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Characterizing Masseter Surface Electromyography on EEG-Related Frequency Bands in Parkinson's Disease Neuromotor Dysarthria

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Abstract. Speech has proven to be an effective neuromotor biomarker, capitalizing on the capabilities of contact-free technology. This study aims to evaluate the behavior of facial muscles' activity estimating the entropy of their surface electromyographic (sEMG) activity during the production of diadochokinetic speech tests. The study explores the entropic behavior of the sEMG signal in certain frequency bands associated to EEG activity comparing participants affected by neuromotor diseases than in age-matched normative participants. Using recordings from two PD vs two HC participants on 5 EEG bands ($\delta, \vartheta, \alpha, \beta, \gamma$), the maximum entropy estimated on the HC group was 5.70 10^{-5}, whereas the minimum entropy on the PD group was 7.25 10^{-5}. A hypothesis test rejected the similarity between the PD and HC results with a p-value under 0.0003. This different behavior might open the way to a wider study in characterizing neuromotor disease alterations from neuromotor origin.

Keywords: Entropy · EEG · Surface electromyography · Neuromotor diseases · Hypokinetic dysarthria · Parkinson's Disease

1 Introduction

Neurological diseases are rated third among health disorders resulting in disability and premature death within the European Union [1], Parkinson's Disease

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(PD) rated as the most predominant neuromotor disorder, with a prevalence rate of 105 cases per 100,000 individuals, an incidence rate of 13 cases, per 100,000 individuals, and an average number of Years Living with Disability (YLDs rate) of 15 years. Characteristic PD symptoms include rigidity, tremor, and general progressive loss of motor control to the point that people with PD (PwP) require continuous assistance in their daily life activity during the late stages of the disorder. Additionally, they often exhibit other non-motor symptoms which may hamper considerably their life quality. Speech is one of the motor symptoms most altered by PD, dysarthria developing at some point during the disease course in about 90% of people with PD (PwP) [2]. Speech involves the respiration, phonation, articulation, and their associated premotor activation systems. Each one of those key physiological mechanisms may be affected in different degrees, therefore, correlates of PD-induced alterations may be found in the analysis of electroencephalography (EEG) frequency bands related with the activity of premotor areas [3].

The aim of the present research is to provide insights into the use of entropy estimations from surface electromyograpy (sEMG) on the masseter on EEG-related frequency bands to characterize PD dysarhria by building on previous work [4] relating some speech physiological mechanisms involved in the articulation gestures of certain diadochokinetic tests with sEMG. It is well known that sEMG is the signal produced by group discharges following the activation of neuromotor units on muscle fibers [5]. Although sEMG reflects groupal activity of multiple fibers, there is some informed opinion on the possibility of finding meaningful correlates with the groupal activity of neuromotor cortical areas related with the activation of the specific muscles involved, especially relevant in the field of neuromotor rehabilitation [3]. In this sense, it is thought that the masseter sEMG could show some features specific of EEG activity in the same frequency bands regarding cortico-muscular coupling, as EEG-EMG coherence showing functional connectivity in limb movement was clearly observed [6] and is being used for rehabilitation purposes [7].

The fact that the movement of the jaw-tongue biomechanical joint is very much conditioned by the activity of the masseter can be used to establish clear relationships between acoustical features as formants, and the neuromotor activity of the masseter by means of inverse projection methods [8]. Therefore, a clear connection may be established between speech acoustics and EEG cortical activity by the interplay of sEMG. Thus, a description of sEMG in EEG frequency bands could offer some insight onto coherence and causality of cortical oscillations and movement.

On its turn, the cortico-muscular relationship between neuromotor activity and limb movement has been quite clearly established by studies on Brain-Computer Interfaces (BCI), and the most relevant EEG-frequency bands associated have been determined [9–12]. A similar relationship is likely expected between cortico-facial, glossal and laryngeal systems, responsible for speech phonation and articulation [13,14].

