Assessment of common information in surface electromyography recordings with adhesive electrodes and an intravaginal probe

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Abstract

Dysfunctions in pelvic floor muscles (PFM) are a highly prevalent group of pathologies which critically alter daily life activities. Surface electromyography (sEMG) of PFM has emerged as a potential evaluative tool but recordings are affected by interferences of nearby muscle groups. The aim of this study is to assess the association between internal and external sEMG signals in order to better identify the different PFM sources . Four monopolar and two bipolar signals were recorded from the perineum (external recordings), and two monopolar signals with an intravaginal probe in 32 women with vulvodynia.. Cross-correlation (CC) and normalized mutual information (NMI) were computed between signal pairs to assess their common information. External monopolar electrodes showed high CC (82 %) and NMI (19 %) among them, probably due to common mode interferences and volume conduction. External monopolar signals on posterior PFM have relevant common information with probe signals of the same side (CC: 55 %, NMI:6.5 %), suggesting that deep PFM activity could be monitored without using intravaginal probes, which are painful for some patients. Little common information was found between intravaginal probe and external bipolar signals, suggesting that deep and surface activity can be assessed separately with these recordings set-ups. These findings can be relevant for the recording and interpretation of sEMG signals when assesing PFM electrophysilogical condition in the clinical management of PFM disorders.

1. Introduction

Pelvic floor muscles (PFM) are a group of muscles and ligaments that lay at the base of the abdominal cavity. They are responsible for supporting pelvic organs (bladder, rectus, and uterus/prostate) in right position. Moreover, they play a key role in providing stability in standing, as well as in sphincteric and sexual functions [1]. They are classified in 3 layers depending on their depth, so activity from deep muscles is different from the surface ones.

Dysfunctions of PFM include urinary incontinence, pelvic organs prolapse, anal incontinence, sensory abnormalities of the lower urinary tract, defecatory dysfunction and chronic pain syndromes related to the pelvic floor. They may significantly affect common daily living tasks of patients and have a high economic impact, as in the case of urinary incontinence, which accounts for at least 2% of the health budget in developed countries [2]. The high estimated probability (23.7 % in USA population [3]) of suffering from one or more of these pelvic floor disorders makes it necessary to develop accurate and quick diagnostic tools and treatments approaches. Diagnosis may include from an initial manual examination to some extra tests such as defecating proctogram, uroflow test and surface electromyography (sEMG) [4].

Electrophysiological evaluation with sEMG can be a powerful tool to objectively assess PFM condition. Although some studies in the field have recorded PFM sEMG with self-adhesive surface electrodes, their use has been questioned because of their high susceptibility to crosstalk from neighboring muscular groups, which is often due to volume conduction of electrical activity [5]. On the other hand, intracavitary probes are used for mainly recording deep PFM activity, although they can also be affected by crosstalk and can cause pain and discomfort to the patients.

The aim of this study was thus to quantify the common information between PFM sEMG signals internally and externally recorded and to assess the origin and implication of this shared information. The starting hypothesis is that external sEMG signals also contain information from deep PFM and therefore the use of an intravaginal probe could be eliminated. To do this, sEMG signals were simultaneously acquired with an intravaginal probe and self-adhesive electrodes on the perineum surface.

2. Materials and methods

2.1. Database

A cohort of 32 female patients diagnosed with chronic pelvic pain associated with vulvodynia participated in a prospective follow-up study performed at the Hospital Universitari i Politècnic La Fe (Valencia, Spain), which met the Helsinki Declaration.

Simultaneous sEMG recording with external adhesive electrode and intravaginal probe was performed for each patient. Two pairs of disposable Ag/AgCl electrodes (Red Dot 2660-5, 3M, St. Paul, MN, USA) were placed on both sides of the vulva over the perineum and two additional electrodes (ground: GND, reference: REF) were attached on both iliac spines. These regions were previously exfoliated with an abrasive gel (Nuprep 114g, Weaver and Company, Aurora, CO, USA) to reduce skin-electrode impedance. An intravaginal probe with recording poles on both sides (Periform®+, Neen, Sutton-in-Ashfield, Nottinghamshire, UK) and lubricated with conductive gel was also used to record deep PFM activity of left and right sides.

