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Assessment of Muscular Sustained Fatigue: a TD-NIRS and sEMG Study

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Abstract: We assess the muscular fatigue during sustained exercises with both sEMG and TD-NIRS. We found that during the "slow" phase of TD-NIRS signal, the best fatigue biomarkers are: MF, O_2Hb, HHb and SO_2.

1. Introduction

Muscular fatigue is a progressive impossibility to maintain the muscle performances during an exercise. Fatigue assessment can be performed with invasive blood drawn or some non-invasive exams, but the determination of the best parameter for its description is still under debate [1].
One of the non-invasive techniques employed is surface electromyography (sEMG), which allows to study the muscle contraction from a myoelectric point of view [2]. The parameters which are typically determined are the root-mean-square (RMS), related with the signal amplitude, and the median frequency (MF), a spectral variable which should decreases with the onset of the fatigue during the exercise.
For the characterization of the muscular fatigue, from an oxidative metabolism point of view, it is possible to employ the near infrared spectroscopy (NIRS) technique [3]. These optical measurement, in particular in its time-domain (TD) modality, allows for the retrieving of the absolute values for the oxy- (O_2HB) and deoxy- (HHb) hemoglobin time course and, then, to calculate the total hemoglobin (tHb) content and tissue oxygen saturation (SO_2) for the muscle.
The combined use of NIRS and sEMG shows interesting potentialities, but it is not yet widely explored, in particular during clinical studies [4]. Therefore, in this work we have investigated the possible correlations between their characteristic parameters simultaneously acquired during sustained isometric exercises.
Furthermore, we focused on the analysis of the "slow" phase of the fatigue arising, which to the best of our knowledge was never investigated before. Indeed, the typical NIRS response during sustained exercises can be divided into two parts: a first "fast" response, related with the aerobic metabolism, and a "slower" one, which is characterized from an anaerobic metabolism due to the energy turnover.

2. Material and methods

The study was approved by the Ethical Committee of Politecnico di Milano and was conducted in compliance with the Declaration of Helsinki. Before the study, each subject was informed about the experiment modality and gave a written consent. Twelve healthy subjects (28.9 ± 3.2 age), 6 males and 6 females, were enrolled.
sEMG acquisitions were performed with a commercial device (Cometa, Italy); one probe was positioned in the belly of the deltoid lateralis muscle of the dominant arm.
TD-NIRS acquisitions were accomplished with a medical device previously developed at the Department of Physics, Politecnico di Milano [5]; one injection and one detection optodes, with an interfiber distance of 30 mm, were placed perpendicular to the sEMG electrodes and fixed with a black elastic bandage. sEMG and TD-NIRS acquisitions were synchronized by means of a TTL signal.
The subjects were sitting on a chair holding their dominant arm elevated laterally at the shoulder level to keep the arm horizontal. The position was hold until exhaustion, or for a maximum time of 330 s. The subjects hold a bottle of water with an amount of liquid calculated to reach a certain static torque of the shoulder, customized on the anthropometric data of each subject.
After a pre-processing of the signal root means square (RMS) and median frequency (MF) parameters were then computed and normalized to their maximum value within each subject. The acquired TD-NIRS reflectance curves were fitted with the solution of the diffusion equation for a semi-infinite homogenous medium and from the absolute values of the absorption coefficient, O_2HB and HHb were retrieved with the Beer's law. tHb and SO_2 were then calculated.

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Both sEMG and TD-NIRS time courses were divided into adjacent consecutive time-windows of 5 s. We then discarded the first time-window from the following analysis since the movement of the arm toward the horizontal position was not yet ended. For details about this transient period the reader can refer to the work from the same authors [6].

To couple all the extrapolated quantities from the two signals, we identified, at first, the "fast" and "slow" phase of the TD-NIRS signal. To this aim, after having applied a 5th order Butterworth low pass filter (fc= 0.3* $f_{NYQUIST}$), local maxima and minima were found with a first derivative algorithm. The first maximum/minimum was used for dividing the "slow" from the "fast" phase. Then, a correlation analysis (Pearson linear correlation coefficient) was performed to all the sEMG and TD-NIRS measure pairs during the "slow" phase, using different "driver signals", which controlled the segmentation of the epochs. The role of the driver signal was assigned, alternatively, to three out of four TD-NIRS variables: O_2Hb, HHb and SO_2. The effect of different segmentations was tested, after the outlier removal, with ANOVA tests, where the significance level was set at α=0.05.