It is well known that entropy is strongly related with information contents of a given stochastic process. A possible characterization of the sEMG signal could be provided in terms of its entropy description, using different approximations, as Renyi's [15], approximate and sample entropy [16], multiscale [17], or transfer entropy [18], to estimate causality relationships among bands' activity. In the present research simple entropy will be used on an exploratory study.

The main hypothesis to be treated in the present research is the possibility of successfully distinguishing PD from HC speech articulation from the utterance of a sequence of five peripheral vowels in terms of the EEG-related frequency bands' entropy from the surface myoelectrical signal measured on the masseter.

The paper is organized as follows: A description of the Information Theory methods based on Entropy contents proposed in the study is provided in Sect. 2, explaining the influence of neuromotor disorders in the statistical properties of amplitude Probability Density Functions (PDFs) of EEG-related frequency bands found in the sEMG signals. The data set used in the research is also described in Sect. 2. Section 3 is devoted to present the results of processing the recordings from the four participants in the study in terms of their PDFs, and in their entropy contents, which are compared graphically and in tables. Section 4 is intended to discuss the implications of the comparisons, analyze their possible clinical applications, and remark the study limitations and its possible future extension. Section 5 summarizes the main contributions, findings and conclusions.

2 Experimental Framework

2.1 Methods

An experimental framework has been devised to test the relative effects of HD by means of the recording of the sEMG signal produced by the participants during the utterance of a fast repetition of the dyphthong [a → i]. The main features considered are the EEG-equivalent frequency bands in the sEMG signal ($\delta, \vartheta, \alpha, \beta, \gamma$, and μ). The working hypothesis is that these characteristic sEMG bands might be considered associated to EEG activity in the motor cortex when inducing speech related neuromotor discharges on the masseter. The methodology used in the study is based on the estimation of the EEG-related bands by the following procedures:

- The sEMG signal was recorded on a Biopac MP150 EMG100 platform at 2 kHz and 16 bits. The fixture to record sEMG from the masseter is shown in Fig. 1.
- A notch filter tuned 50 Hz and its higher harmonics was used for electric power artifact removing.
- EEG-related band filtering was implemented on the notch-filtered unbiased (zero-mean) sEMG signal, s_n (n being the discrete time index) using 6-order bandpass filters $F_i\{\cdot\}$ following (1), tuned to each one EEG band:
  i = 1, δ: $0 \leq f < 4$ Hz;

i = 2, ϑ: 4 ≤ f < 8 Hz;
i = 3 α: 8 ≤ f < 16 Hz;
i = 4, β: 16 ≤ f < 32 Hz;
i = 5, γ: 32 ≤ f < 64 Hz;
i = 6, μ: 8 ≤ f < 12 Hz).

– The amplitude histogram h_i of EEG-related band i is built on the filtered sEMG signal in band i $s_{i,n}$, following (2), where $b_k = k\delta_b$ and $b_{k-1} = (k-1)\delta_b$ are the k-th bin limits for the bin index $1 \leq k < K$ and the bin size δ_b, W being the time window considered.
– The probability density function $p_{i,k}$ of band i, is estimated from its normalized histogram $h_{i,k}$ following expression
– The entropy of band i is estimated following expression (4).

$$s_{i,n} = F_i\{s_n\} \tag{1}$$

$$\forall n \in W \Rightarrow \quad h_{i,k} = \begin{cases} h_{i,k-1} + 1 & b_{k-1} \leq s_{i,n} < b_k; \\ h_{i,k-1} & otherwise \end{cases} \tag{2}$$

$$p_{i,k} = h_{i,k} / \sum_{k=1}^{K} h_{i,k} \tag{3}$$

$$E_i = -\sum_{k=1}^{K} p_{i,k} log_{10}(p_{i,k}) \tag{4}$$

The band entropy E_i is estimated by a normalized 400-bin amplitude histogram of frequency band signals $s_{i,n}$, where i is the band index. Smooth approximations of the band PDFs $p_{i,k}$ may be produced using the Kolmogorov-Smirnov fit [19].

2.2 Materials

The behavior in terms of EEG frequency band entropy contents was assessed on stable vowel production (minialterations due to poor or unstable articulation) and on continuous gliding diadochokinetic voice production.