A multipurpose biomedical signal amplifier (Grass 15LT+4 Grass 15A94, Grass Instruments, West Warwick, RI, USA) was used to record four monopolar signals (M1, M2, M3, M4) from the perineum surface and two monopolar signals (P1, P2) from the intracavitary probe. The device was configured with a band-pass filter between 3 and 1000 Hz and signals were digitalized at a rate of 10 kHz with 16 bits. Two bipolar signals were additionally computed as the difference of the two external monopolar signals of the same side (B1 = M1 – M3 (right), B2 = M2 – M4 (left)).

During the recording, patients were in a dorsal lithotomy posititon and were asked to follow a protocol of PFM voluntary contractions designed by clinicians. Each sEMG recording consisted of 5 maximum voluntary contractions of 5 s separated by 10 s of maximum relaxation. The signal segment recorded from1 s before the first contraction to 1 s after the last one was annotated for subsequent analysis. Signals were digitally filtered to attenuate frequency components out of [30, 450] Hz bandwidth and the power line interference (50 Hz), as in [6]. An example of the 8 sEMG signals of one patient is represented in Figure 1.

2.2. Similarity metrics

Common information between sEMG signals was assessed according to two different similarity metrics: cross-correlation (CC) and normalized mutual information (NMI). Signals were previously standardized to have zero mean and unit variance.

Cross-correlation is one of the common indicators for assessing crosstalk in electromyography [7]. It quantifies the magnitude of any common component contained in two signals, following the assumption that the shapes of the waveforms from both muscles under consideration are the same. Since we aim to quantify instantaneous common information, we used Pearson's correlation coefficient that is a simple and normalized (range -1 to 1) indicator:

$$CC = \frac{cov(X,Y)}{\sigma_X\, \sigma_Y} \tag{1}$$

, where $cov(X,Y)$ is the covariance of signals x[n] and y[n], and σ_X, σ_Y are their standard deviation.

Normalized mutual information in probability and information theory expresses the mutual dependence between two random variables and has been used in several sEMG applications[8]. Based on Shannon entropy mutual information is computed as in (2):

$$MI(X;Y) = \sum_{x_i y_j} P_{X,Y}(x_i, y_j) log_2 \frac{P_{X,Y}(x_i, y_j)}{P_X(x_i) P_Y(y_j)} \tag{2}$$

, where P_X and P_Y are the probability distributions of x[n] and y[n], and $(P_{X,Y})$ their joint probability distribution. P_X, P_Y and $P_{X,Y}$ were obtained by computing the histograms of x[n] and y[n] and their joint histogram, respectively, for b bins and dividing them by the number of signal samples (N). Value of b was determined by the Rice's rule:

$$b = \left|2\sqrt[3]{N}\right| \tag{3}$$

To set the range of $MI(X;Y)$ from 0 to 1, it is normalized according to equation (4):

$$NMI(X;Y) = \frac{MI(X;Y)}{\sqrt{H(X)H(Y)}} \tag{4}$$

, where $H(\cdot)$ is the Shannon entropy estimation for an individual signal, computed as follows:

