromyography recorded with concentric ring electrodes

L. Estrada[1,2,3], A. Torres[1,2,3], J. Garcia-Casado[4], L. Sarlabous[1,3], G. Prats-Boluda[4], R. Jané[1,2,3]

[1] Institute for Bioengineering of Catalonia (IBEC), Barcelona, Spain,
{lestrada, atorres, lsarlabous, rjane}@ibecbarcelona.eu
[2] Universitat Politècnica de Catalunya (UPC) – Barcelona Tech, Barcelona, Spain
[3] Biomedical Research Networking Center in Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), Spain
[4] Centro de Investigación e Innovación en Bioingeniería, (CI2B-UPV), Valencia, Spain,
{jgarciac, geprabo}@eln.upv.es

Abstract

The use of non-invasive methods for the study of respiratory muscle signals can provide clinical information for the evaluation of the respiratory muscle function. The aim of this study was to evaluate the electrical activity of the sternocleidomastoid muscle recorded superficially by means of a concentric ring electrode (CRE) in bipolar configuration. This sensor enhances the spatial resolution of the signal recorded, attenuates interferences, as the cardiac activity, and also simplifies the orientation problem associated to the electrode location on the muscle under study. Five healthy subjects underwent a respiratory load test in which an inspiratory load was imposed during the inspiratory phase.

During the test, the electromyographic signal of the sternocleidomastoid muscle (EMGsc) and the inspiratory mouth pressure (Pmouth) were acquired. The EMGsc signal was processed using the fixed sample entropy (fSampEn), a technique for the amplitude estimation of signals that is robust in presence of impulsive noise as cardiac activity. The agreement between the Pmouth and the fSampEn over the EMGsc signal showed a moderate Pearson's correlation value at the lowest inspiratory load (0.46 ± 0.11) and a very strong value at the highest inspiratory load (0.84 ± 0.08). In conclusion, the surface recordings of the EMGsc signal using a CRE and the estimation of its amplitude using the fSampEn technique can be used for the study of muscle respiratory activity.

1. Introduction

The breathing process involves the activation of the diaphragm; the most prominent muscle of inspiration that essentially never stops working. When there is an increased work of breathing, accessory muscles of respiration are recruited. The sternocleidomastoid (SMC) is an accessory muscle, located at the neck region which originates at the medial sternal head and the lateral clavicular head and is inserted on the mastoid process. It also flexes the neck and contributes to its rotation. Its study reveals important impairments in the respiratory function. The electromyographic signal of the SMC muscle (EMGsc) has become evident in patients suffering from chronic pulmonary obstructive disease (COPD) [1] who present acute respiratory failure and undergo a weaning trial [2].

In a respiratory muscle training study, COPD patients have shown an increased participation of the sternocleidomastoid muscle in comparison to the diaphragm to overcome an inspiratory threshold load, whilst the activity of both muscles increased in elderly [3]. Despite being a muscle of easy access to study, some issues are necessary to take into consideration when the EMGsc activity is evaluated. EMGsc activity can be distorted by movement artifacts during the breathing due to neck movement. Also, it can be contaminated by the underlying musculature, especially that of the scalene muscle during resting breathing [4]. Furthermore, the electrocardiographic signal (ECG) contaminates the recordings of the EMGsc signal. In addition, the spectrum of the ECG signal overlaps the spectrum of the EMGsc signal, which makes the interpretation of the breathing activity difficult. The EMGsc signal is usually acquired using conventional disc electrodes in monopolar or bipolar configuration; however, they have a poor spatial resolution.

In this work we propose the use of concentric ring electrodes (CRE) to acquire the EMGSc signal. CRE estimates the Laplacian potential of the body surface [5]. It has proven to enhance the spatial resolution of biosignal recordings compared to the conventional use of disc electrodes in bipolar configuration, reducing interferences as the cardiac activity [6] and the orientation problems in the electrode location [7]. CRE electrodes have been used for picking-up surface electromyographic signals from biceps [7], diaphragm [8], and masseter muscles [9]. In clinical practice, the amplitude of electromyographic muscle signals is routinely evaluated with the average rectified value or the root mean square [10], [11]. In this study we propose the use of the fixed sample entropy (fSampEn) [12] to evaluate the amplitude of the EMGsc signal. Recently, fSampEn has demonstrated to be less sensitive to the influence of impulsive noise, such as the ECG signal in diaphragm electromyographic signals compared to the average rectified value and root mean square [12]. In this context, the aims of the present work were (1) to investigate the use of a CRE for the non-invasive recording of EMGsc signals in healthy subjects performing an inspiratory load test, and (2) to estimate the EMGsc amplitude using the fSampEn technique.