The specific articulation test used in the present study because it fulfills both conditions consisted in the sustained utterance of the peripheral five-vowel sequence test [a: → e: → i: → o: → u:]. Results from recordings by two PD participants (a male 69 year-old and a female 70 year-old, respectively) from the APARKAM association of PD patients were analyzed following the methods described in expressions (1–4). The results from these recordings were compared to similar tests against age- and gender-matched normative HC participants (69 and 62 years-old). The recording protocol was approved by the Ethical Committee of UPM (MonParLoc, 18/06/2018). The voluntary participants were informed about the experiments to be conducted, the protection of personal data,

Fig. 1. Recording fixture of sEMG on the masseter, accelerometry, and speech from a male PD participant (MP1).

and signed an informed consent form. The methodology was strictly aligned with the Declaration of Helsinki. The biometrical data of the participants are given in Table 1.

Table 1. Participants' biometrical data. MC: male control participants; MP: male PD participants; FC: female control participants; FP: female PD participants; H&Y Hoehn and Yahr PD rating scale; State: medication state (on: under medication; –: not applicable)

Code	Gender	Age	Condition	H &Y	State
MC1	M	69	–	–	–
FC1	M	62	–	–	–
MP1	M	69	PD	2	ON
FP1	M	70	PD	2	ON

3 Results

The utterance recordings of the peripheral vowel sequence test [a: → e: → i: → o: → u:] from each participant were processed to obtain the frequency band contents described in Subsect. 2.1. An example of one such recording produced by the male HC participant MC1 is shown in Fig. 2.

