The Slice-Timing Problem in Event-related fMRI

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The desiderata for functional neuroimaging are high spatial and high temporal resolution. Recent developments in rapid echo-planar functional resonance imaging (fMRI) and event-related analyses [1,2] combine a spatial resolution of millimetres with a temporal resolution of seconds. A fundamental trade-off remains however: large brain coverage at high spatial resolution requires many, thin image planes (slices), resulting in a longer interscan interval (TR) and hence poorer temporal resolution. Though staggering stimulus times relative to scan times allows a higher effective sampling rate, existing volume-based analysis techniques such as SPM [2] assume simultaneous sampling of all slices. We show that this assumption can result in poor model fits and hence type II errors. Two popular solutions are compared: the use of multiple regressors and the interpolation of data in time.

The Slice-Timing Problem

Approximately 34 slices are necessary for full-cortical coverage (excluding cerebellum) at a resolution of 3mm. With the minimum resulting TR of 3s, we scanned a volunteer pressing keys to visual stimuli presented every 8s, producing an effective sampling rate of 1Hz. 2.5mm transverse slices were acquired sequentially in a descending order with a 0.5mm interslice gap. SPM{F}s of voxels evidencing significant event-related responses were created using a canonical haemodynamic response function (HRF) [2] as the regressor of interest (after realignment, normalisation, global scaling, 1/240Hz highpass filtering, 8mm spatial smoothing, and 4s temporal smoothing). The regressor was synchronised with acquisition of either the top (Fig. 1A) or bottom (Fig. 1B) slice (shifting it in time by one TR). Motor cortex responses (upper slices) were captured better in the former case, whereas visual cortex responses (lower slices) were captured better in the latter case. The markedly different SPMs illustrate the slice-timing problem.

Multiple Regressors

The use of multiple regressors can overcome the slice-timing problem. A Fourier basis set for example is insensitive to phase differences resulting from different slice timings. The unconstrained nature of a Fourier basis set however means the model can fit periodic signals that are unlikely to reflect haemodynamic responses (e.g., movement artifacts), and is not efficient in its use of degrees of freedom. A more constrained set comprises the canonical HRF and its first-order derivative with respect to time [2]. The effects of including an HRF derivative are shown in Fig. 1C (regressors synchronised with the top slice). The combination of two regressors is better able to capture both motor and visual cortex responses, despite the extra degree of freedom in the model. Although the SPM{F} has a more uniform sensitivity with this approach however, specific contrasts using SPM{t} (e.g., tests of HRF height or onset [2]) may not have, especially if the TR is long relative to the time constants of the haemodynamic response.

Interpolation of Time Series

An alternative approach to the slice-timing problem is to interpolate the data in time. Fig. 1D shows the effect of shifting the data in time relative to the acquisition of the top slice, using a full sinc interpolation prior to spatial realignment. Using only a single canonical HRF regressor, responses in visual cortex are now captured better than without interpolation (cf. Fig. 1A). The advantage of interpolation is that inferences concerning differences in HRF height between slices (or HRF onset, if a derivative regressor is also included [2]) are less likely to be confounded by different slice acquisition times. A limitation with this approach however is that interpolation will not accommodate experimental power at frequencies above the Nyquist sampling limit (i.e. 1/{2TR}). A spatial-temporal trade-off remains therefore: With a TR of 3s for example, interpolation will alias frequencies greater than 1/6Hz, meaning that interstimulus intervals less than 6s are likely to experience significant loss of experimental power.

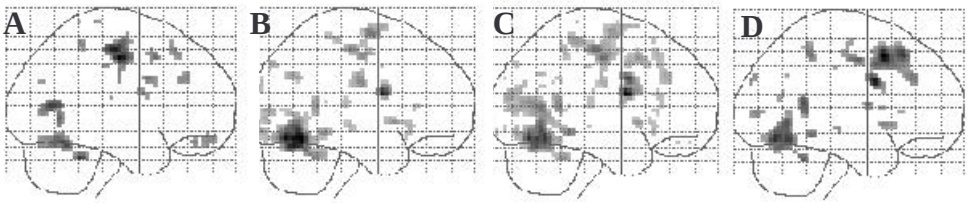

Fig. 1. SPMs of the F-statistic that survive voxel-wise correction at $p<.05$ synchronised with top (A) or bottom (B) slice, with multiple regressors (C), or with data interpolation (D).

Conclusion

Both the above solutions have limitations. A third solution uses slice-specific models, in which regressors are generated separately for each slice. We are currently investigating the implications of this approach for Gaussian Field theory corrections to SPM significance levels.

References

1. Dale, A. M. & Buckner, R. L., Human Brain Mapping, 1997, 5, 329-340.
2. Friston, K. J. et al., Neuroimage, 1998, 7, 30-40.