# Time-Frequency Analysis of fMRI signal Response

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**Introduction**: Most fMRI data analysis methods can be classified into 2 types: time-domain and frequency-domain methods. Time-domian methods use signal intensities to differentiate between activation and control states, any information regarding the periodicity is typically not present. Frequency-based methods although provide information regarding periodicities present in the data sets including task/stimulus frequencies and other physiological parameters including respiration frequency, etc. In this study, Time-Frequency Analysis of fMRI signals is explored. Time-frequency analysis allow for representation of signals through its energy content on a 2 dimensional graph with one axis representing time and the other representing the frequencies present at the given time.

**Methods**: Four healthy male subjects, age 22-35 with no history of head trauma or neurological diseases were scanned on a Siemens Allergra Magnetron® 3-T imaging system equipped with dedicated radio-frequency coil to obtain higher signal-to-noise ration (SNR) was used. The study was approved by the Institutional Review Board at this institution. Written informed consent was obtained from all volunteers. Each subject was positioned supine on the scanner gantry, with RF coils placed over the head. Head foam were provided for comfort and to minimize head motion. Subjects also used earplugs to protect the ears from the loud noises from the gradient coils.

Single shot EPI images covering the sensorimotor cortex were obtained. Imaging parameters consisted of the following parameters: TR=1sec, TE=40 msec, slice thickness = 5 mm, FOV = 20 cm, MAT = 64x64. 300 EPI images were obtained during each experimental condition.

Each subject of this study underwent two fMRI scans in which a visual stimulus was provided to the subject to indicate when to begin finger-tapping and when to rest. These ON-OFF reference stimuli waveforms were provided to the patient visually via a projected "GO" for ON and a project "STOP" for OFF. The first scan used an ON-OFF reference stimulus waveform generated using four random time lengths between 3-32 seconds. The times generated for this stimuli were 4, 25, 11, and 19 seconds. The stimuli was digital with the magnitude of the ON signal equal to 1 for each of the four time lengths while the magnitude was 0 for the OFF signal. Each 'ON' period was followed by an 'OFF' period of similar length, to assign a frequency to the time length. A second ON-OFF reference stimuli waveform was generated with the four above time lengths but in different sequential order. The order for this waveform was 19, 11, 4, and 25 seconds. This was chosen to demonstrate a potential problem with Fourier transform analysis methods.

All datasets from this study were examined in time-domain using cross-correlation, in frequency-domain analysis using Fourier analysis, and in time-frequency space using a smoothed-pseudo-Wigner-Ville Distribution along with their respective stimuli.

**Results:** Two ON-OFF reference stimuli used in this study shown. They contain the same four random time lengths (4 sec, 11 sec, 19 sec, and 25 sec) of ON followed by a similar OFF period. The repetitions are maintained in each signal however the time lengths are in different sequential order. Representative response fMRI signal time-course from a sensorimotor cortex voxel is shown for the respective two stimuli. The magnitude of the Fast Fourier Transform of the two ON-OFF reference stimuli signals shown in Figure 1. These reference stimuli were both used in this study. No significant difference in the magnitude of the frequency spectrum (using FFT ) between the two stimulii was observed. Similarily, the frequency content of the two response signal was virtually the same making the two stimuli indistinguishable by the magnitude of the FFT.

A contour map of the smoothed-pseudo-Wigner-Ville time-frequency distribution for the First ON-OFF Reference Stimuli (Stimulus 1) is shown. It can be seen from this plot that one can not only detect the time during which the stimulus was preseny, but also the different frequency content that was present during any period of time. Thus while stimulus 1 and stimulus 2 and their corresponding responses were indistinguishable in the frequency domain (and the time domain response not able to provide any frequency information), the TFD was able to provide simultaneously both the time and frequency response (Figure 1). Also, the magnitude of the response is ssimultaneously visible through the magnitude of the time-frequency plot.

**Conclusions:** Many potential advantages exist with time-frequency analysis over solely time or frequency analysis methods. One is able to better visualize data and compares its components by comparing time-frequency distribution graphs. Both time and frequency aspects of the signal are preserved and viewable. This technique also allowed for a novel experiment paradigm that randomized the ON-OFF time lengths of finger tapping. This paradigm can be modeled for stimuli that may need various different time lengths or are unpredictable before the time of the study.