Optimum Voxel Size in fMRI

J.S. Hyde, B.B. Biswal, and A. Jesmanowicz
Biophysics Research Institute, Medical College of Wisconsin, Milwaukee, WI USA

Purpose. Because of tortuosity of the cortical ribbon, it seems self-evident that fMRI studies should in principle be carried out using cubic voxels. It can be further hypothesized, for voxels of size d^3, that the value of d should lie between the thickness of neuronal layers 3 and 4 from which the signal is presumed to arise and the thickness of the ribbon itself. The purpose of this study is to address the question of whether or not an optimum value of d exists.

Methods. The task was self-paced bilateral finger tapping. Single shot half-k-space gradient-recalled EPI was used (1). A scout data set of 10 contiguous 1 mm axial slices with 1×1 mm in-plane resolution was obtained through the motor cortex, and from this data using real-time analysis methods (2) an optimum 6 mm thick slab was identified by the criterion of greatest volume of activation. This slab was sampled in six different ways in six separately acquired data sets: 7, 6, 5, 4, 3, and 2 slices (viz., .86, 1, 1.2, 1.5, 2 and 3 mm slice thickness.) The in-plane matrix size was held fixed at 192×192 and the field-of-view varied in each case to achieve cubic voxels. The order of acquisition of the six data sets was randomized. For each of the data sets, the number of activated pixels was determined as a function of the correlation-coefficient threshold. For each pixel time course, the delay of the boxcar reference waveform was adjusted for maximum response. Multiplication of the number of activated pixels by voxel volume yielded the total activated volume as a function of threshold. Data from the six sets were merged by plotting total activated volume versus the parameter d for various threshold values. Image acquisition technical parameters were: 3 Tesla, TE = 30 mS , Bandwidth = 166 kHz, 16 partial k-space overscan lines, TR = 2 sec, 4 cycles of 32 sec on—32 sec off.

Results. Figure 1 shows individual results from 6 subjects. Note that the 3 mm slice thickness data set was added to the protocol midway in the study. Well defined peaks were obtained at d = 1.5 mm in four subjects, 1.2 in one and 2.0 in the other. It is concluded quite generally that fMRI experiments ought to be carried out using $1.5 \times 1.5 \times 1.5$ mm cubic voxels.

Discussion. The existence of a maximum in the plots of Fig. 1 can be rationalized in a qualitative manner. Key to this rationalization is the assumption of spatially encoded low frequency physiological fluctuations as the dominant noise source. Assume an fMRI volume V_0 of uniform activation, and that spatially encoded noise is not spatially correlated. If a voxel is smaller than V_0, the signal in a voxel that lies within V_0 varies as d^3 and the noise as $d^{3/2}$: CNR $\propto d^{3/2}$. The activated volume is V_0. If a voxel is larger than V_0, the signal from a voxel that contains V_0 is independent of d and the noise varies again as $d^{3/2}$: CNR $\propto d^{-3/2}$. The apparent activated volume is d^3. In the real case with a distribution of activation levels, physiological noise levels, spatial correlation of noise, and irregular activation volumes, the situation is much more complex. Nevertheless a maximum in the plots of Fig 1 is expected when d^3 matches V_0, Duvernoy, et al, define a venous unit as an arterial ring surrounding a penetrating vein that drains neuronal layers 3 and 4, and state that the volume of cortical grey matter tissue drained by a venous unit lies between 0.75 and 4 cubic mm (3). The peak values seen in Fig. 1 are consistent with this range of volumes, and it is therefore hypothesized that the fMRI limit of spatial resolution is the venous unit.

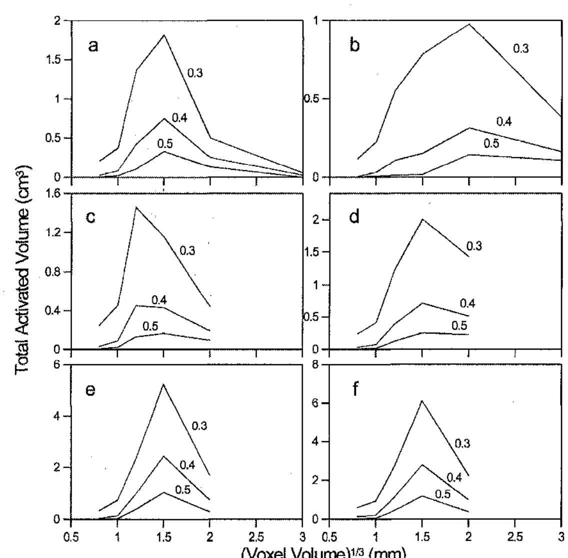

Figure 1. Data demonstrating that use of 1.5 mm^3 cubic voxels is optimum in fMRI.

References

1. Jesmanowicz, A., Bandettini, P. A., Hyde, J. S., *Magn. Reson. Med.* 40, 754, 1998.
2. Cox, R. W., Jesmanowicz, A., Hyde, J. S., *Magn. Reson. Med.* 33, 230, 1995.
3. Duvernoy, H. M., Delon, S., Vannson, J. L., *Brain Res. Bull.*, 7, 519, 1981.