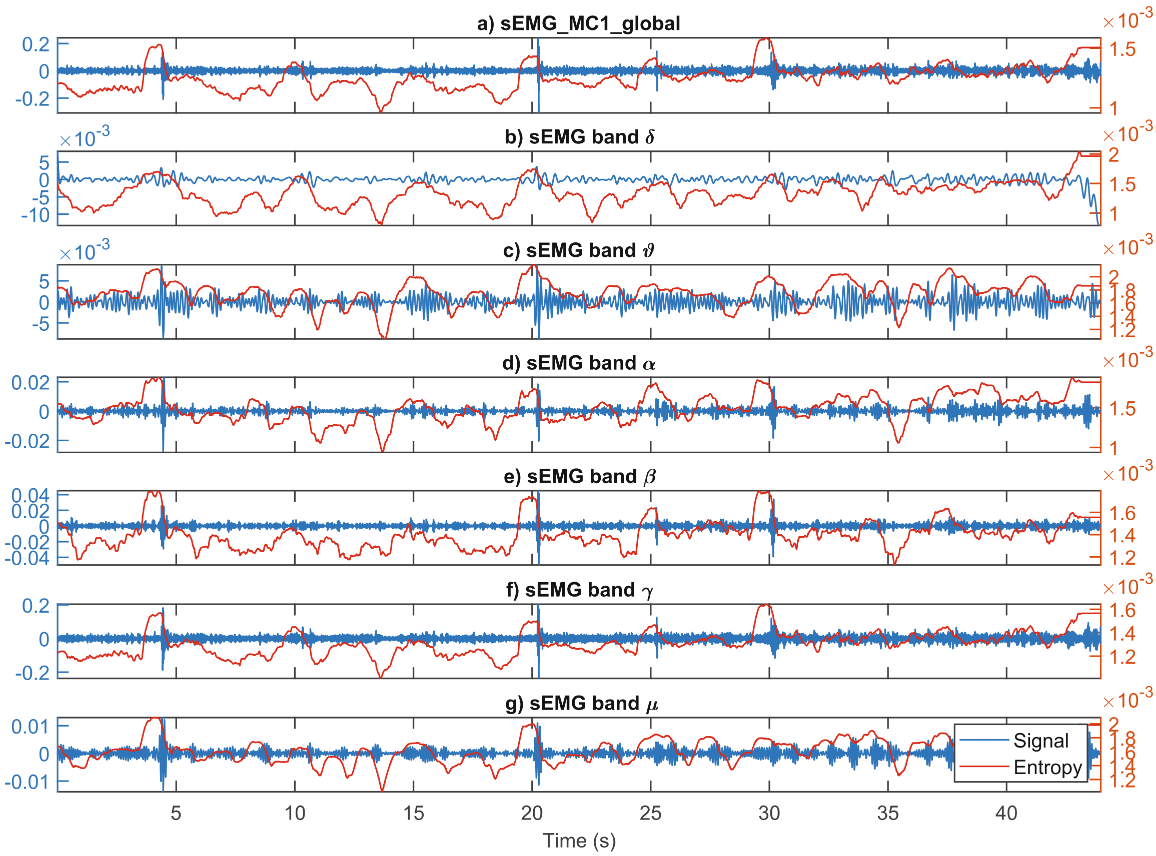

Fig. 2. Example of sEMG contents in terms of EEG-related frequency bands during the utterance of the peripheral vowel sequence test [a: → e: → i: → o: → u:] by the HC male participant (MC1): a) sEMG signal; b) δ band; c) ϑ band; d) α band; e) β band; f) γ band; g) δ band; (blue: sEMG band component, red: short time entropy). (Color figure online)

The PDFs of each frequency band from the four participants was estimated accordingly to expressions (2–3) on 400 bin amplitude histograms over the whole band window, and are presented for reference in Fig. 3.

The entropy associated to each PDF in Fig. 3 is estimated accordingly to expression (4). The result of these estimations are presented in Table 2.

For the sake of a better interpretability the band entropies per participant are also depicted in Fig. 4.

Table 2. Entropy of sEMG activity of participants in the different EEG-Bands.

Participant	Global	δ	θ	α	β	γ	μ
MC1	4.56E−05	5.05E−05	5.70E−05	5.13E−05	4.88E−05	4.67E−05	5.40E−05
FC1	4.21E−05	3.42E−05	5.16E−05	5.29E−05	4.84E−05	4.24E−05	5.53E−05
MP1	7.49E−05	7.72E−05	7.58E−05	7.28E−05	7.25E−05	7.88E−05	7.55E−05
FP1	1.17E−04	1.23E−04	1.20E−04	1.22E−04	1.17E−04	1.14E−04	1.22E−04

