MOTOR UNIT SYNCHRONIZATION AND FIRING RATE CORRELATE WITH THE FRACTAL DIMENSION OF THE SURFACE EMG: A VALIDATION STUDY

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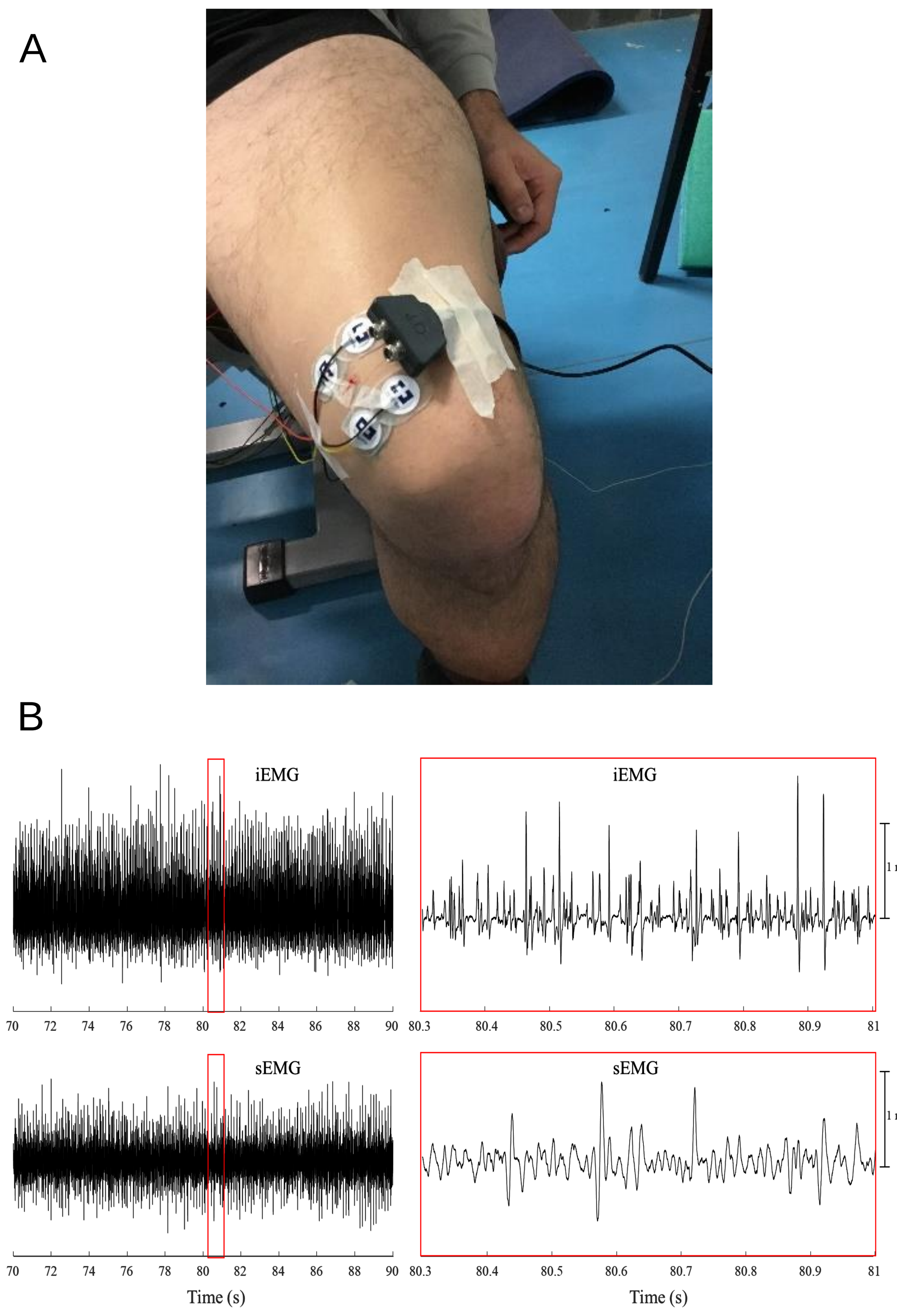
Background and aim

