Evidence towards columnar organization of human area MT with sub-millimetric, 3D, T2 weighted BOLD fMRI at 7 Tesla.

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INTRODUCTION. Vision is the human's primary interface to the outside world. To build a coherent percept, the visual system must computationally solve the problem of recognizing objects and colors that can vary over space and time. One important requirement is therefore the understanding of the spatial relations of objects in the visual scene. However, since the visual scene rarely remains stable, it is of decisive importance to understand the information that is carried by the displacement of objects, or the displacement of ourselves making us perceive visual motion.
The superior temporal sulcus (STS) of the macaque monkey's brain contains a multitude of areas that have been found to be selective to visual motion [1 - 2]. In particular, while the columnar organization residing within the middle temporal (MT or V5) cortex of the monkey brain has been estimated to be around the size of 0.5 mm^2 [3], no evidence about the size and organization of these columns has been found in humans despite several attempts [4 - 5].
Here we provide direct evidence of columnar organization of direction selective features (DSF) in human area MT using spin echo BOLD based fMRI at ultra high fields (7 tesla) [6]. We demonstrate that the functional selectivity and sensitivity of high field high resolution SE BOLD fMRI is sufficient to resolve the fine grained organization of feature representations within higher level folded cortical areas.

MATERIAL AND METHODS. Measurements were performed at 7T (Siemens, Erlangen, Germany) using a custom 6 channel receive array, with elements (6 cm) distributed symmetrically along the right - left direction, and a separate open half-volume quadrature transmit coil to provide uniform excitation in visual areas. Five healthy volunteers (2 males, 3 females) without prior history of psychiatric or neurological illness as well as normal or corrected to normal visual acuity gave their informed consent and participated in the study. Motion direction preference was mapped using a T2 weighted high-resolution 3D GRASE sequence with inner volume selection [6] (TE = 40 ms, slices = 12, TR = 2000 ms; FOV = 25.6 × 204.8 mm^2; resolution = 0.8 × 0.8 × 0.8 mm^3). Stimuli consisted of dots moving coherently into one of 8 (0º, 45º, ..., 225º, 315º) randomly presented directions. Moving dot patterns were presented for 6 seconds followed by a variable inter trial interval (ITI) of 9-12 seconds to reduce BOLD carry over effects. A total of 24 trials per motion direction were obtained by randomly presenting each motion direction 4 times in 6 consecutive runs to reduce motion artifacts within the single runs. Coherent dot motion was chosen to maximize activity elicited by a single direction. Slice placement covered functionally localized human MT (low resolution gradient echo data acquired in a separate session) in one selected hemisphere of each subject (figure 1).

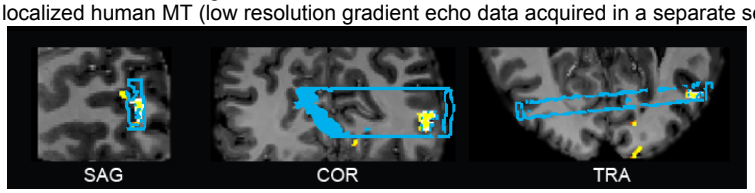

Figure 1

T1 and proton density weighted (3D-MPRAGE) (176 slices, FOV = 136 × 256 mm^2) anatomical data were acquired for each subject for visualization of the functional results [6]. Two subjects were removed from data analysis because of uncorrectable within-session head motion. All analyses were performed using BrainVoyager QX (Brain Innovation, The Netherlands) and custom software developed in Matlab.

RESULTS. Figure 2 shows the tuning characteristics of all voxel sharing the same preferred motion direction for all analyzed subjects. A characteristic peak at the preferred pair of opposing motion directions can be observed in all subjects. Consistency of the measured selectivity was evaluated using cross-validation and permutation testing. Of all 1343 analyzed voxels in our subjects only 8.7 % (115 voxels) fall within the chance level consistency distribution. The vast majority of voxels therefore have a high degree of consistency and the labeled opposing motion direction forms a highly reliable estimate of the voxels underlying neuronal tuning properties.

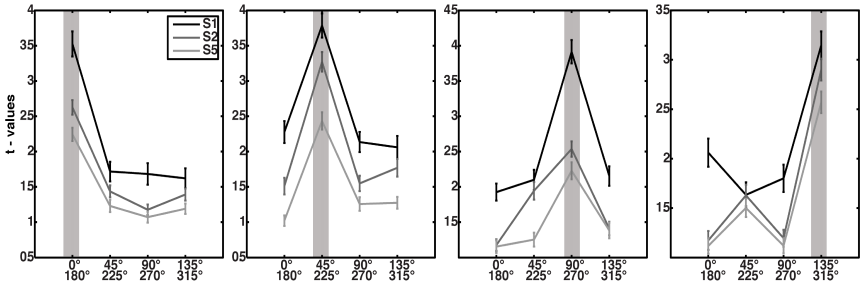

Figure 2

Mapping of opposing motion direction tuning was performed using a novel cortical depth sampling approach that is based on preprocessing steps used in cortical thickness measurements [7]. Based on this preprocessing step, functional data can be sampled at any specified cortical depth on a grid with equidistant points to obtain results sensitized to different cortical laminae. To sample the co-registered individual DSF maps, high-resolution cortical grids were created at three depth planes covering the entire subjects MT ROI. Figure 3 shows the results of the high-resolution cortical grid sampling for subject S1 at three relative cortical depth levels (0.2, 0.5, 0.8) with a geodesic size of 78.12 mm^2 (12.4 mm anterior-posterior × 6.3 mm inferior-superior). Visual observation reveals an arrangement of smooth varying gradients of opposing motion direction tuning *within* the cortical plane. Further, an equally important finding is that this topographical columnar organization also extends relatively smoothly *through* the sampled cortical layers, by sharing similar opposing motion direction preferences vertically.

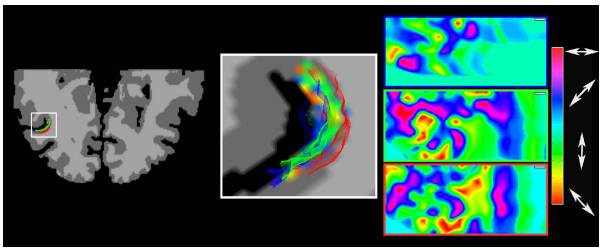

Figure 3

DISCUSSION. Our results can be seen as first direct evidence of a systematic organization of directional motion tuning in human area MT that is comparable to results obtained with invasive techniques on the monkey brain [3]. Additionally, in a novel demonstration, we have successfully mapped this columnar organization in 3D with respect to cortical depth and curvature. By combining ultra high field 3D SE BOLD imaging and advanced analysis methods we demonstrate that columnar level functional mapping [8] can be extended to higher order functional areas characterized by a convoluted geometry.

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