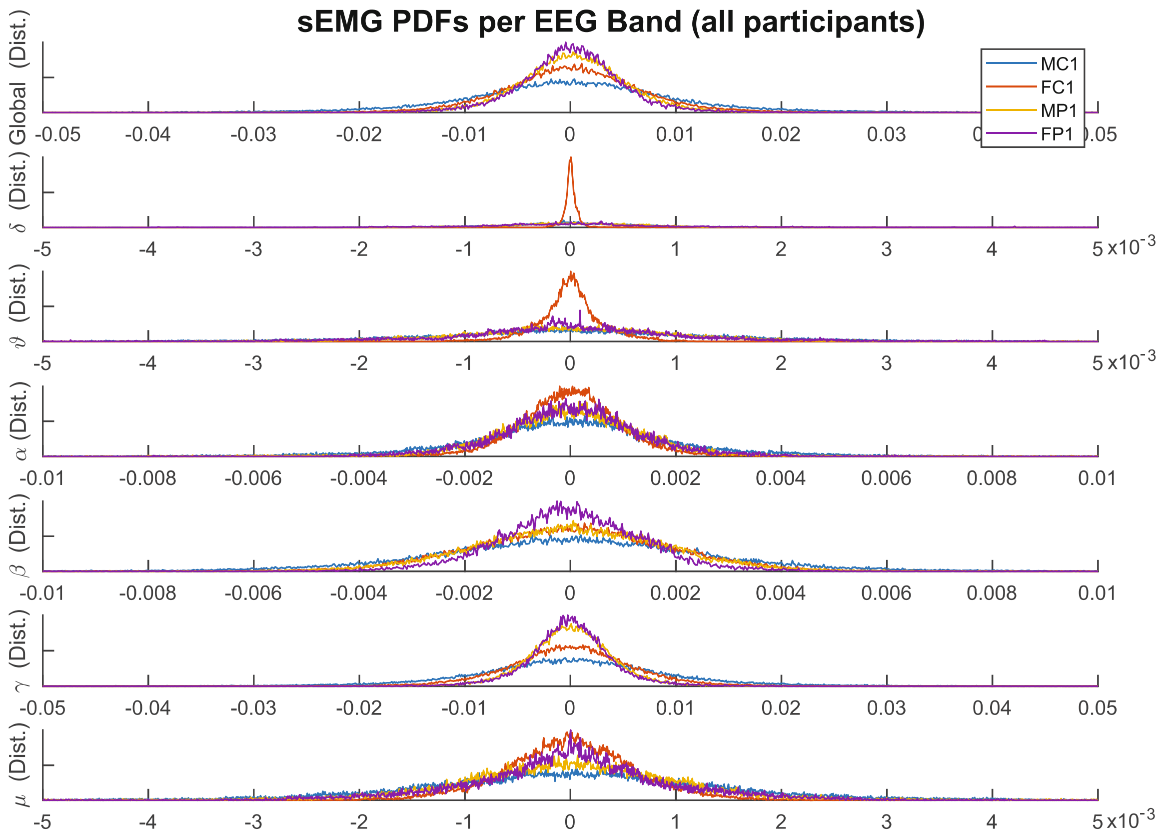

Fig. 3. Probability distributions of the sEMG amplitude in the EEG-related bands from the participants: HC male (MC1: blue) and female (FC1: red), and PD male (MP1: orange) and female (FP1: purple). PDFs of the different bands from top to bottom: whole unbiased notch-filtered sEMG; δ; ϑ; α; β; γ; μ. (Color figure online)

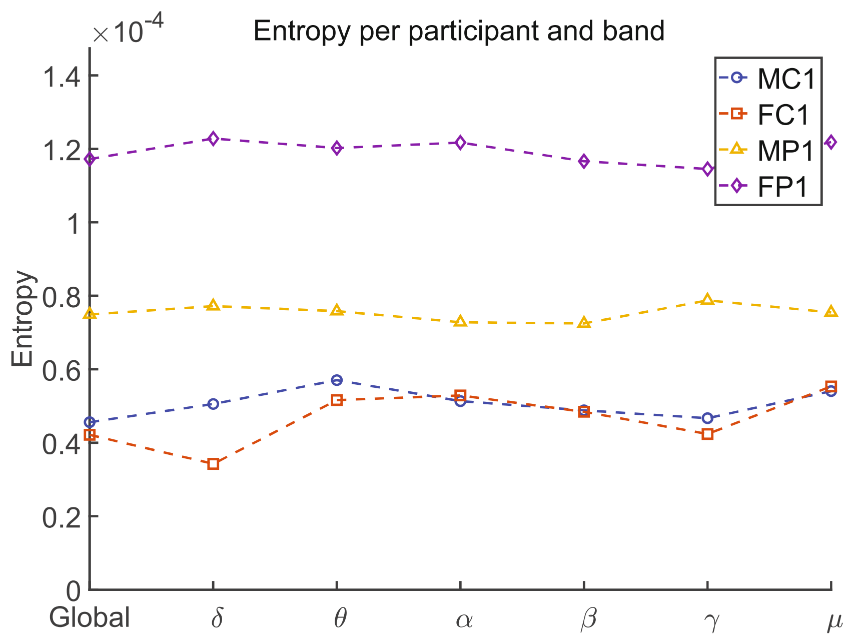

Fig. 4. Entropy of sEMG activity in the EEG-related bands from the participants: HC male (MC1: blue circles) and female (FC1: red squares), and PD male (MP1: orange triangles) and female (FP1: purple diamonds). (Color figure online)

