

The hand representation in the human cerebellum overlaps with the digit representations

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Introduction Although the cerebellum forms an important part of the motor/somatosensory feedback loop and plays a vital role in motor control, it is often ignored in fMRI studies because of its small size and high inter-subject variability. Detailed knowledge of the somatotopic body representations in the cerebellum could be very useful to motor control studies in addition to information from lesion studies¹. The aim of this study was to map the representations of individual digits in the human cerebellum using a natural stimulus. To distinguish between digits, the high spatial resolution and BOLD sensitivity available at 7 Tesla were employed. To retain spatial resolution, data analysis was performed separately for each individual brain.

Methods Six male, righthanded subjects were scanned on a head-only 7T scanner (Siemens Medical Solutions, Germany) with a purpose-built tranceive surface coil. 1.2*1.2*1.2 mm³ resolution fMRI data were acquired using a sinusoidal readout EPI sequence² and FOV=154*154mm, TE/TR/α=27ms/2.5s/60°. One volume contained 36 coronal oblique slices covering the cerebellum. 0.85*0.85*0.85 mm³ anatomical data were acquired using the MP2RAGE sequence³ (TE/TI_{1,2}/TR_{mpage} = 3.75ms/0.7,2.2s/5s). Subjects were positioned supine in the scanner with their right arm comfortably extended. An experimenter was positioned at the entrance of the bore where he could easily reach and stroke two distal phalanges of a digit (one at a time). E-prime was used to cue the experimenter via MR-compatible headphones (NNL, Norway). The order of digits being stroked was D1-D3-D5-D2-D4, with 20s ON, 10s OFF alternated. Two functional runs of 10 minutes each were acquired per subject. A third functional run was acquired during which the right palm and forearm were alternatively stimulated for 20s ON, followed by 10s of rest.

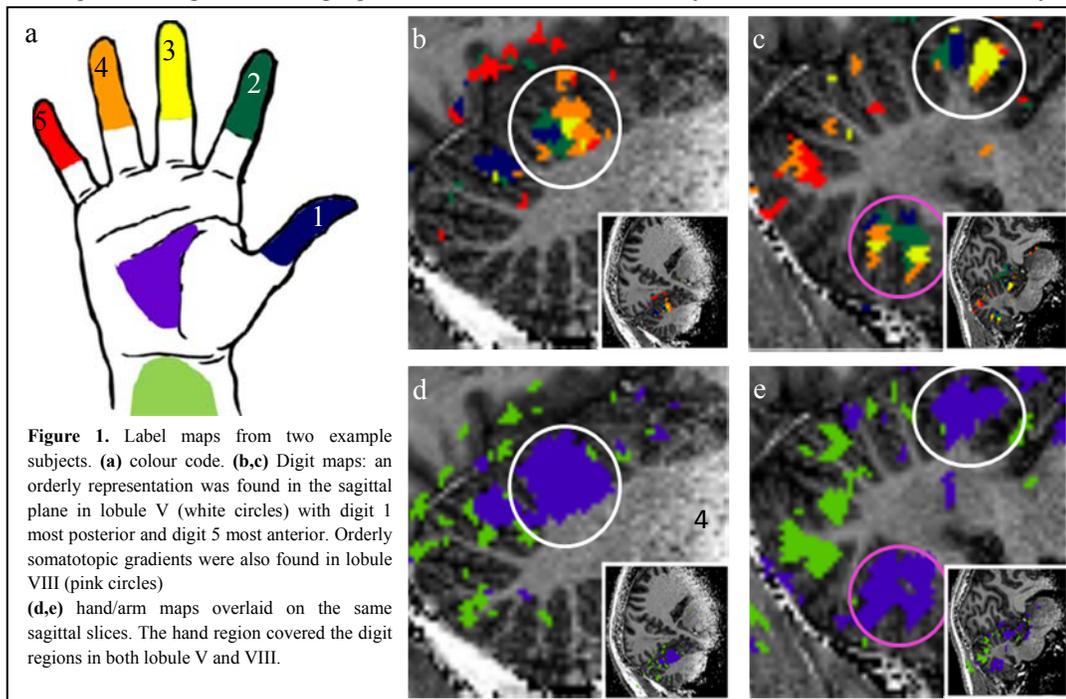


Figure 1. Label maps from two example subjects. (a) colour code. (b,c) Digit maps: an orderly representation was found in the sagittal plane in lobule V (white circles) with digit 1 most posterior and digit 5 most anterior. Orderly somatotopic gradients were also found in lobule VIII (pink circles) (d,e) hand/arm maps overlaid on the same sagittal slices. The hand region covered the digit regions in both lobule V and VIII.

Data was processed using SPM8. After realignment, smoothing (FWHM 1.5mm) and co-registration of the anatomical and fMRI data, a mask for the digit region was obtained via an F-contrast ($p < 0.001$) over all digits. Within the mask, voxels were labeled with the number (Fig 1a) of the digit with the highest t-value for the voxel. Hand/arm maps were generated separately with an identical procedure.

Results For all six subjects, areas corresponding to the five digits were identified in ipsilateral lobule V. The thumb, D1, was located most posterior/medial and D5 most anterior/lateral. Areas were small and varied in size (220 ± 45 mm³), with a Euclidian distance of 3.0 ± 0.3 mm between centers-of-mass of digit representations. No significant contralateral activation was

detected. Four out of six subjects showed in addition activation in lobule VIII, which was smaller than in lobule V (110 ± 20 mm³). Three of those four subjects displayed an orderly somatotopy, although the orientation of the somatotopic gradient differed between subjects. Two subjects displayed a superior-inferior orientation (as in Figure 1c), while the third showed an inferior-superior orientation. The hand region (1250 ± 300 mm³ in lobule V and 320 ± 70 mm³ in lobule VIII) covered the digits area for all subjects, in both lobules V and VIII. Mostly scattered voxels were found for the arm, although a small region posterior and medial to the hand area was detected in three volunteers, in agreement with the literature¹.

Discussion and Conclusion The small distance between cerebellar digit representations highlights the need for high spatial resolution in somatotopic mapping. However, even with the current spatial resolution, orderly somatotopic maps of the digits and hand were found in lobules V and VIII of the cerebellum. The general topography of the digit representations in individual subjects in lobule V corresponded well to a previous group study which used lower spatial resolution data and a multivariate data analysis⁴. The strong inter-subject variability in cerebellar anatomy may explain the diverging results found in lobule VIII. The overlap of hand and digit regions was threshold independent. Hand regions covering and incorporating the digit regions have also been found in the primary motor cortex in humans⁵, and these data suggest that a cerebellar equivalent exists.

We conclude that (1) the increased BOLD sensitivity at 7T and the high spatial resolution used in this study allow somatotopic mapping of the individual digits in the human cerebellum and the (2) the hand representation in the cerebellum incorporates the digit representations in both lobules V and VIII.

References and acknowledgements ¹Manni et al, 2004, Nature Reviews. ²Speck et al, 2008, Magma. ³Marques et al, 2010, NeuroImage, ⁴Wiestler et al, 2011, J Neurophysiol, ⁵Meier et al, 2008, J Neurophysiol. This work was supported by the Centre d'Imagerie BioMédicale of the UNIL, UNIGE, HUG, CHUV, EPFL and the Leenaards and Jeantet Foundations.