Rapid Time-Series Mapping of the Longitudinal Relaxation Time of the Brain During Neuronal Activity

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Introduction. The most frequently used method in fMRI is T_2^*-weighted scans, which utilizes the variation of the transverse relaxation time caused by the blood-oxygen-level-dependent (BOLD) effect. The longitudinal relaxation time T_1 is another interesting quantity in fMRI and there have been reports on the change of T_1 related to the neuronal activity, e.g., Refs [1,2]. However, these results are inferred from T_1-weighted scans rather than obtained by direct T_1 measurement. Conventional methods for direct T_1 measurement, e.g., inversion recovery and saturation recovery, require long scan time and are not ideal for fMRI. Recently, a rapid method of T_1 mapping has been developed [3,4] which is capable of obtaining T_1 values at a time resolution feasible for brain fMRI; in this work, this method is applied to obtain activation maps.

Methods. The MRI pulse sequence is depicted in Fig 1. A spiral scan [5] follows each α RF pulse to sample the k-space. The theory and details of the T_1 mapping method are given in Refs [3,4]. In summary, the RF pulse train in Fig 1 is executed repeatedly during the course of the fMRI experiment. In each pulse train, the signals of the second half train (divided at the 180° inversion pulse) are subtracted from those of the first half and then an image is reconstructed for each sample time t_i. The reconstructed images are further normalized by division with $\cos^{i-1}\alpha$. The normalized images are the samples of an exponential decay curve at time t_i and are curve-fit, pixel by pixel, to obtain the decay time constant, which is equal to $1/T_1$. Linearized least χ^2 fitting is employed. T_1 maps are also constructed from the second half of a pulse train and the first half of the next pulse train, which equivalently doubles the time resolution in the data collection. In this work, the transverse relaxation was eliminated by setting a very short echo time T_E = 4.7 ms. The spiral scan acquired data equivalent to a 64×64 matrix for Fourier transformation. Slice thickness was 5 mm with 2-mm spacing between slices and field-of-view 22 cm. Referred to Fig 1, α = 35°, q = 3, τ_1 = 450 ms, τ_2 = 450 ms, D_R = 890 ms, and D_P = 10 ms; with these parameters, a T_1 map can be constructed per 1.8 sec. For comparison, a conventional T_2^*-weighted fMRI was also performed with T_E = 40 ms and T_R = 1.8 sec. The functional task was a periodic blocked design with 18-sec on and 18-sec off blocks and a total of seven cycles. During the on-block, the subject was cued to tap fingers. The statistical analysis followed that in Ref [6]. The experiments were performed at 1.5T with a clinical scanner (Excite, GE Healthcare) and an eight-channel array head-coil.

Results and Discussion. Figure 2 shows the activation maps of a healthy volunteer. The color scale represents the value of the correlation coefficient. The background image is the average T_1 map of the direct T_1 mapping experiment and the gray scale represents the window of [550,1750] ms. Although noisy, the activated areas in the activation map derived from direct T_1 mapping can be easily identified and are in agreement with the map derived from conventional T_2^*-weighted fMRI. Periodically, the value of T_1 drops during the on-block and the change is in the range of 20–45 ms. The relatively lower value of the correlation coefficient is most likely originated from the fluctuation along the time series of the measured T_1 values. A challenge in T_1 mapping is that, because T_1 of the cerebrospinal fluid (CSF) is a few seconds greater than that of the gray matter, for a pixel that partially contains CSF, the uncertainty in T_1 of CSF can overwhelm the small T_1 change of the gray matter. The present preliminary success in capturing neuronal activity by direct T_1 mapping prompts further development of the methodology. Conventional fMRI usually is performed with a long T_E to optimize the BOLD effect; therefore it is vulnerable to inhomogeneity of the magnetic field. Thus, in addition to providing an alternative contrast mechanism for fMRI, T_1 mapping offers an opportunity to fMRI study of brain areas that have been hampered by signal loss caused by field inhomogeneity, e.g., the inferior portion of the frontal lobe.

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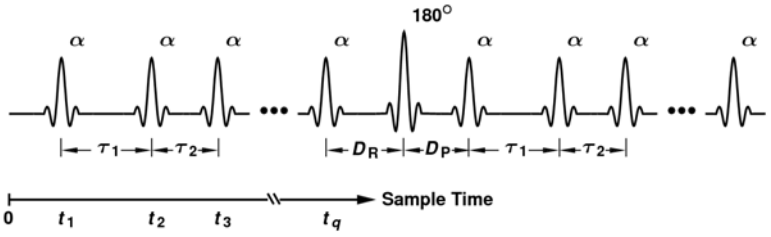
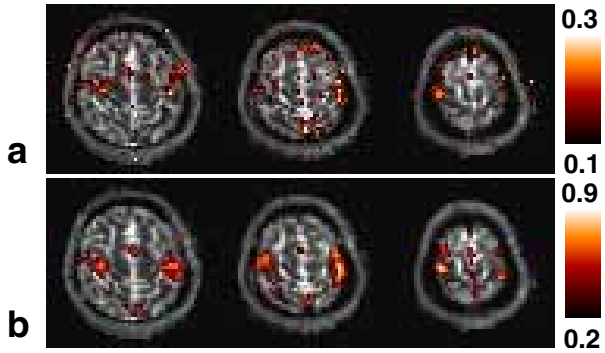


▲ **Figure 1** Pulse sequence for acquiring q samples for curve-fitting the longitudinal relaxation time (only RF output line is shown). Acquisition of imaging data follows each α RF pulse; in this work, a spiral scan is employed.



► **Figure 2** Activation maps of slices covering motor areas derived from (**a**) direct T_1 mapping and (**b**) conventional T_2^*-weighted MRI scans.