Detection and correction of motion-induced susceptibility changes in fMRI time series of the alert monkey

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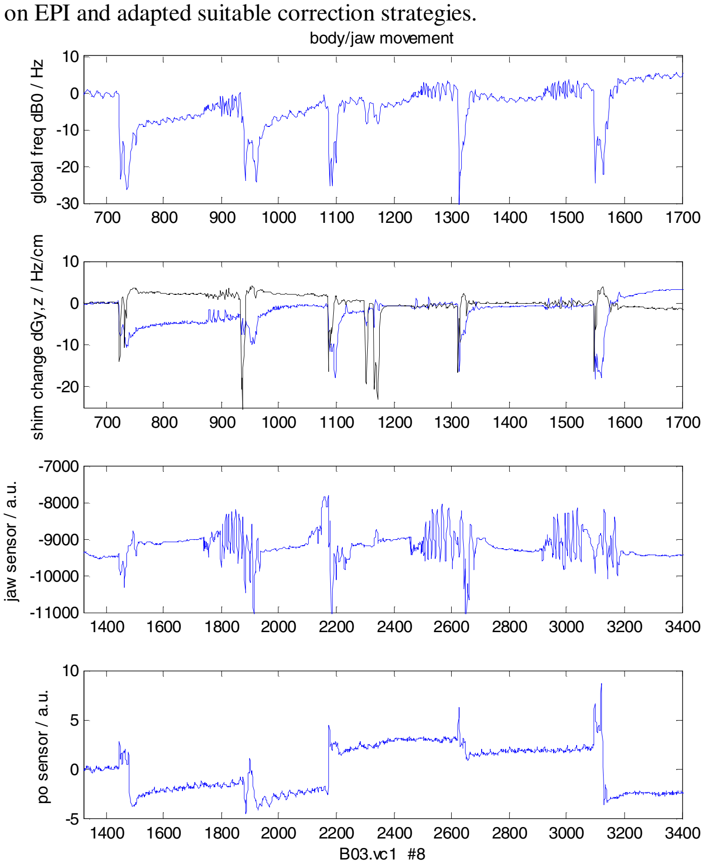
Introduction Functional MR imaging in *alert* monkeys promises to build a bridge between brain research in humans and the large body of systems neuroscience work in animals. In addition combination of fMRI with other invasive neuroscientific methodologies may provide us with important information regarding the neural origin of the hemodynamic responses. Indeed, simultaneous fMRI and electrophysiology was recently used in anesthetized macaques to elucidate the neural activity underlying the fMRI signal [1]. Experiments in *alert* animals were until recently hampered by motion artifacts that are almost unavoidable in the long sessions required to collect reliable physiology and fMRI data. Here we present the first monitoring and correction strategies for dynamic susceptibility changes in fMRI time series in the *alert* monkey using a 7 T vertical-bore MR system. Typically, in electrophysiology experiments with trained monkeys, the restraint of the animal's head by means of a 3-point head post is sufficient for the acquisition of reliable data. In contrast, acquisition of echo-planar images for fMRI is extremely sensitive to all sorts of body movement. Thus, we evaluated the effects of mouth (jaw and tongue), arm, leg and rump movement on EPI and adapted suitable correction strategies.

Methods Upright positioning of the animal, being used over the last 50 years in all alert-monkey laboratories, was chosen for fMRI to minimize discomfort in the animals, expedite their training process, and ensure longer cooperation during the demanding psychophysical testing. Single-shot EPI was performed on a *vertical* 7T/ 60 cm system with a 38-cm inner diameter gradient insert [2]. Surface coils with 40 to 60 mm diameter were used in transceive mode [2].

Mouth and body movement was monitored by custom-built sensors, which provided real-time signal coupled to MR acquisition as well as the stimulus and task presentation. In addition, cameras were mounted inside the chair and magnet: 1) The **mouth sensor**, placed on the jaw of the monkey, monitored jaw and tongue movement during sucking of the juice (reward after successful trials). 2) The **body sensor,** placed under the monkey's seat, monitored respiration, movement of extremities (arms and legs), and changes in seat position. For MR detection of dynamic susceptibility changes, orthogonal **shim navigators** [3] in X, Y, and Z direction were used to detect global B_0 frequency as well as linear shim changes in Gx,y,z relative to a reference frame (TR 100 ms). In EPI fMRI series, the center of k-space phase/frequency was used to calculate dynamic off-resonance changes (DORK) [4] and to correlate external motion sensor data with MR.



Results and Discussion For reference, dynamic susceptibility changes were measured in anaesthetized monkey experiments, in which only respiration-induced B_0 fluctuations were present. The change of global frequency ΔB_0 with respiration was 1 – 2 Hz depending on the individual animal. Shim changes ΔGx,y,z were typically 0.7 – 1.5 Hz/cm depending on monkey position and direction. We found that shim changes in y- and z-direction were typically a factor of 2-3 increased compared to the x-direction. Both, ΔB0 and ΔGx,y,z were stable over time and did *not* reveal a significant baseline drift.

In contrast, the data from the *alert* monkey showed significant additional influences. To distinguish different sources of movement artifacts, we separated different event periods based on the recorded sensor data from mouth and body. In periods with no jaw or body movement, ΔB0 and ΔGx,y,z changes were similar to the anaesthetized monkey (1–3 Hz p-p). **Jaw movement** correlated with moderate changes in ΔB0 up to 5 Hz and ΔGx,y,z up to 3 Hz/cm p-p. **Body movement** affected most significantly the MR signal with two differing effects: 1) Slow changes in the baseline corresponded to more subtle changes of extremities. 2) 'Catastrophic' events with huge jumps up to 30 Hz corresponded to abrupt changes in seat position. In Fig. 1, mouth and body sensor data (c,d) of a selected series is shown together with ΔB0 (a) and ΔGy,z (b).

For acquisition of fMRI event-related data, animals were effectively trained to keep still in event periods based on real-time feedback from the mouth- and body-sensor signals. In between trials, juice reward caused relatively small effects on the EPI series. Body movement was directly detectable from tracing DORK information alone and if present, fully vanished fMRI periods. For postprocessing of EPI images, two problems were tackled: 1) Detection of usable trial periods based on correlated sensor data, DORK, and MR images. 2) Correction of baseline drifts and averaging of different trials was based on DORK and rigid body models for realignment using linear translations and sinc-interpolation in image space.

With the detection strategies described, we provide a framework for targeted training of alert behaving monkeys and report reliable detection and exclusion of movement related artifacts in fMRI time series.

References 1. *Nature* 412:150 (2001). 2. MRI 22:1343-59 (2004). 3. MRM 48:771-80 (2002). 4. MRM 47:344-53(2002).