Non-linear interactions between scanner acoustic noise and auditory stimuli in fMRI.

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Introduction

When performing functional MRI (fMRI) of the central auditory system, scanner acoustic noise is a major obstacle since it leads to an elevated baseline activation level and a reduced dynamic range for further auditory stimuli. Sparse scanning paradigms[(1)] using clustered volume acquisitions are in wide-spread use, but because of large gaps between scans these are rather inefficient. A series of experiments was conducted to gain insight in the form of the interaction between the hemodynamic response to scanner noise and that to other auditory stimuli. The results not only allow sparse paradigms to be optimized, but also give more insight in the non-linear mechanisms behind the hemodynamic response function (HRF).

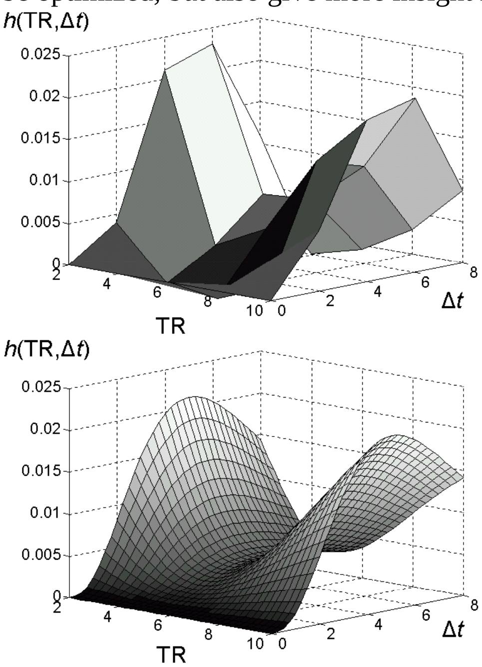

Fig 1: Upper panel: the measured average hemodynamic response h to a tone as a function of Δt and TR; lower panel: a model based on a multiplicative interaction term and gammavariate response shapes.

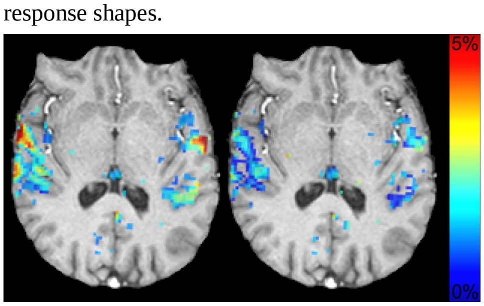

Fig 2: The amplitude of the tonal response ($A_{response}$; left) and interaction term ($A_{interaction}$; right) in one of the subjects; regions showing large responses show large interactions as well.

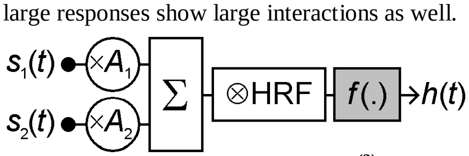

Fig 3: A simple non-linear model[(2)] involving two stimulus inputs $s_i(t)$ and a non-linear function f to result in an output hemodynamic signal $h(t)$.

Materials and Methods

A piezo-electric MRI-compatible headset was used to present 12 subjects with short pure tone stimuli. Scans and stimuli were matched for loudness (70 dB) and duration (1.3 s). T_2*-weighted EPI scans were conducted of the superior temporal cortex (1.5 T, TE 50 ms, voxel size 2.5×2.5×3.5 mm^3). The stimulus-to-scan (Δt) and scan-to-scan (TR) intervals were varied independently between 0 and 10 s. The response signal was segregated into a tonal response, depending upon Δt only, and an interaction between scanner noise and stimulus, depending upon both Δt and TR.

Results

Fig. 1 displays the response data averaged over all active voxels ($p < 0.001$) in all 12 subjects. A hemodynamic response as a function of Δt is visible for all TR, with a maximum at intermediate Δt (4-6 s). However, for intermediate TR (4-6 s) the amplitude of the response is lower than for either the lowest or highest TR by an approximate factor of 4. The data were split into a (positive) tonal response and a (negative) interaction term. The spatial distributions of the absolute amplitudes of both terms are illustrated in Fig. 2; regions with large tone responses all show substantial decreases due to scanner noise interaction. The functional dependence of the interaction term proved to be well separable with regard to Δt and TR.

Conclusions

The large decrease in response amplitude for intermediate TR is caused by the fact that at TR = 4-6 s the delayed response to the previous scanner noise has reached a maximum. The separability of the interaction term allows it to be modeled as a product of two functions, each only depending upon Δt and TR respectively. For comparison, the resulting function according to

$$h(\mathrm{TR},\Delta t) = A_{response} \cdot G(\Delta t) - A_{interaction} \cdot G(\Delta t) \cdot G(\mathrm{TR}) \qquad [1]$$

is plotted in the lower panel of Fig. 1 (G is a gammavariate HRF). Such a multiplicative functional form agrees exactly with simple first-order non-linear models, for example a model based on Fig. 3 that involves a conventional linear step that is followed by the application of a non-linear function[(2)].

References

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2. Friston, K. J., O. Josephs, et al. (1998). *Nonlinear event-related responses in fMRI.* Magnetic resonance in medicine **39**(1): 41-52.