2. Materials and Methods

2.1. Respiratory load test

The study was performed in five healthy nonsmoking subjects (mean ± standard deviation: age 35.20 ± 4.55 years, height 1.76 ± 0.08 m, weight 79.40 ± 8.59 kg) with no relevant medical conditions. Subjects underwent a respiratory test which consisted of 4 sets of loaded inspirations each with 1 min of duration, with 2 min of rest in between. Initially, they inhaled with no inspiratory load and at quiet breathing.

Subsequently, they inhaled by imposing an inspiratory load adjusted to a level of 19, 29, and 41 cm H_2O using a hand-held inspiratory muscle training device (Threshold IMT, Philips Respironics, Amsterdam, The Netherlands). Subjects were seated in a chair and wore a noseclip to prevent leakage through the nostrils. Furthermore, subjects were encouraged to follow a feedback that was displayed on a computer screen to maintain the breathing pattern. The respiratory rate was set to 15 breaths per minute and the ratio of the duration of inspiration to the total respiratory cycle time to 0.42.

2.2. Recording of signals

The EMGsc signal was recorded from the left side of the neck using a disposable bipolar CRE (Code®, Spes Medica, Genova, Italy). As illustrated in Figure 1, this electrode is made up of an inner central disc and an external ring. A common ground electrode was placed on the right ankle (pre-gelled, disposable, 10-mm diameter contact area, foam electrode 50/PK – EL501, Biopac Systems Inc., Santa Barbara, CA, USA). The subjects' skin was slightly abraded with gel (Nuprep, Weaver and Company, Aurora, CO, USA) and cleaned using alcohol. CRE was placed over the lower half of the EMGsc based on the palpation of the muscle [10].

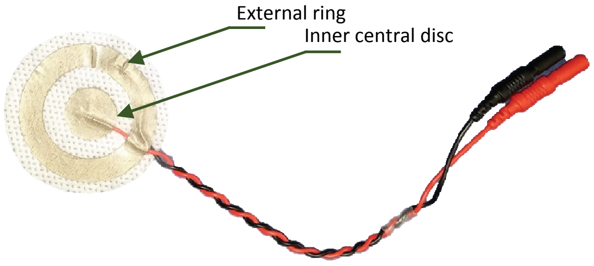

Figure 1. *Concentric ring electrode (CoDe®) used for the recording of the electromyographic signal of the sternocleidomastoid muscle*

CRE was connected to a modular amplifier (EMG 100C, Biopac Systems Inc.), with an analog band-pass filter with cut-off frequencies of 1 and 500 Hz and a gain of 5000. Inspiratory mouth pressure (Pmouth) was measured with a differential pressure transducer (TSD160, Biopac Systems Inc.), connected to a modular differential amplifier (DAC100C, Biopac Systems Inc.) with an analog low-pass filter with a cut-off frequency of 300 Hz and a gain of 50. Signals were sampled at 2000Hz, using a 16-bits analogue-to-digital converter data acquisition system (MP150, Biopac Systems Inc.), fed into a computer,

