Adding Transients to model BOLD fMRI Time Courses for Somatosensory-Motor Activations

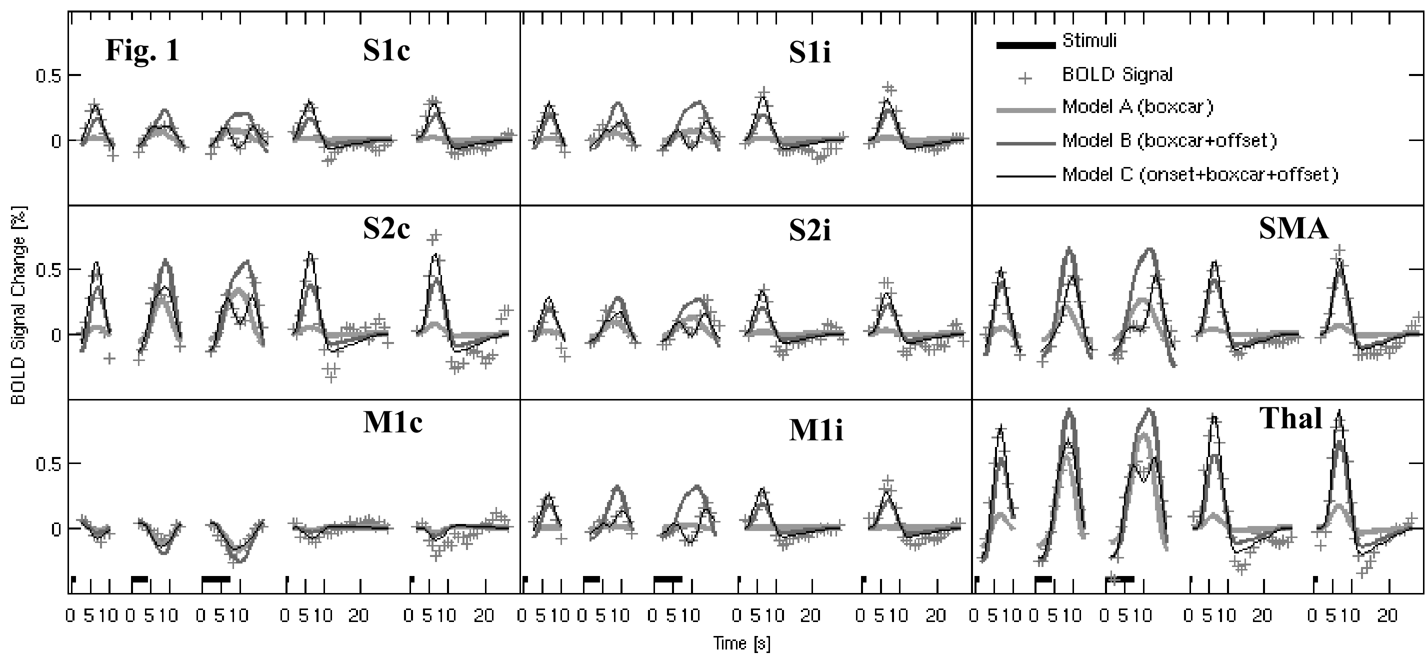
M. Marxen[1,2], R. J. Cassidy[1], T. L. Dawson[1], B. Ross[1,2], and S. J. Graham[1,2]

[1]Rotman Research Institute, Baycrest, Toronto, Ontario, Canada, [2]Heart and Stroke Foundation Centre for Stroke Recovery, Toronto, Ontario, Canada

Introduction: Within the General Linear Model (GLM) framework of analyzing fMRI data, an assumed neuronal input function is convolved with a hemodynamic response function (HRF) to model the fMRI time course. For stimulation of sensory-motor cortex, the simplest model of the neuronal input is a boxcar function with the same duration as the stimulus. Electrophysiological recordings, however, show that the associated neuronal activity commonly exhibits onset and offset transients [1,2,3]. Here, we investigate use of neuronal input functions with and without transients and variable HRF latency to explain the fMRI time courses in major centres of the somatosensory-motor system. The simple boxcar model, which implies linearity of the integrated BOLD response with respect to stimulus length, may work for some stimulus types and longer stimuli [4, 5]. However, non-linear deviations from this model have been observed and discussed in detail [5, 6] mostly for primary sensory cortices including the primary somatosensory cortex [7]. In this context, it is likely, that a model including transient components will fit fMRI data better.

