ELECTROMYOGRAPHY OF TRUNK MUSCLES IN TIME-FREQUENCY DOMAIN DURING CORE STABILITY EXERCISES

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The aim of this work was to compare the electromyogram (EMG) of trunk muscles, in the time-frequency domain, among core exercises. The EMG of 17 men was recorded by electrodes placed on external oblique (EO), rectus abdominis (RA), lumbar erector spinae (LES) and multifidus (MT) muscles. Short-time Fourier transform was performed and instantaneous median frequency (MedFreq) was calculated and averaged. MedFreq of the EO and RA were significantly higher ($p < 0.0001$) during double leg back bridge exercise. Contrarily, LES and MT showed significant higher ($p < 0.0001$) MedFreq during frontal and left side bridge. Antagonist muscles showed greater MedFreq than agonist muscles. This may be explained by the low-pass filtering effect of the adipose tissue, which could attenuate the increase of high frequencies EMG energy of agonist muscles.

KEY WORDS: EMG, core training, time-frequency analysis.

INTRODUCTION: The core region functions as a "muscle belt" that stabilizes the lumbo-pelvic region, with or without the presence of upper and/or lower limbs movements (Kavcic, Grenier & McGill, 2004). The training of this region has been adopted for increasing athletic performance, as well as for clinical purposes in order to prevent and rehabilitate orthopedic injuries (McGill & Karpowicz, 2009). The intensity of muscle contraction and the loads on the spine in different movements and postures have been investigated. Generally, frontal bridges activate mainly flexor muscles, back bridges activate mainly extensor muscles and side bridges activate ipsi-lateral flexor and extensor muscles, while bird dog exercises activate external oblique and extensor muscles (McGill & Karpowicz, 2009; Leporace, Praxedes, Metsavaht, Pinto, Chagas, Pereira & Batista, 2010). Despite the high number of studies in this area, the majority analysed electromyogram (EMG) during core stability exercises in the time-domain. Muscular activation can also be evaluated in the frequency and time-frequency domain by extraction of parameters such as median frequency (Bilodeau, Cincera, Gervais, Arsenault, Gravel, Lepage & McKinley, 1995). The rate of decrease in median frequency is normally used to monitor muscle fatigue (Merletti & Lo Conte, 1997; Potvin, 1997), since the decrease of this variable has a high correlation with the decrease in muscle strength (Mannion & Dolan, 1996). Besides, fatigue is also related to decreases in motor units firing rate (De Luca, 1985). Recently, new strategies for myoelectric signal processing related to the time–frequency representation have been applied, revealing valuable information and important interpretations concerning the motor units (MU) recruitment (Von Tscharner & Goepfert, 2003). Thus, the purpose of this study was to compare the EMG of trunk muscles, in the time-frequency domain, among different core stability exercises.