$$H(X) = -\sum_{x_i} P_X(x_i) log_2(P_X(x_i)) \tag{5}$$

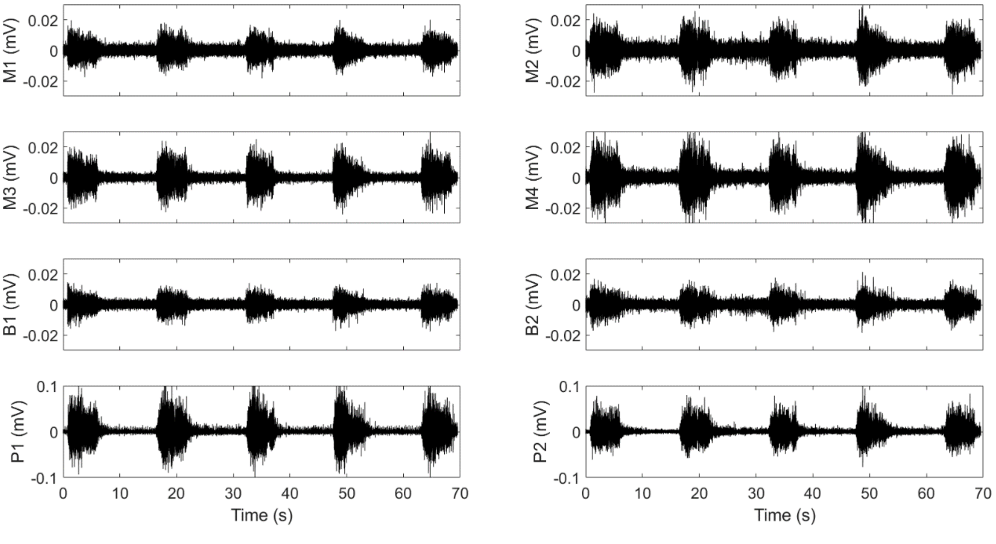

Figure 1. *Conditioned signals including 5 voluntary contractions and 4 inter-contractions resting periods. M1, M3, B1 and P1 correspond to right PFM side and M2, M4, B2 and P2 to the left PFM side*

3. Results

Table 1 shows the mean ± standard deviation of the parameters assessing common information (CC: lower triangular matrix, NMI: upper triangular matrix) over the whole population. Relevantly coupled signal pairs for both CC and NMI have been selected based on a threshold criterion. Relevant pairs were considered those whose absolute values were cumulatively added (from highest to lowest) until they reached the 50% threshold of the total sum of all absolute values of the same metric. Relevantly coupled signal pairs are shown in gray in Table 1, and are represented in Figures 2 and 3, with different color according to the type of connection (brown: left-sided, blue: right-sided, green: inter-sided).

The highest CC and NMI values were obtained between ipsilateral and contralateral sEMG signals of external monopolar electrodes. Particularly, values between M1 vs. M2 (anterior area of PFM) and M4 vs. M2 (left area of PFM) were higher than those between M3 vs. M4 (posterior area of PFM) and M1 vs. M3 (right area of PFM). On the other hand, contralateral bipolar and probe signals (B1 vs. B2, P1 vs. P2, respectively) showed low CC and NMI values.

Both probe and bipolar signals showed higher CC and NMI values with posterior than anterior external monopolar signals of their same side. However, common information between bipolar surface signals and probe signals was low and their CC and NMI were below the relevance threshold (CC: 42 %, NMI: 6.0 %).

4. Discussion

In the present study common information in sEMG signals recorded with self-adhesive electrodes and intravaginal probes were assessed according to CC and NMI, which provided similar results. Some studies have previously assessed correlation between two bipolar configurations (ipsilateral and contralateral recordings) of sEMG with the same vaginal probe [10] and between PFM sEMG and intravaginal pressure computing Pearson's coefficient of mean scores of contractions [11]. However, no study has so far quantified the common information between deep and superficial PFM activity recorded simultaneously with sEMG electrodes. Monopolar signals externally recorded (M1, M2, M3, M4) showed the highest common information rates, which was especially remarkable in electrodes located in contralateral PFM sides. One reason could be that motoneurons of different motor units are synchronized: although PFM sides have their own nerve supply, they cannot be contracted independently, which suggests that same pre-synaptic signal may be exciting their motoneurons simultaneously leading to similar waveforms [12]. However, this would also lead to significant common information between P1 and P2, that was not found. The most plausible reason is that these high common information rates were a result of crosstalk, i.e. electrical potentials detected not only from the muscle under the electrode, but also from muscles further away due to volume conduction.

Crosstalk potentials would be more similar in nearby electrodes, since signals' characteristics change as they travel through the body tissue [13], what would also justify smaller common information in diagonal (more distant) monopolar pairs.

An instrumental factor could also have influenced high CC and NMI values obtained between external monopolar signals. Reference electrode was placed over the patient's right ischiatic spine, what may not be far enough for not sensing part of the activity of right posterior PFM.