3. Results

Positive correlation between MF and HHb, negative correlation between MF and SO_2 and between MF and O_2Hb were found in most of the subjects. No clear correlations between MF and tHb were observed, instead. Moreover, tHb showed the lowest correlation with the other TD-NIRS variables, and with a high variability (with O_2Hb: 0.715 ± 0.397; with HHb: 0.062 ± 0.528; with SO_2: 0.411 ± 0.493). For this reason, it has not been used as a driver signal. In table 1, we report the correlations between the TD-NIRS and sEMG parameters of the dataset, considering the whole signals not yet divided in "fast" and "slow" phases. Because of the poor cross-domain correlation and the high variability of these results, the RMS was excluded from further analyses. On the contrary, MF showed good cross-domain correlation.

Table 1. Correlation matrix (mean±standard deviation)

	O_2Hb	HHb	SO_2	tHb	RMS	MF
O_2Hb	1	-0.478 ± 0.503	0.878 ± 0.106	0.715 ± 0.397	0.023 ± 0.581	0.530±0.507
HHb	-0.478± 0.503	1	-0.786±0.346	0.062 ± 0.528	-0.023± 0.436	0.133±0.577
SO_2	0.878 ± 0.106	-0.786±0.346	1	0.411 ± 0.493	0.015± 0.556	-0.438±0.475
tHb	0.715 ± 0.397	0.062 ± 0.528	0.411 ± 0.493	1	0.016± 0.625	-0.619±0.456
RMS	0.023 ± 0.581	-0.023± 0.436	0.015 ± 0.556	0.016 ± 0.625	1	-0.112±0.623
MF	-0.530± 0.507	0.133 ± 0.577	-0.438 ±0.475	-0.619±0.456	-0.112±0.623	1

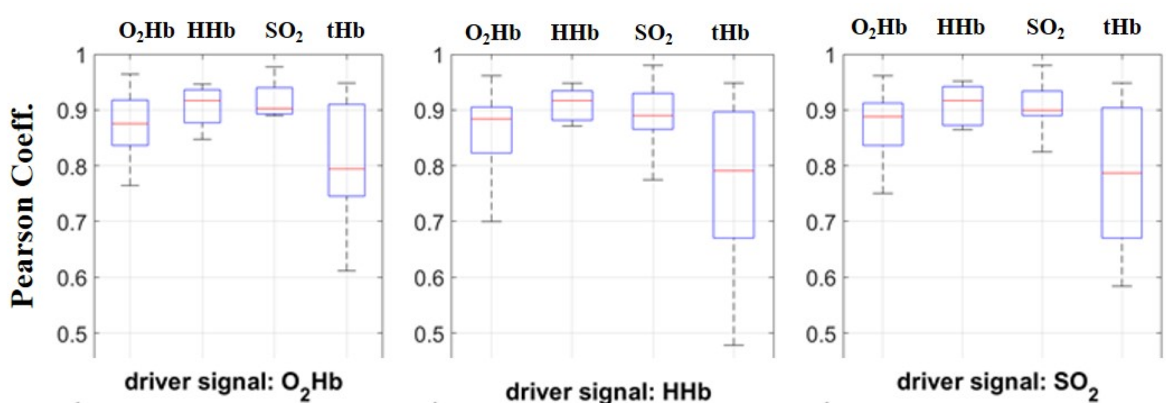

Fig. 1. Pearson coefficient computed with ANOVA tests on the MF and TD-NIRs after normalization.

After the segmentation of the signal in “fast” and “slow” phases and after the outlier removal, we focused on the “slow” phase of the signals. In Fig. 1 we show the results of the one-way ANOVA on each segmentation. Significant differences were found for all the test: in particular, for the O_2Hb-driven dataset, we found p= 0.008; for the HHb-driven dataset we found p= 0.016 and, lastly, for the SO_2-driven dataset p= 0.006 was detected.
From the previous analysis, we can affirm that 3 out of 4 TD-NIRS parameters (O_2Hb, HHb and SO_2) highly correlate with MF during the “slow” phase, and then are as well good candidates for the description of the muscular fatigue during isometric sustained exercises.

3. Conclusion

In this work, we present an attempt to assess the muscular fatigue with sEMG and TD-NIRS during isometric sustained exercises. We focused on the “slow” phase of the muscle metabolism, which was not previously widely characterized from this point of view. Thanks to the fact that with TD-NIRS we can consider contemporary all the four muscular hemodynamic parameters, it was possible, for the first time, to show correlations between their absolute values and the sEMG signals detected simultaneously. The main finding was that O_2Hb, HHb and SO_2 showed high correlation with the sEMG’s MF. We could also affirm that tHb and RMS, are not good candidates as muscular fatigue biomarker.

4. References

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