Fourier Analysis of Muscle BOLD Data After Exercise

A. D. Davis[1], and M. D. Noseworthy[2,3]

[1]Medical Physics and Applied Radiation Sciences, McMaster University, Hamilton, ON, Canada, [2]Electrical and Computer Engineering, School of Biomedical Engineering, and Department of Radiology, McMaster University, Hamilton, Ontario, Canada, [3]Brain Body Institute, St. Joseph's Healthcare, Hamilton, Ontario, Canada

Introduction:

Functional Magnetic Resonance Imaging (fMRI) exploits the blood oxygen level dependent (BOLD) signal to obtain concurrent information about blood oxygenation, flow and volume. After acquiring time series BOLD data in the brain and applying the Fourier transform (FT), cardiac and respiratory signals have been reported to be present, and exploited for study [1,2]. To satisfy Nyquist conditions data needs to be acquired with (1/TR > 2 x Heart Rate) to show the signals.

BOLD imaging has also been applied to skeletal muscle, and shows promise for examining physiological parameters related to perfusion and oxygenation [3]. It is hypothesised the frequency spectra of BOLD data could be used to assess muscle physiological response to exercise. The goal of this work was to investigate whether cardiac and/or respiratory frequencies would be present, and become more prominent, in healthy post exercise skeletal muscle. Previous work on chronic compartment syndrome (CCS) showed 15 minutes of intense exercise produced a loss of physiological frequencies in the affected muscle, suggesting strangulation [4]. Here we try a more controlled attempt to quantify these changes.

Methods:

MR imaging data was collected using a GE 3T HD Signa MRI and a single channel, general purpose flex coil (GE Healthcare, Milwaukee, WI). A gradient echo EPI pulse sequence (TE=35ms, TR=250ms, α=33˚) was used to acquire 3 10mm thick, axial slices of BOLD data in the lower leg with a 64x64 pixel resolution and a 16cm FOV. Plantar flexion exercise was performed during the scan using an in-house built MRI compatible ergometer. A one repetition maximum (1RM) test was performed to determine the subject's maximum voluntary contraction (MVC) on a day prior to the scan. ROI analysis was performed with AFNI [5], and motion correction of functional data was accomplished with a custom script using the FSL FLIRT tool [6]. FT and time-series analysis was done using the matplotlib library for python [7].

An intense exercise protocol of 2.5 minutes plantar flexion at 0.5 Hz at 50% of the subject's MVC was performed. Immediately following the exercise, a 2400 point time course of BOLD data was acquired, for a total scan time of 10 minutes. Region of interest (ROI) analysis was performed on the data to segment the muscle groups of the lower leg, with both broadly inclusive ROIs that included arteries, and more carefully drawn ROIs that excluded them. Next, an exercise protocol was performed twice under continuous scanning. Three 10 second isometric contractions (70% MVC), spaced at 1 minute intervals were performed during the scans. The protocol was performed twice, with inferior and superior 40mm saturation bands applied just outside the field of view during one of the scans.

Results and Discussion:

Almost no physiological signals were present from the carefully drawn ROIs (**Figure 1, bottom**). The peaks only showed when the ROIs included the arteries (**Figure 1, top**). The plots represent the broad and careful ROIs from the soleus muscle, with the respiratory and cardiac signals visible near 0.5 Hz and above 1.0 Hz, respectively. The broad cardiac peak probably arose because of the gradual post-exercise decrease in heart rate after exercise.

Time course plots for the Sat bands test revealed no obvious effects on the BOLD signal course due to the SAT bands. (**Figure 2**). Note that only 1 slice of data was used to produce the plots in an effort to reduce the saturation effects immediately after exercise, but the effect was not completely eliminated, as is evident from the anterior compartment time course. SAT bands do no not seem to affect BOLD signal recovery characteristics; base-peak heights of recovery curves agree within their uncertainty for each muscle.