NMI (%)

CC (%)	M1	M2	M3	M4	B1	B2	P1	P2
M1		12.0 ± 5.0	10.0 ± 5.5	8.2 ± 3.9	5.9 ± 2.9	2.4 ± 1.5	4.6 ± 3.6	4.3 ± 2.3
M2	70 ± 11		6.6 ± 3.2	19.0 ± 6.9	3.5 ± 1.6	3.4 ± 1.8	4.2 ± 3.1	6.0 ± 2.9
M3	64 ± 16	44 ± 17		7.9 ± 3.5	6.5 ± 3.8	2.6 ± 1.8	9.0 ± 4.9	4.9 ± 2.4
M4	56 ± 15	82 ± 14	50 ± 15		2.6 ± 1.3	5.7 ± 3.1	4.8 ± 3.5	8.1 ± 3.4
B1	35 ± 27	26 ± 18	-45 ± 24	4 ± 20		3.7 ± 1.9	3.8 ± 2.2	2.4 ± 1.4
B2	14 ± 16	14 ± 20	-15 ± 18	-42 ± 18	36 ± 13		2.5 ± 1.5	3.6 ± 1.9
P1	31 ± 18	18 ± 18	55 ± 16	22 ± 17	-31 ± 18	-10 ± 13		4.8 ± 3.4
P2	32 ± 13	40 ± 13	34 ± 13	50 ± 12	-4 ± 12	-26 ± 17	24 ± 13	

Table 1. *Lower triangular matrix represents CC mean ± standard deviation values of the population between each pair of signals. Upper triangular matrix shows the same information for NMI.*

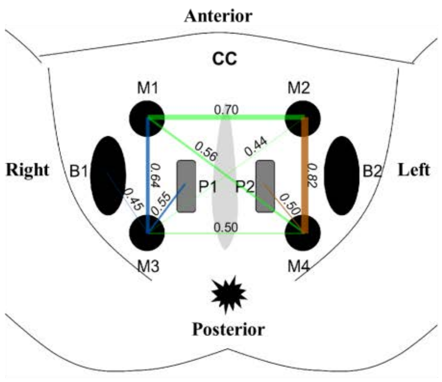

Figure 2. *Relevant cross-correlation values between channel pairs*

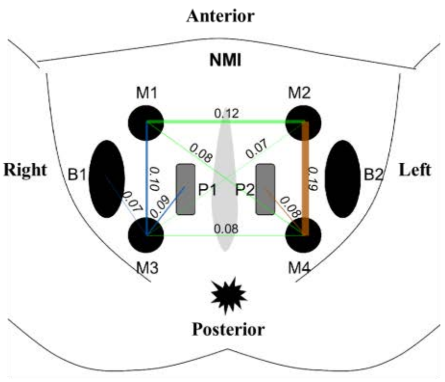

Figure 3. *Relevant normalized mutual information values between channel pairs*

This would partially cancel common information with M3 (closest electrode) and would explain why CC and NMI between anterior (M1 vs. M2) and left-sided external signals (M4 vs. M2) was greater than the ones for right side (M1 vs. M3) and posterior (M3 vs. M4).

Unlike external monopolar signals, contralateral probe and external bipolar recordings (independently assessed) shared minimum information. In view of the above, the reason in the first case would be that crosstalk had a significantly lower power than PFM activity at the intracavitary recording site (electrodes close to activity source); while in the second case it would be that common mode interferences on perineum surface were mostly cancelled in bipolar signals when subtracting monopolar signals. It is also noteworthy that minimum common information was found in probe-bipolar signal pairs.

On the other hand, signals recorded by intravaginal probe electrodes exhibited high common information with those of posterior monopolar electrodes of their corresponding side. This could be related to the fact that from an anatomical point of view, posterior external electrodes are closer to deep PFM than the anterior ones [14].

Bipolar channels also showed a high degree of common information with posterior monopolar electrodes of the same side. This was expected since bipolar signals were obtained from same-sided monopolar signals. The reason why similarity was higher with posterior than with anterior monopolar electrodes could be that signal-to-noise ratio of the first ones is generally higher since they are closer to the deep PFM [15] which generate the majority of the electrical activity that is associated with PFM as a whole.

5. Conclusions

The present study assessed common information in surface electromyography recordings performed with self-adhesive electrodes and intravaginal probes. Monopolar signals recorded from the perineum surface showed the highest level of common information among them, probably associated to crosstalk rather than to common activation patterns. On the other hand, the minimum shared information was found between external bipolar signals and recordings of intravaginal probes, suggesting that they could be used by clinicians to separately assess the activity of superficial and deep PFM.

A relevant degree of common activity was also found between posterior monopolar signals from the perineum and probe recordings on the same side, suggesting that further studies could focus on retrieving the activity of deep PFM from external monopolar sEMG recordings to avoid the use of intracavitary probes, which can cause pain in patients suffering from chronic pain syndromes.

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