Changes in the surface electromyogram (sEMG) during fatiguing contractions may be detected using fractal analysis. Previous publications suggested that a decay of fractal dimension (FD) of the sEMG signal during isometric fatiguing contractions, may be associated to an increase in motor unit (MU) synchronization, which is the tendency of separate MUs to discharge near simultaneously (within 1-5 ms of each other) more often that would be expected by chance[1], as expression of the central nervous system adaptation to fatigue[2].

However, other studies using intramuscular EMG (iEMG) have reported no change in MU synchronization[3]. Later, Mesin et al.[4] evidenced during simulated contractions the existence of an inverse relationship between FD and MU synchronization and a positive relation with MU firing rate (FR). Hence, the purpose of this study was to investigate in vivo whether the FD of the sEMG signal is related to MU synchronization and FR. This methodology was compared with findings obtained from single muscle fiber recordings and cross-correlation analysis.

Figure 1



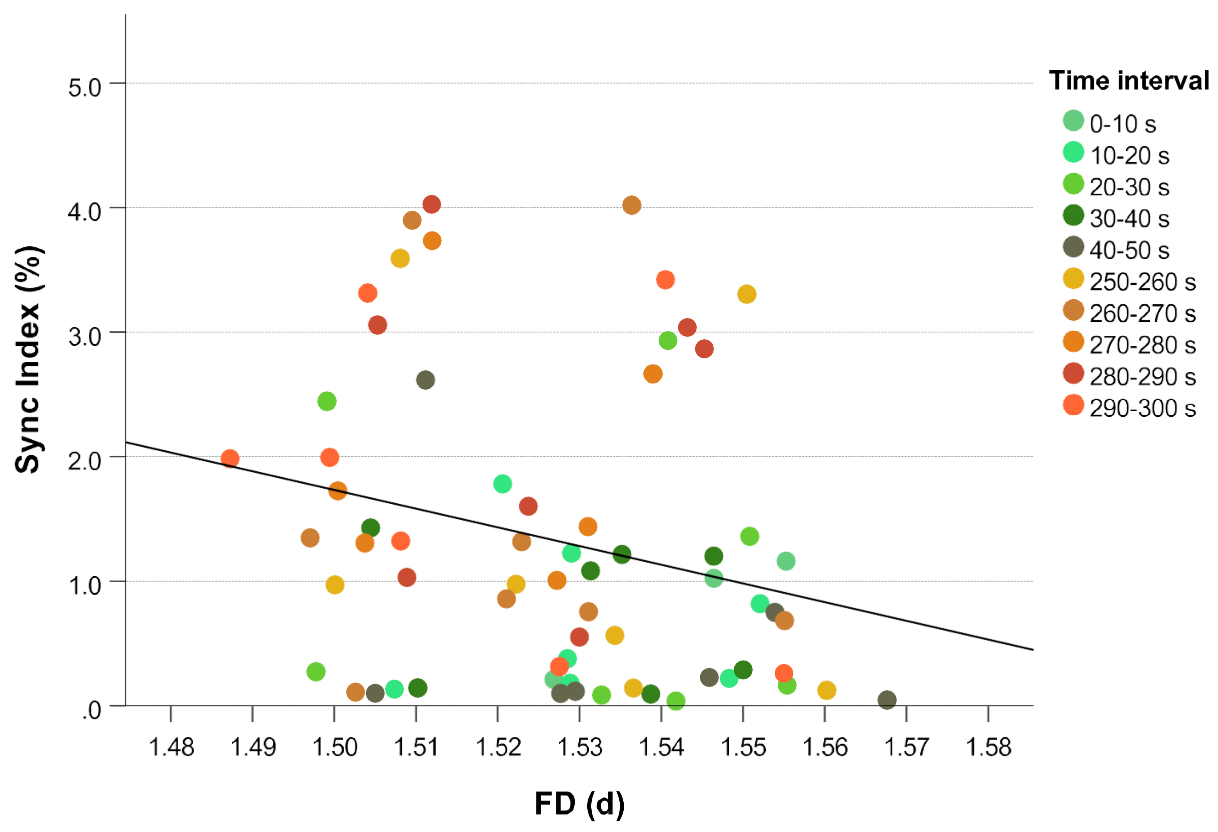
Surface and intramuscular EMG signals were detected from the vastus medialis obliquus, using bipolar and fine-wire electrodes, respectively (A). Examples of intramuscular (iEMG) and surface EMG (sEMG) signals from a representative participant (B).

