Combined pre- and intra-operative fMRI for neurosurgical guidance: data alignment and Bayesian analysis.

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Target audience: fMRI methodologists; clinicians who use fMRI for planning neurosurgery.

Purpose: Intra-operative fMRI (ifMRI) combined with pre-surgical fMRI planning is expected to provide crucial information to guide neurosurgery. Combining ifMRI and fMRI may be difficult, since the intra-operative MRI (iMRI) environment poses instrumental and physiological challenges and the ifMRI quality may be compromised. We developed methods for spatially aligning the different types of fMRI data including correction of distortions due to gradient non-linearity and susceptibility artifacts. Surgical planning requires information not only about activated but also non-activated brain areas, which classical inference statistics frequently used for fMRI do not provide. We propose to use Bayesian posterior probability maps (PPMs), providing explicit information defining activated and non-activated areas and areas where the data do not allow for a robust decision.

Material and acquisition: 10 healthy subjects were scanned using: 1) a 3T TIM Trio (Siemens AG) used for pre-surgical scanning with a 32-channel RF head coil, and 2) a short-bore, 70cm wide intra-operative 1.5T Espree system (Siemens AG) equipped with an 8-channel intra-operative head coil (Noras) consisting of two surface coils covering the anterior and posterior regions of the head. During scanning the subjects' right hand fingers were passively flexed and extended at 1.5 Hz by an operator following a block design comprising 10 rest and 10 active blocks each of 16s duration. The fMRI data were acquired with the manufacturer's EPI sequence with the following parameters: TR|TE|BW=2260|30|2112 [ms|ms|Hz/Px] for the Trio and TR|TE|BW=3100|40|1446 [ms|ms|Hz/Px] for the Espree. Both protocols provide a spatial resolution of 3x3x3 mm^3 with 42 oblique axial slices along the AC-PC line. A B_0 field map and an anatomical T_1-weighted reference image were acquired on both scanners.

Data processing: The iMRI system design causes the patient's head position to fall partially in an area where the scanner gradients are non-linear, necessitating that, following field-map calculation, all 1.5T images be corrected for 3D gradient spatial non-linearity distortions [1] using in-house MATLAB code. Off-line distortion-correction was necessary because the scanner-based algorithms were not applicable to 4D EPI volumes or complex field map data. All data were processed with SPM12a (Wellcome Trust Centre for Neuroimaging, London): the EPI images were realigned and corrected for susceptibility-related distortion using a field-map approach. Data from both scanners were then co-registered to the mean 1.5T EPI image for that subject. The calculation of Bayesian posterior probability maps requires an estimate of the expected effect size, i.e., the percent BOLD signal change. The effect size was estimated for each subject with a semi-automated method based on the local standard for pre-surgical planning: a radiologist and a physicist experienced in interpreting pre-surgical fMRI data independently defined the activated functional motor cortex based on conventional inference statistics, providing a reference for the next step. The radiologist and physicist independently compared this reference map with Bayesian posterior probability maps (log base threshold 10), varying the Bayesian analysis effect size to provide as close a match as possible. Effect sizes were determined for the Trio data and then down-scaled for the Espree by 50%, since the BOLD signal change is expected to decrease by 50% going from 3T to 1.5T [2]. The final posterior probability maps were displayed as activated areas with aPPM=log(p/(1-p))(including activation and deactivation) and non-activated with nPPM=1-aPPM based on [3]. The threshold for a robust decision was set at the log base threshold of 10 for the Trio and 3 for the Espree due to the reduced contrast-to-noise ratio (CNR) at 1.5T.

Results: Visual comparison of the off-line corrected 1.5T images with the co-registered 3T data for all 10 subjects revealed no clinically-relevant anatomical mis-registration in the motor areas. The posterior probability maps for a representative subject are shown in Fig.1. The Trio map (left) shows a localized activated region (red) in the motor cortex and in the supplementary motor area. Non-activated regions are labeled green. The active areas were enclosed by an area which could not be robustly classified and thus was not labeled with a color. The corresponding Espree results (right) were less clear cut and major brain areas could not be robustly classified as either activated or not activated, presumably due to CNR limitations.

Discussion: Careful pre-processing of ifMRI and fMRI data from different MRI scanners made the data well comparable except for the CNR. We attribute this difference to the intrinsically lower BOLD sensitivity at 1.5T and the lower SNR of the surgical RF head coil. The Bayesian posterior probability maps proved very useful in defining activated and non-activated areas, corresponding to the expected functional neuroanatomy (mainly post- and precentral gyri contralateral to the flexed fingers). The value of the Bayesian activation maps was particularly evident in defining brain areas which could neither be classified as activated or non-activated. These maps reflected well the reduced CNR distribution in the 1.5T ifMRI data. The CNR limitation may be addressed in the future by a redesign of the surgical RF coil.

Conclusion: We achieved accurate alignment of fMRI data from two different scanners and field strengths, correcting for both susceptibility and gradient nonlinearity based distortions inherent in our intra-operative setup. The Bayesian activation maps promise to be very useful in defining activated and non-activated areas for neurosurgery. In particular, they inform the surgeon about areas where a robust decision cannot be made. We are planning patient studies to determine the clinical robustness and usefulness of the method.

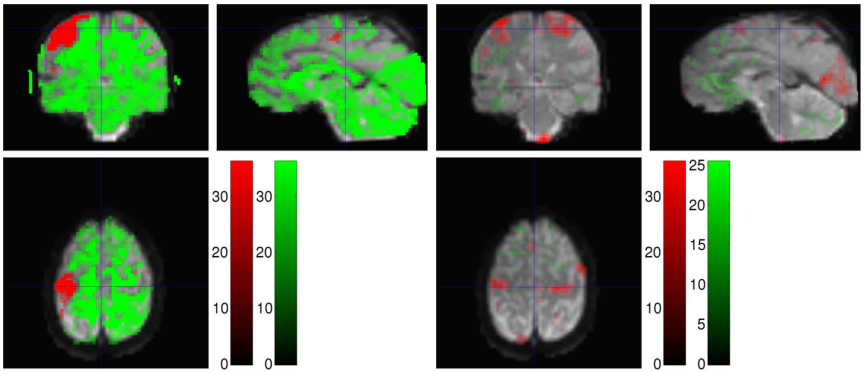

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Fig.1: Bayesian posterior probability maps of a right hand passive movement paradigm. At 3T (left) and from the 1.5T intra-operative system (right): activated regions = red; non-activated = green.