Detectability of the BOLD signal

J. Goense[1], H. Merkle[2], and N. Logothetis[1,3]
[1]Department of Physiology of Cognitive Processes, Max-Planck Institute for Biological Cybernetics, Tuebingen, Germany, [2]Laboratory of Functional and Molecular Imaging, NINDS, NIH, Bethesda, MD, United States, [3]Division of Imaging Science and Biomedical Engineering, University of Manchester, Manchester, United Kingdom

Introduction

The BOLD signal is a weak signal, and hence if no BOLD signal is found in an area this does not automatically mean there is no neural activity in that area. Signal dropout, artifacts, instability, physiological noise, RF-coil inhomogeneity etc. can all reduce the SNR locally leading to decreased detectability of the BOLD signal. Here we illustrate that calculation of the spatial distribution of the detection thresholds allows us to assign a degree of confidence to the activations as well as identify areas where detectability of functional activation is compromised.

Methods

Data were acquired on a vertical 7T scanner (Bruker BioSpec 70/60v) in anesthetized monkeys (*macaca mulatta*) weighing 4-10 kg, while the monkeys were viewing a full-field rotating checkerboard stimulus alternating with blank periods (block design with 48s periods, 64 images). The setup and methods have been described previously [1,2]. Anesthesia was a balanced remifentanyl/mivacurium regimen. For anesthetized monkeys a custom-designed phased array was used. Multi-shot GE-EPI functional images were acquired with an in-plane resolution of 0.5 mm and a slice thickness of 2 mm. TE/TR was 20/750 ms. For the two-sample t-test the t-value depends linearly on the difference in the means divided by the standard deviation (SD) of the distributions [3]. Hence, for a given significance level the detectable %change (S) depends on the coefficient of variation (CV) according to S = k * CV, with k a constant that depends on the significance threshold and number of samples.

Results

Figure 1 shows the %change as a function of CV for all activated voxels in a single 6-min GE-EPI scan. This indicates that the size of the detectable BOLD signal depends linearly on the variation over the time series.

Fig. 1

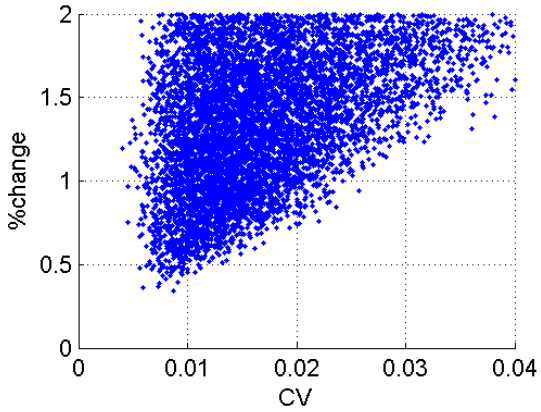

Figure 2 shows the raw image for a slice in early visual cortex of an anesthetized monkey (upper panel). The middle panel shows the activation map and the lower panel shows the voxel-wise map of the minimum BOLD signal (in %) required to achieve a significance level of $p = 0.05$.

Fig. 2

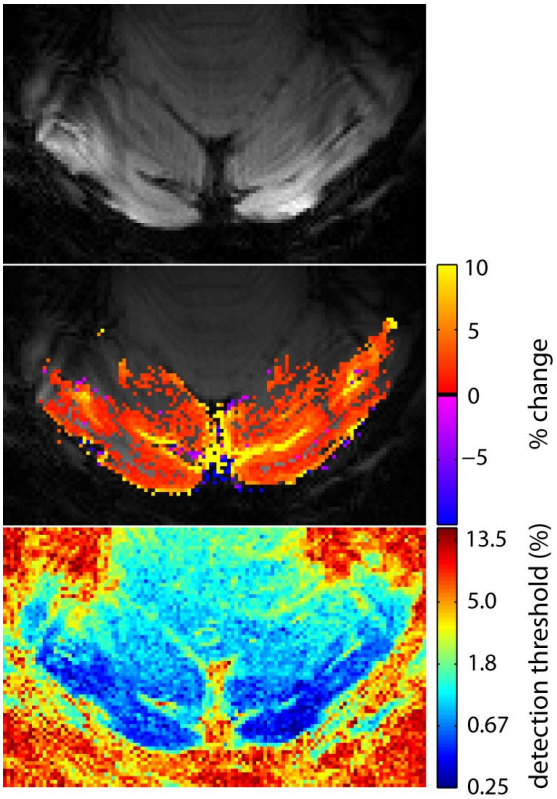

Figure 2 shows that the detection thresholds for fMRI have an inhomogeneous distribution with higher detection thresholds in areas with low SNR, near large blood vessels, and further away from the receiver. The stimulus is known to activate the entire operculum but BOLD signal is weak or lacking in locations near large superficial vessels. The susceptibility gradients near such vessels are sufficiently large to decrease detectability of the BOLD signal. In the vessels themselves detection thresholds are also elevated but the BOLD signal in large vessels is strong. The inhomogeneous detection thresholds and progressively decreasing detection thresholds further from the receive array indicates physiological noise is not dominant.

Although SNR in this scan was high, and detection thresholds in V1 (0.3-0.5%) are well below the BOLD signal, verifying detection thresholds becomes important when SNR is low, for example in areas with susceptibility artifacts, or when weak stimuli are used.

Conclusion

A lack of significant activation does not necessarily mean there is no neural activity in an area. By calculating detection thresholds one can more reliably quantify performance. Evaluating the minimum detection thresholds for a given set of experimental conditions allows us to estimate the confidence by which absence of an fMRI signal can be interpreted as an absence of neural activity.

References

[1] Pfeuffer et al., MRI 22:1343-1359 (2004); [2] Logothetis et al., Nat Neurosci 2:555-562 (1999); [3] Student, Biometrika 1:1-25 (1908);