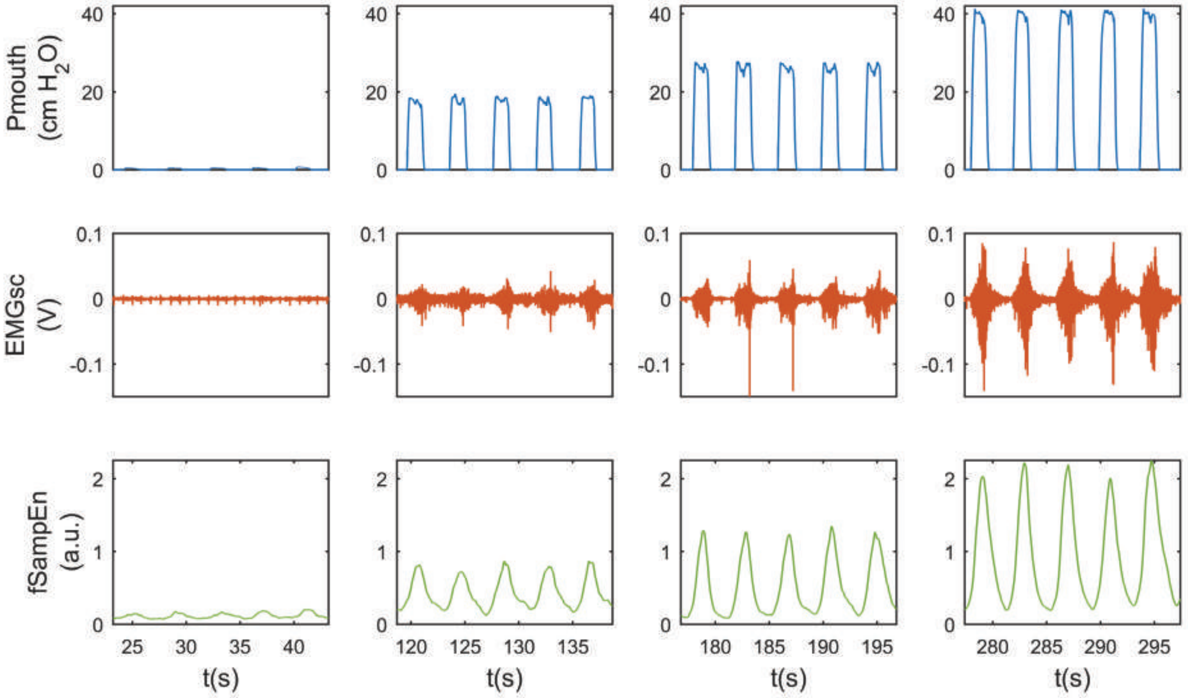

Figure 2. *Respiratory cycles of Pmouth and EMGsc signal from one representative subject in a respiratory load test and the evaluation of fSampEn over the EMGsc signal. From left to right: Increments in the inspiratory load corresponding to quiet breathing, 19, 29 and 41 cm H_2O*

Subjects	Quiet breathing	19 (cmH_2O)	29 (cmH_2O)	41 (cmH_2O)
1	0.52	0.88	0.92	0.94
2	0.52	0.60	0.72	0.79
3	0.55	0.87	0.91	0.91
4	0.28	0.67	0.71	0.82
5	0.41	0.66	0.70	0.74
Mean	0.46	0.74	0.79	0.84
SD	0.11	0.13	0.11	0.08

Table 1. *Pearson's correlation coefficient between the Pmouth signal and the fSampEn during the respiratory load test. SD: standard deviation*

monitored and stored (AcqKnowledge software v.3.2, Biopac Systems Inc.). Acquired signals were decimated at a sampling rate of 1000Hz and the subsequent analysis was performed using MATLAB (v. R2011b, Natick, MA, USA).

2.3. EMGsc signal processing

The EMGsc signal was digitally band-pass filtered using a zero-phase second-order Butterworth filter with a cut frequency of 5 and 400 Hz. The amplitude of the EMGsc signal was estimated by the fSampEn [12]. For calculating the fSampEn, two parameters are defined: the embedding dimension m (length of compared runs) and the tolerance value r (similarity criterion). For this study, $m = 1$ and $r = 0.3$ times of the standard deviation of the whole signal under study as proposed in [12] and [13]. Furthermore, a 1-sec moving window of analysis with steps of 0.1-sec was applied to the EMGsc signals [12].

2.4. Data analysis

In order to quantify the agreement between the Pmouth signal and the use of the fSampEn over the EMGsc signal the Pearson's correlation coefficient was calculated at different levels of the inspiratory load.

The peak values detected in each respiration of the fSampEn at different levels of inspiratory load were averaged; and subsequently normalized to the mean value corresponding to the quiet breathing. This represents an indirect measure of the neural respiratory drive. Similarly, to evaluate the inspiratory muscle effort, the peak values found in each respiration of the Pmouth were averaged at different levels of inspiratory load.

3. Results

Figure 2 shows an example of the Pmouth signal recorded simultaneously with the EMGsc signal picked up by a CRE, and the fSampEn calculated over the EMGsc signal from a representative subject who performed a respiratory load test. It is noted that as the inspiratory load increased from quiet breathing to $41cmH_2O$, the amplitude of the EMGsc also increases as well as that of the fSampEn. Pearson's correlation coefficient between the Pmouth signal and the fSampEn over the EMGsc signal at different levels of inspiratory load are reported in Table I.