Materials and Methods

A total of 13 active healthy subjects (12 men and 1 woman) participated in the study after giving written informed consent. Participants seated on an isokinetic dynamometer and performed two maximal voluntary isometric knee extensions (MVC_pre), followed by a 5% MVC contraction for 300 s. Immediately after, a third MVC was performed (MVC_post).
Intramuscular and surface EMG signals were recorded concurrently using a couple of fine-wire electrodes and two couples of bipolar surface electrodes from the left vastus medialis obliquus (Figure 1).
Synchronization (Synchronization Index, Synch Index) and firing rate (FR) were calculated from the decomposed intramuscular EMG signal, while FD was estimated using the box-counting method from the sEMG signal[5,6].

The first (t1) and last 50 s (t2) of contractions were considered during the correlation analyses, calculated using the Spearman's correlation coefficient (r_s).

Figure 2



Scatter plot of the relation between the synchronization index (Synch Index) calculated from the intramuscular EMG signal, and the fractal dimension (FD) of the surface EMG signal. Time interval refers to the initial and final 50 s of the isometric knee extension. R^2 =0.06.

Results

The median MVC_pre was 568.8 [196.1] Nm, while the MVC_post was 362.9 [186.3] Nm. Consequently, the maximal strength post fatigue was 36.2% significantly lower than the value at rest ($p<0.01$).

Full decomposition of the iEMG signals revealed 389 MUs at t1, and 456 MUs at t2. Four subjects were excluded from further analysis due to poor decomposition accuracy.

