Identifying and separating the RF fluctuations from the measurement noise

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Introduction

It is well accepted that the statistical assessment of fMRI data can be improved by estimating the measurement noise as well as the fMRI series fluctuations due to slow physiological processes [1]. While recent fMRI literature has characterized a larger array of increasingly subtler physiological fluctuations, [2], there is still an overriding assumption that the “leftover” variance in the data can be described by “stationary Gaussian noise”. The necessity for a much more refined description of the "leftover" noise become apparent when analyzing the daily QA stability curve. Specifically, we show below that the extracted temporal series (from a typical gradient echo echo planar imaging (EPI) over 8 minutes) demonstrate the presence of signal fluctuations that are non-random and consistent across multiple runs. We also show that these fluctuations are site dependent and propose and demonstrate a method that could be used to characterize them and minimize their effects on the statistical power of the fMRI time series.

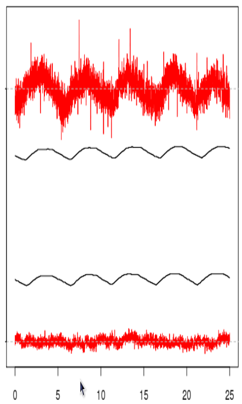


Figure 1: the signal, compared with the humidity(black line) for the body transmit (upper) and local CP transmit (lower)

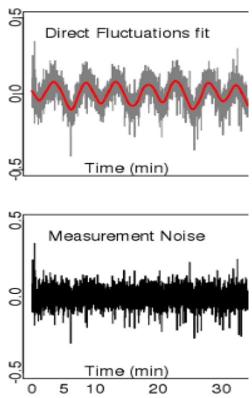


Figure 2: Estimating the RF fluctuations/noise. Spline fit to estimate the fluctuations (upper); remaining noise, Gaussian distribution (lower)

Methods

For practical reasons, all experiments were conducted of strictly identical systems, namely, Siemens Tim Trio, running VB15 software, with an identical complement of “standard” coils (e.g., 12 channel receive-only head coil and the circularly polarized extremity). For all experiments, the standard Siemens 1.9L phantom (solution of $NiSO_4$ and NaCl) was used. Direct measurements the T1/T2 of this phantom were performed and yielded as 120/90 msec, respectively, These values were used as the basis for the chosen timing parameters for the GRE EPI acquisition (TR/TE=500/20 msec). Using a flip angle of 50 degrees and an acquisition matrix of 64x64 (FOV=320mm, 5mm thickness) 4096 frames were acquired in 34:08 minutes. The time series of interest was obtained from the average image intensity in a circular ROI completely contained in the phantom’s cross section. These acquisition were repeated over multiple days and at three different sites in order to evaluate the site and or time effects in the signal.

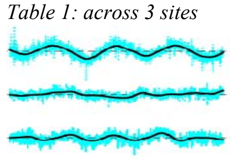
Results

(a) Main System: While the stability the main system is excellent, an oscillatory behavior was clearly identified in the MR signal (Figure 1). To prove that the effect detected is related with the output of the RF amplifier, the experiment was performed in two configurations. In the “12CH” configuration, the body coil transmits the RF, using the air cooled Astex 35 kW amplifier. In the “EX” configuration the transmit-receive circularly polarized extremity is used, engaging in this way the water cooled Dressler 8kW amplifier. During those experiments the temperature and the humidity in the equipment room were sampled with an USB-thermometer-humidity monitor (ThermoWorks, Lindon, UT) every 10 seconds. Since the cooling in the RF room is provided by an air conditioning Liebert unit, the measured humidity level accurately reflects the ON/OFF status of the Liebert. During the normal functioning of the MR scanner, the Liebert unit is periodically turning ON and OFF. The data acquired in 12CH configuration displays the oscillatory behavior induced by the ON/OFF cycle of the air cooling; by comparison, the data acquired with the smaller amplifier does not reveal such fluctuations, as expected, since the water cooling circuit is well isolated in the small electronics cabinet. In Figure 1, the detrended signal originating from the 12CH coil shows an clear correlations between the ON/OFF status of the cooling unit and the signal intensity. The lower part of the graph, depicts the data acquired with the extremity coil; it does not show such correlation. The set of investigatory experiments allow us to model the system imperfections reflecting the variable cooling status **inside** the electronics room, through a fluctuating flip angle.

(b) Remote Systems: Long term stability experiments were run at distinct three sites. The work flow is depicted in Figure 2. First (not shown in the picture) a 5 degree polynomial is subtracted. The remaining time course would be considered the "noise" in most of fMRI analyzes. On the phantom experiment we understand the nature of the fluctuations, and we can directly detect them, therefore we can afford to subtract a spline fit and therefore we obtain a good separation of the fluctuations from the "measurement noise". This is repeated on all three sites and the results are summarized in Table1; for illustration purposes the detendred time-courses are shown for all 3 sites (normalized deviations from the mean, showing the -0.3% to 0.3% range.)

Site	Var	Fluct	Noise
A	0.36	0.18	0.26
B	0.22	0.12	0.17
C	0.24	0.11	0.21

Table 1: across 3 sites



Conclusions and Discussions

On phantom data, one can estimate the oscillatory component from the data itself. For the typical fMRI experiments, the absence of an efficient fluctuation removal, leads to incorporating of the fluctuations in the “measurement noise”. The differences in the RF amplifier and/or in the cooling system (the 'siting' of the magnet) will manifest as sources of inter-sites variability, even though the systems itself are identical. For example, the system B has the largest size RF cooling room, by contrast, the systems A and C have relatively small RF rooms, and as a consequence the Libert unit turns ON/OFF at a relatively fast pace (around 5 minutes period).

This is, to our knowledge, the first demonstration of a non-MRI factor, namely the siting of the RF room, in the overall quality of the MR signal. Since only three MRI systems were fully evaluated in this study, we do not know if the flip angle and consequent signal variations found on these systems represent the full range of variations existing across all systems. Our results suggest that each site should evaluate their 3T MRI systems, to establish whether the variations are more severe. While the variations demonstrated in our MRI systems were not severe enough to create observable image artifacts, more severe signal variations may manifest as observable image artifacts. We advise that each site’s 3T MRI system be evaluated according to the methodology described in this presentation.

Since the RF variability of the GRE sequence is diminished at ideal 90 flip angles, we propose the use of low flip angles protocols (for example the turbo-flash with 5 degrees flip angle) for investigating of this variability. Another class of sequences exhibiting an increase sensitivity to the RF fluctuations are the multi-pulses sequences. The multi-pulse sequences are more sensitive to the RF variations due to the inherent more intricate dependence of the flip angle and/or to the contribution various coherence pathways. One typical example, and possible of practical importance is offered by the long DTI sequences. In effect, the intensity along certain directions appears artificially lower. Those effect may impose limits in the effective angular resolution in the DTI employing large number of directions.

References

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