Conclusions:

The method of examining physiological peaks in BOLD time-course data from muscles after exercise does not seem promising. The technique seems to be sensitive to arterial inflow, but not strangulation of the microvasculature in the tissue. Since SAT bands above and below imaging plane don't seem to affect BOLD data results from tissue oxygenation, but do dampen arterial inflow effects, they should probably be used for all BOLD muscle scanning in the leg in future studies. This may alleviate the contamination of the BOLD signal by inflow effects.

Since the BOLD technique is sensitive to the microvasculature, where no pulsatile blood flow is present, the question is raised as to why the physiologic frequencies show up in BOLD brain studies. Turner attributes the presence of the physiological signals to T1 changes due to bulk brain motion [**2**].

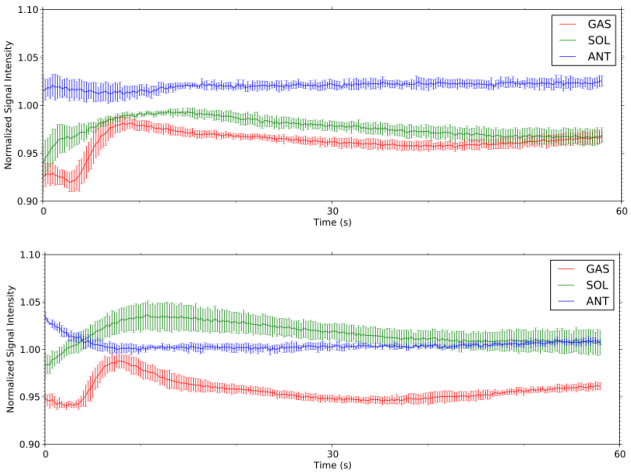

Figure 2: BOLD data with (top) and without (bottom) SAT bands applied. BOLD data represents the 1 minute recovery period after a 10 second 70% MVC flex. 3 runs were averaged to form each curve, with error bars representing 1 standard deviation. Amplitude was normalized to initial resting values. At **top**, I,S saturation bands applied (see text). GAS=gastrocnemius muscle (red), SOL=soleus muscle (green), ANT=anterior compartment (blue).

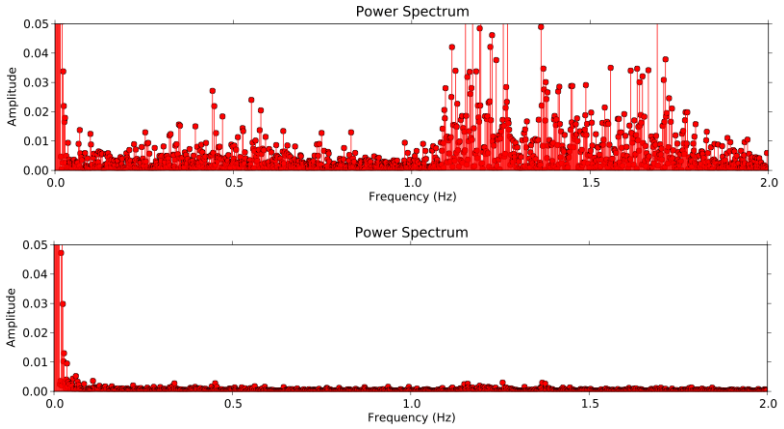

Figure 1: Fourier Transform of BOLD data using broadly inclusive ROIs (top) and careful ROIs (bottom). The carefully drawn ROIs eliminated the physiologic peaks. Data was taken from the soleus ROIs.

References: [**1**] Biswal et al. *Magn Reson Med* (1995) 34(4):537-41 [**2**] Turner et al. *Exp Brain Res* (1998) 123(1-2):5-12 [**3**] Carlier et al. NMR in biomedicine (2006) vol. 19 (7) pp. 954-67 [**4**] Noseworthy et al. *Semin Musculoskelet Radiol* (2010) 14(2):257-68 [**5**] Cox. *Comput Biomed Res* (1996) 29(3):162-73 [**6**] Smith et al. *Neuroimage* (2004) 23(Suppl 1):S208-19 [**7**] Hunter. *Computing in Science and Engineering archive* (2007) 9(3):90-95