The Effect of T2' Changes on Spin-Echo EPI-derived Brain Activation Maps

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Spin Echo acquisitions for fMRI are presumed to better localize function due to their insensitivity to static magnetic field gradients, such as those around large vessels. For echo-planar imaging, however, significant signal decay occurs during the relatively long readout window due to static magnetic field inhomogeneities. Changes in the spin echo signal observed during activation may therefore be due in part to changes in T2', not purely to changes in T2. Simulations performed here predict between 17-38% of the spin echo signal change during function is due to changes in T2'.

Introduction:

Functional magnetic resonance imaging (fMRI) using spin-echo imaging has become more widely used in recent years, especially at high field strengths. Blood oxygenation changes during activation cause increases in the transverse relaxation times, predominantly in T2* and to a lesser extent in T2. The T2 is not as affected by extravascular magnetic field gradients around large vessels. At high field strengths, where blood T2 is so short that no intravascular signal exists, changes in T2 are weighted towards the smaller capillaries which are more localized to the site of neuronal activity. Spin echo images are typically considered to reflect only this T2 contrast. For echo-planar imaging, however, significant signal decay occurs during the relatively long readout window due to static magnetic field inhomogeneities. This T2' effect is also modulated by large vessel extravascular gradients that can therefore cause additional modulation of the signal, ($1/T2^* = 1/T2' + 1/T2$), particularly at the spatial frequencies that are encoded at the edges of the readout window – typically the high frequency components. Changes in the spin echo signal observed during activation may therefore be due in part to changes in T2', not purely to changes in T2 – and particularly so in extremely small or tortuous areas of activation

The goal of this work is to simulate the effects of T2' decay during a spin echo acquisition and estimate the fraction of the spin-echo signal change due to changes in T2'. In addition, the effect of 3 variables were studied: field strength, activation size, and resolution or readout window size.

Methods:

Signal changes during activation in a small region were simulated by considering the effect of a changing T2 and T2' in a small Gaussian region. Due to linear superposition, this is equivalent to the sum of the non-active region multiplied by an exponential with a constant T2 and T2' and an active region multiplied by a T2 and T2' that changes during neuronal activation. For studying differences in signal during activation, the non-active area subtracts out and all that must be considered is the active region modulated by different exponentials.

The Fourier transform of the Gaussian representing the neural activation was multiplied by an exponential,

$$S = S_0 \, e^{\frac{-t}{T2}} \, e^{\frac{-|t-TE|}{T2'}} \qquad [1]$$

The inverse Fourier transform of this modulated signal produced the image of the activated region during either activation or rest. The percent difference in the peak of the Gaussian during activation and rest was compared to a model including only the T2 effect, ignoring T2' changes during activation (see Fig. 1).

The sampling rate was assumed to be 8μs, and the time between lines of k-space in the y-direction was assumed to be 704μs. Changes in field strength from 1.5T to 7T were simulated by changing the T2 and T2' [1.5T: T2=125.8ms (rest) 128.9ms (active), T2'=125.5ms (rest) 135.9ms (active); 7T: T2=55ms (rest) 57.8ms (active), T2'=45.8ms (rest) 52.8ms (active)]. The effect of resolution was simulated by changing the sampling time in the ky-direction from 704μs to 1216μs (equivalent to increasing the resolution from 64x64 to 128x128 with the same sampling rate). The effect of the size of the active region was simulated by changing the width of the Gaussian from a full-width half maximum of 4 pixels (15mm) to 1 pixels (3.75mm).

Results:

For a 64x64 image (sampling time 8μs, time betw. phase encodes: 704μs, activation size 15mm) at 1.5T with a TE of 60ms, 17.6% of the percent signal change due to activation in a spin echo EPI image is due to a change in the T2', not a change in the T2.

Field dependence: Signal changes due to T2' are greater at higher field strengths. The fraction of the spin-echo signal change due to T2' effects depends on the relative change of T2 and T2'. At high fields, the spin-echo signal around large vessels is typically expected to be minimal since the intravascular signal is reduced due to a shorter blood T2. These simulations indicate, however, that a signal change of 3% is still possible for a small activation (~1 pixel) purely due to T2' effects during the spin echo.

Resolution: Doubling the resolution to 128x128 increased the sampling time in the ky-direction resulting in a greater modulation of the signal by T2'. 26.9% of the spin echo signal was due to a change in the T2', for an activation size of 15mm.

Activation size: Reducing the size of the activation from 15mm to 3.75mm increased the effect of T2', with 37.4% of the spin-echo signal caused by T2' changes. This is because the T2' signal decay predominantly affects higher spatial frequencies, which are present to a greater extent in smaller activations.

Resolution	Activation Size	% of SE signal change due to T2'
64x64	15mm	17.6 %
128x128	15mm	26.9 %
64x64	3.75mm	37.4 %

Table 1: Fraction of spin echo signal due to changes in T2' at 1.5T.

Discussion + Conclusion:

A significant fraction of the signal change in spin echo images obtained with echo planar imaging is due to changes in T2'. Therefore, spin echo fMRI data can still be affected by gradients around large vessels. This fraction increases for higher resolution for two reasons. First, the sampling rate in the ky-direction decreased. Second, the active (or hyperoxygenated) areas are smaller due to less partial volume averaging of non-activated (or non-hyperoxygenated) regions with active areas. It is therefore imperative to consider the effect of T2', especially if spin echo imaging is used to obtain greater specificity at higher resolutions.

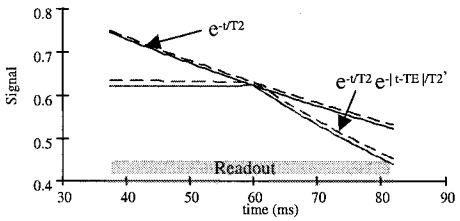

Figure 1: Signal decay during spin-echo EPI with and without T2' decay.