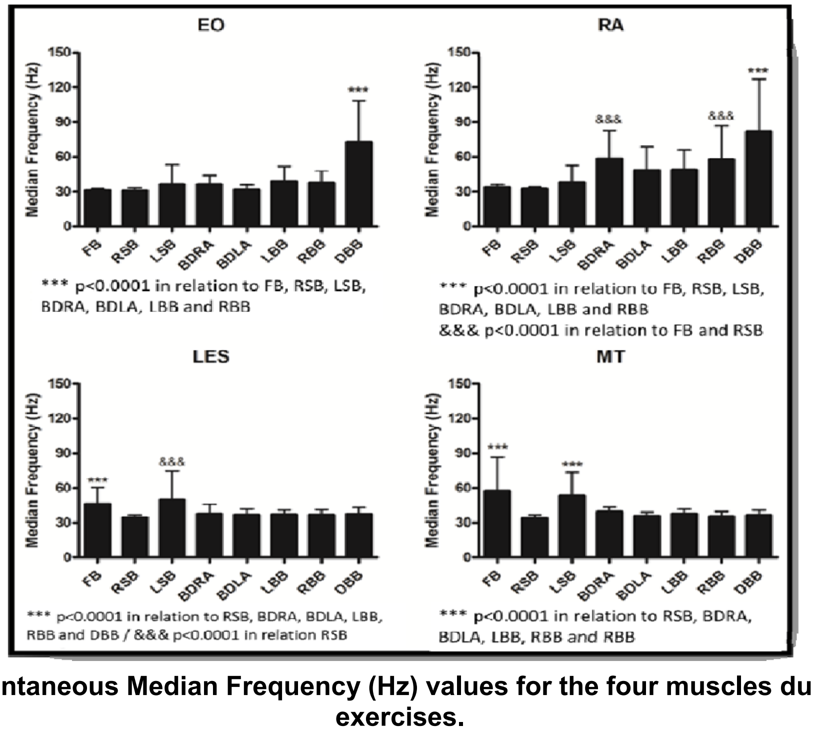
METHODS: Seventeen male were volunteers in this study and signed an informed consent approved by Institutional Board of Ethics in Research. They were age 25.5 ± 5.0 years (mean ± standard deviation), body mass 78.7 ± 8.9 kg and height 1.77 ± 0.07 m. All subjects executed eight core stability exercises (Table 1) lasting 20 s, in a random order with five minutes interval. EMG was captured from right side with Ag/AgCl surface KOBME electrodes (Bio Protection, Korea) positioned according to Cram, Kasman and Holtz (1998) on the external oblique (EO), rectus abdominis (RA), lumbar erector spinae (LES) and multifidus (MT) muscles with interelectrode distances of 2 cm. EMG was recorded (TEL100C, BIOPAC Systems, USA), amplified (differential bipolar amplification, input impedance 2 MΩ, common mode rejection ratio > 110 dB, and gain 1000), and digitized (12 bits resolution, MP100WSW BIOPAC Systems, USA) with a sampling rate of 2 kHz. Signals were filtered by a 4th-order Butterworth filter (20–400 Hz), applied in direct and reverse directions to avoid phase distortions. Electrocardiographic artefacts were removed using independent component analysis (ICA). The FastICA algorithm (Hyvärinen, Karhunen & Oja, 2001) was used to perform the ICA. The instantaneous median frequency (MedFreq) over each second of signal in ten central seconds (5 to 15 s) was obtained using the short-time Fourier transform. MedFreq was averaged and used in subsequent analysis. Analysis of variance (ANOVA) test with repeated measures and the Tuckey's post hoc test were used to compare MedFreq from each of four muscles among the eight exercises, with the 0.05 level of significance. MATLAB version 7.8 (The Mathworks, USA) and GraphPad Prism version 5.0 (GraphPad Software, USA) softwares were used for signal processing and statistical analysis, respectively.

Table 1: Legends of the exercises performed in this study.

Exercise	Frontal Bridge	Right Side Bridge	Left Side Bridge	Bird Dog*	Bird Dog**	Right Single Leg Back Bridge	Left Single Leg Back Bridge	Double Leg Back Bridge
Legend	FB	RSB	LSB	BDRA	BDLA	RBB	LBB	DBB

* Performed with right arm and left leg lifted.
** Performed with left arm and right leg lifted.

RESULTS: The MedFreq of the EO and RA muscles were significantly higher ($p < 0.0001$) during DBB exercise (Figure 1). Furthermore, RA showed MedFreq greater during BDRA and RBB than FB and RSB ($p < 0.0001$). The extensor muscles showed an opposite trend (Figure 1). LES and MT showed significantly higher ($p < 0.0001$) MedFreq during FB and LSB exercises.



*** p<0.0001 in relation to FB, RSB, LSB, BDRA, BDLA, LBB and RBB

*** p<0.0001 in relation to FB, RSB, LSB, BDRA, BDLA, LBB and RBB
&&& p<0.0001 in relation to FB and RSB

*** p<0.0001 in relation to RSB, BDRA, BDLA, LBB, RBB and DBB / &&& p<0.0001 in relation RSB

*** p<0.0001 in relation to RSB, BDRA, BDLA, LBB, RBB and RBB

Figure 1: Instantaneous Median Frequency (Hz) values for the four muscles during the eight exercises.

