Time resolved fMRI: 100 ms resolution in time for extended network analysis of the human brain

J. Reinhardt[1,2], E. Nennig[3], S. Walther[4], S. Heiland[2], and C. Stippich[1,2]

[1]Department of Neuroradiology, University of Basel Hospital, Basel, Switzerland, [2]Division of Neuroradiology, Department of Neurology, University of Heidelberg, Medical Center, Heidelberg, Germany, [3]OptiMed Medizinische Instrumente GmbH, Ettlingen, Germany, [4]Center for Psychosocial Medicine, General Psychiatry, University of Heidelberg, Medical Center, Heidelberg, Germany

Introduction: We describe a method to enhance the time resolution in fMRI below 100 ms enabling to trace neuronal network pathways with extremely short reaction times.

Methods: A healthy male volunteer (44y) got a single tactile stimulus applied to the right index finger. Event-related fMRI was performed on a 3 Tesla Siemens Magnetom Trio (Siemens Healthcare, Germany) scanner with an inter-stimulus-interval of 15.010 s and 99 repetitions (total scanning time 25 min). The 99 different start points were desynchronised in 10 ms steps from TR, evenly distributed within the TR of 1000 ms, thus a temporal resolution of 10 ms (not interpolated) was achieved. An GE-EPI sequence (16 transversal slices, TR 1000 ms, TE 40 ms, slice thickness 6 mm) was used for functional imaging, followed by a T1 weighted 3D MPRAGE sequence. We used Presentation Version 9.9 (Neurobehavioral Systems, Inc., USA) for stimulation and event recording with a temporal resolution of 1 ms. A single-subject GLM analysis was carried out using BrainVoyager QX (BrainInnovation, the Netherlands). Afterwards we selected regions of interest (figure 1) for further analysis, namely the primary (S1) and secondary (S2) somatosensory cortices contra- and ipsilaterally to the stimulated side, and extracted the BOLD signal time courses (by a fixed threshold of q(FDR) <0.05). The time course data were spline interpolated (Matlab 6.5 (The MathWorks, Inc., USA)) to a temporal resolution of 1 ms and divided into portions of 15.010 s duration each, every portion started exactly two seconds before the stimulation event. With the obtained temporal resolution it was possible to compute the mean BOLD signal time course for every region of interest, the normalized results are displayed in figure 2. We used the peak of the BOLD signal time course to determine the latencies compared to the tactile input. Here we present preliminary results of 7 measurements.

Results: Using this approach we were able to study the temporal characteristics of tactile processing in neuronal network pathways of the somatosensory system in S1 and S2 with a resolution of 10 ms by BOLD-fMRI. The temporal dynamics of somatosensory processing could be measured and correspond with the known values from electrophysiological measures. The peak BOLD response in S1 contralateral to the stimulated side (left hemisphere (LH)) was followed by the peak of S2 contralateral to the stimulated side (left hemisphere (LH)) LH with a mean delay of 53 ms and that of S2 ipsilaterally to the stimulated side (right hemisphere (RH)) with a mean delay of 67 ms. The difference between the S2 LH and S2 RH was 14 ms in mean. For details see table1.

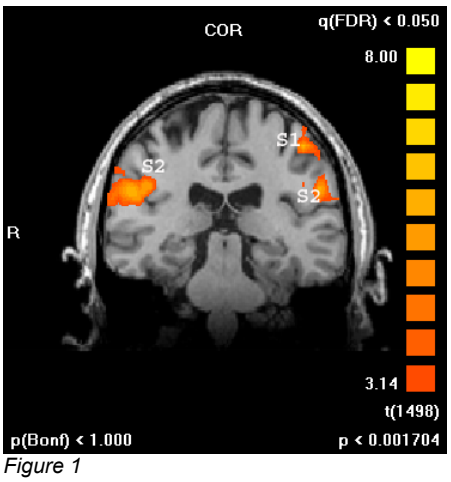

Figure 1

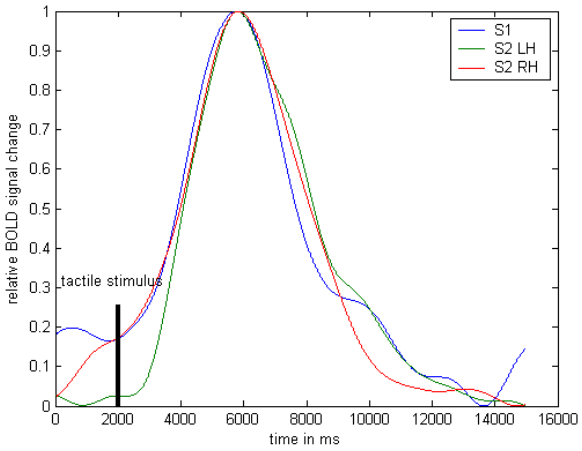

Figure 2

Figure 1: BOLD activations are projected onto a T1w coronal slice of the healthy volunteer. Tactile input of the right index finger shows normal activation patterns (S1 LH, S2 LH and S2 RH).

Figure 2: The calculated high-resolution BOLD time course of the first measurement of selected areas (S1 LH, S2 LH and S2 RH).

	S1 LH	S2 LH	S2 RH	S2 LH - S1 LH	S2 RH - S1 LH	S2 RH - S2 LH
1	5764	5807	5831	43	67	24
2	6388	6440	6449	52	61	9
3	6696	6760	6760	64	64	0
4	6395	6462	6479	67	84	17
5	6806	6853	6886	47	80	33
6	6557	6614	6626	57	69	12
7	6792	6833	6838	41	46	5

Table 1: Comparison of the calculated latencies of the measurements compared to the tactile input indicates their temporal order (time in ms).

Discussion: With this new approach BOLD-fMRI enables to study the temporal dynamics of cortical processing with a temporal resolution of 10 ms. The latencies of the measured peak responses in primary and secondary somatosensory cortices correlate well with the data known from electrophysiology. We interpret the intra-individual discrepancies of the time points of S1 LH, S2 LH and S2 RH as a result of activation fluctuations between days. Direct correlations to MEG, serving as a reference procedure, are under investigation.