Methods: The fMRI design involved 2 runs with 45 stimuli of 1, 4, or 7s length with an inter-stimulus interval (ISI) of 10s and 2 runs with 0.5, or 1s stimuli with an ISI time of 30s. The shorter ISI was chosen to allow sufficient averages for an MEG study with the same design. The longest stimulus duration of 7s was chosen as the estimated minimum duration that would separate onset and offset transients and provide sensitivity for the boxcar component. Stimuli were generated by a pneumatically driven membrane vibrating at 22 Hz placed on the palmar side of the distal phalanx of the right index finger. Subjects were asked to press a button with the opposite hand at the end of each stimulus to maintain attention throughout. 15 young adults (20-38 years, 8 female) were scanned on a Siemens 3T Trio using 16 contiguous, oblique coronal, 3 mm thick EPI slices through S1 with TR/TE/Flip/FOV/matrix of 1s/30ms/50°/20cm/64x64. Data were corrected for motion, heartbeat, and respiration, and smoothed (6mm FWHM) using AFNI [8]. GLM fits were obtained for three different neuronal models: A – boxcar; B – boxcar + offset transient; C – onset transient + boxcar + offset transient. The HRF (3.5s rise time, 5s fall time, 0.2 * peak undershoot, 15s restore time) peak latency was optimized from 3.5-8.5s for model C and maintained for A and B. Transients were modeled as Dirac delta functions. Group averaged, latency adjusted BOLD time courses and fitting results for 14 subjects (one subject plus 7 runs eliminated due to motion) were computed in Talairach space.

Results: Fig. 1 shows BOLD signals from representative voxels in eight anatomical areas: Primary and secondary somatosensory areas contralateral (S1c, S2c) and ipsilateral (S1i, S2i) to the stimulus, primary motor areas (M1c, M1i), supplementary motor area (SMA), and thalamus (Thal). F-tests for model comparisons in each voxel and subject were conducted. The group averaged uncorrected P values for improvements of model C over model A were 0.05, 0.03, 0.0016, 0.01, 0.07, 0.03, 0.04, 0.02 in S1c, S1i, S2c, S2i, M1c, M1i, SMA and Thal, respectively. Corresponding uncorrected P-values for model C over B ranged from 0.20 – 0.35 and for model B over A from 0.22 – 0.42. In individual subjects, large clusters of improvements of model C over models A and B exist at uncorrected $P < 0.05$. Transient activation areas are generally much larger in models B and C than boxcar activations for all models. Group averaged peak latencies varied from ~4.5s in S2 and SMA, ~5.5s in S1 and M1 to ~6.5s in Thal.



Discussion and Conclusion:

Fig. 1 demonstrates that including onset and offset transients for the 'neuronal' input function of a somatosensory stimulus improves the conventional boxcar GLM model significantly in areas relevant for somatosensory processing. In fact, the transient components predominate, in agreement with a previous MEG study [9]. Model C provides, therefore, more comprehensive activation maps than the other two models. Only model C is capable of fitting the bimodal nature of the response to the 7s stimulus. Because a button press was required at the end of the stimulus on the contralateral side, transient offset activation is not purely related to the stimulus but also to the button pressing task. Though model C is capable of explaining the group averaged BOLD time courses well, the interpretation of the input function as neural activity remains to be verified. To test this hypothesis, MEG data in the same participants are currently being analyzed.

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