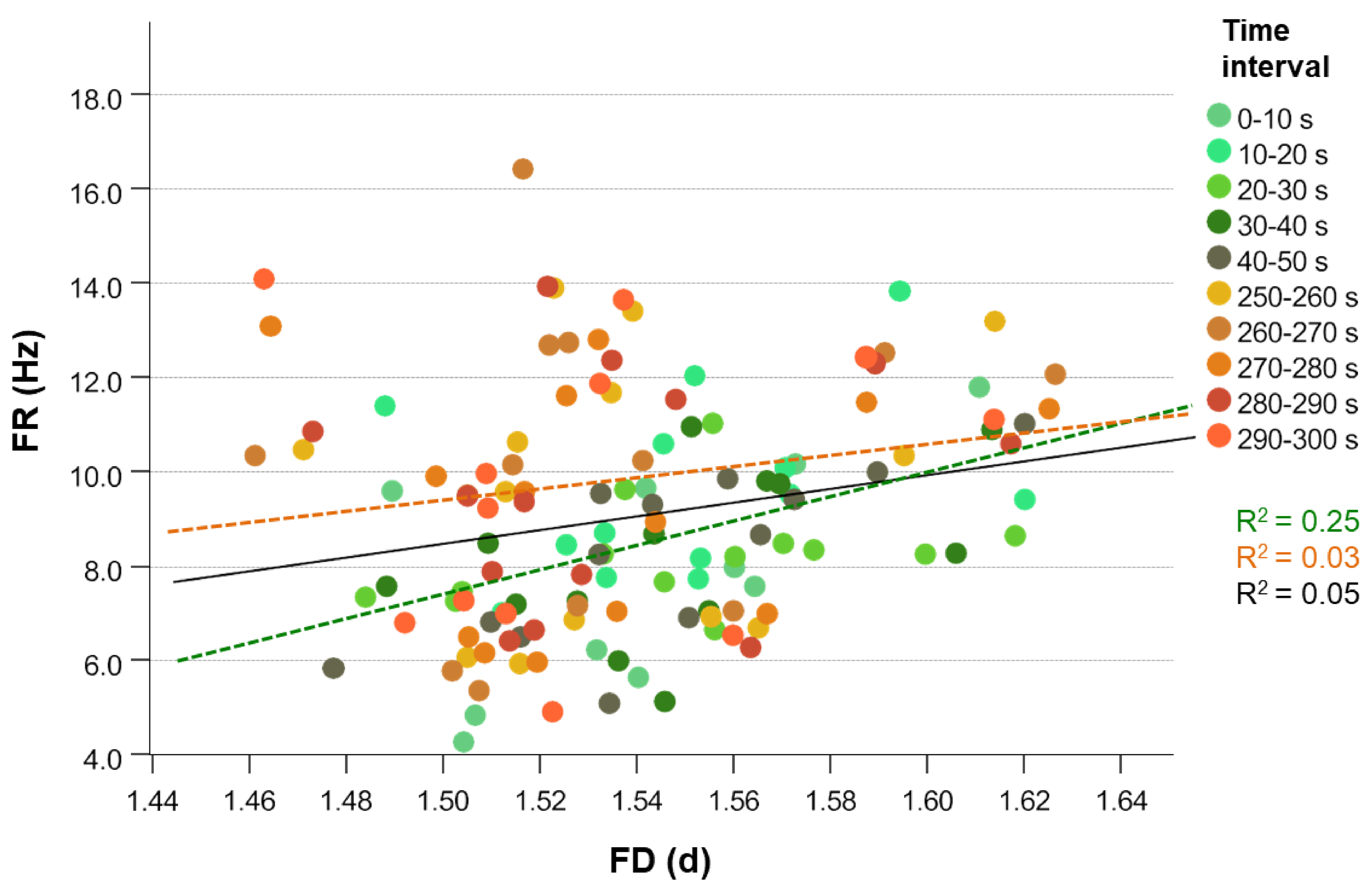
The Synch Index between t1 and t2 increased from 0.33 [1.07] to 1.39 [2.21] ($p=0.002$), whereas FD decreased from 1.535 [0.022] to 1.522 [0.032] ($p<0.001$). Significant low to moderate correlations were obtained between FD and Synch Index (Figure 2), and between FD and FR (Figure 3) when all data were pooled together ($p<0.05$). Results of the correlation analysis are presented in Table 1.

Table 1

		Synch Index*		FR	
		r_s	p-value	r_s	p-value
FD	0-300 s	-0.30	0.03	0.25	0.004
	0-50 s (t1)	-0.09	0.65	0.52	<0.001
	250-300 s (t2)	-0.18	0.31	0.20	0.12

FD, Fractal dimension; Synch Index, synchronization index; FR, firing rate.
* Analysis was conducted in nine subjects.

Figure 3



Scatter plot of the relation between the firing rate (FR) calculated from the intramuscular EMG signal, and the fractal dimension (FD) of the surface EMG signal. Time interval refers to the initial and final 50 s of the isometric knee extension. The green and orange dashed lines represent the linear correlation between FR and FD during the initial and final 50 s, respectively.

Conclusions

FD of the sEMG signal is a parameter mostly related to the firing rate when fatigue does not develop and may be considered as an index of performance fatigability during sustained or at the end of prolonged contractions at very low forces.

FD cannot be considered as an exclusive index of motor unit synchronization during fatiguing contractions, but rather as largely related to central factors.

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