DISCUSSION: The flexor and extensor muscles showed a higher MedFreq during extension and flexion exercise, respectively, when these muscles are antagonists. These results were apparently opposites to those found in a previous study (Leporace et al., 2010), in which time-domain amplitude estimators of EMG were evaluated. Leporace et al. (2010) showed that the EMG of the same four muscles in the same exercises have patterns consistent with their anatomies. However, EMG amplitude and MedFreq are related to different physiological phenomena. In time-domain, the EMG amplitude estimates muscular activation level, since for modulating muscle tension, either the number of active MU or the average firing rate (rate coding) of active MU must be modulated (Milner-Brown, Stein & Yemm, 1973; Kukulka & Clamann, 1981; Moritani & Muro, 1987). In either case, the standard deviation of the EMG is increased. In the other side, the behavior of the MedFreq depends on the fiber type composition and the volume conductor. Kukulka and Clamann (1981) showed that for muscle groups with predominantly type I fibers (69.5-92.5%) (Johnson, Polgar, Weightman & Appleton, 1973), rate coding plays a prominent role in force modulation. For a muscle group composed of both types I and II fibers, MU recruitment seems to be the major mechanism for generating extra force above 50% of maximal voluntary contraction (Kukulka & Clamann, 1981). Therefore, in the intrinsic muscles of human hands as the adductor pollicis, MU recruitment is essentially complete at about 50% of maximal force, but the recruitment in the biceps brachii (34.4-61% type I fibers) (Johnson et al., 1973), and deltoid muscles (43.1-76.8% type I fibers) (Johnson et al., 1973) may continue until more than 80% of maximal force is attained (Kukulka & Clamann, 1981; De Luca, LeFever, McCue & Xenakis, 1982; Moritani & Muro, 1987). Based on Johnson et al. (1973), one can assume the LES (26.7-74.6% type I fibers in five of six male adults at autopsy) and RA (31.6-56.2% type I fibers) as mixed muscles, therefore MU recruitment plays an important role in force modulation. Thus, given the role of MU recruitment for modulating the force of these muscles, MedFreq would be higher in agonist muscles because of the additional recruitment of surface high threshold MU that most likely possess large and sharp spikes affecting high frequency bands of the surface EMG power spectrum (Moritani & Muro, 1987). The present study also disagrees with the findings of Moritani and Muro (1987) for the biceps brachii, which is also a mixed muscle with a lower volume conductor comparing with the trunk muscles.

One possible explanation for this divergence may be due to the differences between the amount of adipose tissue surrounding the anatomical regions considered, which has an effect of low-pass filtering on their MU activity (Bilodeau et al., 1995). Therefore, the increased recruitment of MU of the trunk muscles is sufficient to increase signal amplitude, as seen by Leporace et al. (2010). However, the effect on MedFreq can be attenuated by low-pass filtering performed by adipose tissue in core region (Bilodeau et al., 1995). Additionally, according to Bilodeau, Arsenault, Gravel and Bourbonnais (1990), increased MedFreq due to modulate muscle tension could be detected only with an interelectrode distance lower than 1 cm, which was not the interelectrode distance adopted in present study.

Furthermore, the intensity of core stability exercises could have been low for a significant recruitment of type II fiber, which would prevent the increase of MedFreq. We also believe that fatigue had low influence regarding the decrease of MedFreq, since the duration of each exercise (20 s) does not seem to be sufficient to generate fatigue and the time to rest was long enough (5 min) for full recovery. Moreover, higher MedFreq during antagonist function may be due to the high frequency noise present in the EMG. The Fourier transform amplitude of the antagonist muscles' EMG is lower in the signal band (20-400 Hz). Therefore, the high frequency noises band limited to 1 kHz could have a significant effect, increasing the MedFreq.

CONCLUSION: During core stability exercises, the instantaneous median frequency of the antagonist muscles was greater than agonist. Despite the favorable fiber type composition to increase instantaneous median frequency of the agonist muscles, thicker skinfold of the trunk muscles would have an attenuating effect on this variable. It is suggested that the low-pass filtering effect of the adipose tissue could have prevented the observation of an increase of energy of the high frequencies of the EMG. Furthermore, the higher instantaneous median frequency of the antagonist muscles can be explained by high frequency noise beyond the signal band that influences low amplitude EMG.

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