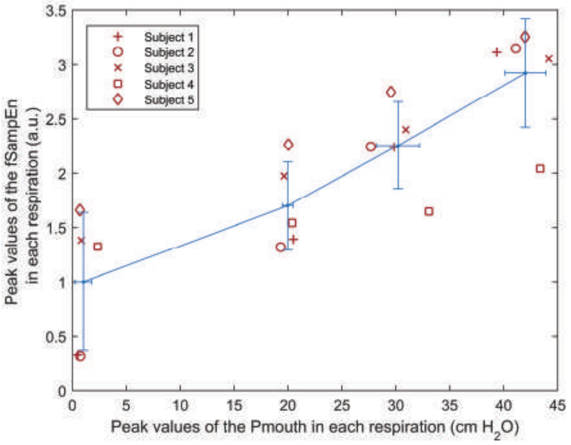

Figure 3. *Neural respiratory drive evaluated in EMGsc signals during an inspiratory load test. The mean peaks of the fSampEn were normalized to the average value of the lowest load. Symbols represent data from different subjects evaluated. Horizontal and vertical error bars indicate the standard deviation of the mean peak values from the Pmouth and the fSampEn, respectively*

Overall, the Pearson's correlation increases as the inspiratory load increases resulting in a moderate correlation at quiet breathing (0.46 ± 0.11); whilst a very strong correlation was found at the highest inspiratory load (0.84 ± 0.08).

Figure 3 shows the evaluation of neural respiratory drive estimated by fSampEn and calculated over the EMGsc signal. It revealed a positive tendency of the normalized fSampEn peaks to increase in each subject as the inspiratory load increases, with a Pearson's correlation of 0.83. On the other hand, error bars reflected a reduction in the scatter of the peak fSampEn and an increase in the scatter of the peak Pmouth as the inspiratory load increases.

4. Discussion and conclusions

The use of non-invasive technologies for measuring the respiratory function along with novel signal processing techniques is advantageous to obtain information of clinical utility of the respiratory muscles. In this respect, we considered the use of a CRE for recordings the electrical activity of the EMGsc.

The use of CREs has been proposed to increase the spatial selectivity of bioelectrical signals, attenuating the main interferences that affect them as the ECG signal [6], [8].

Also, it simplifies the problem associated to the orientation of the electrode which is an essential issue to consider when a bipolar electrode configuration is used [7]. On the other hand, it is important to mention that the CRE we have employed can cover a larger area over the skin of the EMGsc than necessary. This can increase the inherent crosstalk effect from nearby muscles. Nonetheless, if any accessory muscle is recruited during the respiratory load test, its contribution should reflect the progressive increase of the inspiratory effort.

Concerning the use of fSampEn, it has shown to be valuable for the amplitude estimation of the EMGsc activity, especially when impulsive noise was present.

The strength of correlation between the Pmouth and the fSampEn calculated over the EMGsc signal improved as the inspiratory load increased. Factors that may have contributed to a poor correlation at the lowest inspiratory load (quiet breathing) were a high prevalence of ECG activity along with a low EMGsc activity recorded.

The highest correlation was found at 41 cmH_2O in which the cardiac activity was less predominant since the collected EMGsc activity was stronger. Similarly, fSampEn has been applied for the study of diaphragm electromyographic signals recorded superficially at the right side under the same respiratory test but using a pair of disc electrodes in bipolar configuration [12]. Despite having used a different location and a different electrode configuration, our results are consistent with those obtained in [12]. In that study, the correlation increased (0.38 to 0.83) as the inspiratory load increased (from quiet breathing to 33 cmH_2O). On the other hand, the use of fSampEn has shown to be an indirect estimator of the neural respiratory drive from EMGsc signals. As it can be observed, an increase in the peak Pmouth resulted in an increase in the peak fSampEn showing that EMGsc amplitude provides information related to the neural respiratory drive.

Finally, in this work we highlight that using CRE for the non-invasive recording of electromyographic activity from accessory respiratory muscles could be beneficial in the medical practice as an alternative technique to using conventional electrode configurations. Furthermore, valuable information can be extracted from respiratory muscle activity using fSampEn.

To overcome the limitations of this study and give more strength to work and results, future work is aimed to increase the number of subjects evaluated, to analyze the influence of ring dimension, to compare the results with conventional electrodes, and to carry out tests in clinical sets with pathological subjects.

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