4 Discussion

An important feature of normative behavior is dispersion. As the frequency band sEMG signals have been unbiased to remove their means, it is expected them to be centered with respect to their amplitude axes (horizontal). As it might be expected, the distributions showing more dispersion will spread their amplitudes over a larger span. The more stable a distribution is, the lower dispersion, and the smaller its associated entropy. This is the case of FC1, which shows a large stability on the δ and ϑ bands. The analysis of entropy by participant and band given in Table 2 and Fig. 3 give also a general idea on the behavior of each participant's neuromotor stability through the dispersion of their sEMG activity on the masseter. The first observation is that there is a strong alignment between the two normative participants (MC1 and FC1), which repeat a very similar and stable pattern. The minimum entropy is estimated for FC1 in the δ band, associated with a very small dispersion. MP1, on its turn, shows a larger entropy in all the examined bands, with a really stable pattern among them. At a farther distance, corresponding to extremely large values, participant FP1 shows the worst results in terms of instability (maximum entropy), also in all the bands considered. Comparing the results the PD vs the HC participants on 5 EEG bands ($\delta, \vartheta, \alpha, \beta, \gamma$), the maximum entropy estimated on the HC group was 5.705E−05, whereas the minimum entropy on the PD group was 7.247E−05. A hypothesis test rejected the similarity between both groups on the same EEG bands with a p-value under 0.0003.

Obviously, the results reported lack any statistical relevance, given the small size of the sample studied. This is due to the exploratory nature of the research, which has considered a minimum number of cases including normative and PD participants of both genres. If these results could be generalized to a larger sample size, they would open a new perspective to analyze a neuromotor symptom severity associated with sEMG as a possible diagnostic tool in terms of information theory contents. An interesting characteristic of this kind of feature as entropy, associated with information contents, is that it could open the study using mutual information measurements, as Kulback-Leibler or Jensen-Shanon divergence, as well as other entropy definitions, as Renyi's, sample and multiscale Entropy, or transfer entropy, to estimate causality relationships among bands' activity.

Given the limitations posed by the small size of the dataset studied, a further study is needed to confirm this assumption by using larger size databases of HC and PD participants including, other diadochokinetic exercises, and studying the use of these estimations in pathology severity evaluation with clinical enhanced explainability.

The results of the research may help in the design of other characterization methods for PD speech, essential in the design of application-specific PD speech monitoring approaches, also for clinical purposes.

5 Conclusions

The differential behavior of sEMG band entropy contents between PD with respect to HC participants is a most inspiring insight, as it could lead to open new possibilities of adding meaningful features acceptable for clinical application. As the semantics behind entropy is quite clear under the point of view of interpretability in terms of instability in functional behavior, it can be easily accepted under the clinical point of view. One important challenge for its direct applicability is its relatively complex protocol, as it requires fixing electrodes on the participants' face, which raises concerns about its acceptability. Nevertheless, if a direct association may be established between facial sEMG and recorded speech, showing reliable resolution and correlation, an interesting methodology could be open in the application of EEG-related frequency band contents through the vehicular use of speech, as a much more ubiquitous and simpler recording procedure.

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Acquisition of Relevant Hand-Wrist Features Using Leap Motion Controller: A Case of Study

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Abstract. All the gestures and movements we make are influenced by our psychomotor abilities. This mobility deteriorates over the years. It is logical to think that an older individual has worse mobility than a younger one if they do not suffer from other pathologies. On this premise, the main aim of this research work is based on the detection of semantic biomechanical features, using a hand-tracking controller (Leap Motion) through three calibration tests. The data collected by this hand-tracker has allowed to measure hand-wrist movements. Likewise, this paper aims to highlight different tasks based on those used by neurologists customarily based on the Hoehn Yahr [11] and UPDRS scales [9]. Indeed, this study intends to visualize the differences between healthy participants. The manuscript provides some promising findings that will help tailoring biometric indicators for non-normative participants in future research using this technology.

Keywords: Hand-tracking · Leap motion controller · Hand-wrist movement · Parkinson

1 Introduction

Computer graphics have always sought ways to make visual information more realistic and accessible to the user. With this objective in mind, its use in the research aims to provide accurate and high quality virtual feedback. Indeed,

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