Somatovisual processing in the deep layers of the human superior colliculus

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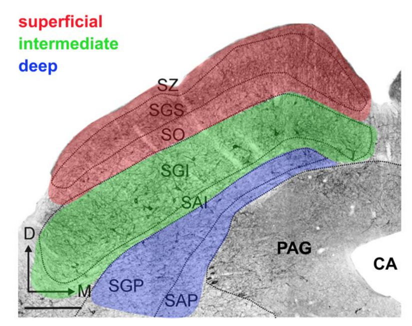
Motivation

The deep layers of superior colliculus (SC) integrate sensory information from multiple modalities to create a coherent sensory representation of the world [1,2].

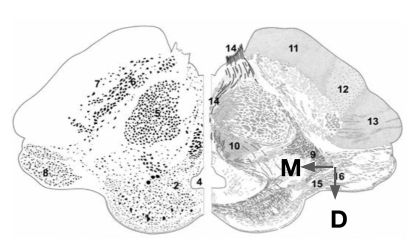
However, information about the human SC is limited due to the technical challenge of imaging small structures deep within the cranium [3].

Advances in ultra-high field MRI enable imaging with greater signal-to-noise ratio in smaller voxels, allowing us to probe functional responses deep within SC [4].

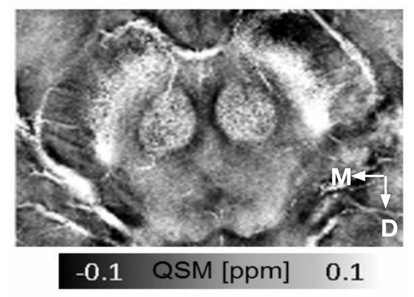
To understand how human SC integrates information across somatosensory and visual modalities, we utilized functional MRI (fMRI) at 9.4T during an integration task.



Bajo et al. (2010)



Nieuwenhuys et al. (2008)



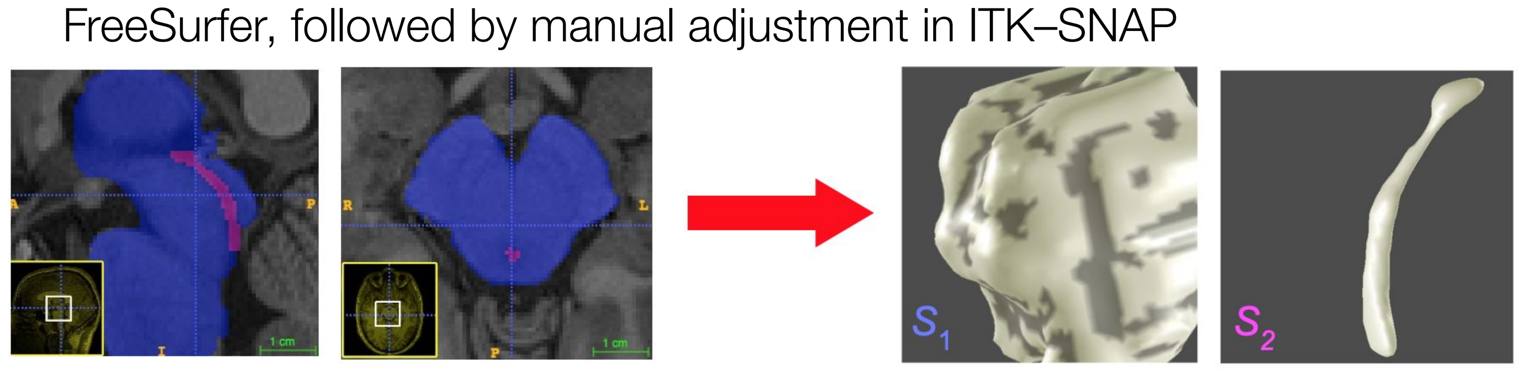
Loureiro et al. (2018)

Somatovisual integration task

- Air puffs delivered to participants' fingers cued them to attend (but not saccade) to a quadrant of the visual field
- Single air puffs were continually presented in alternation to the index and ring fingers
- Randomly timed double air puffs cued the subject to attend to the upper (via index finger stimulation) or lower (via ring finger stimulation) visual fields
- Participants counted the number of "+" signs that appeared in dot patterns in the cued quadrant while ignoring "X" and other random patterns
- Stimulation alternated between left and right hands (cuing left and right visual fields) every 15 s, enabling sinoidal data analysis
- In one participant, a second session used a visually cued paradigm with no tactile stimulation, allowing us to compare visual-only to somatovisual collicular processing

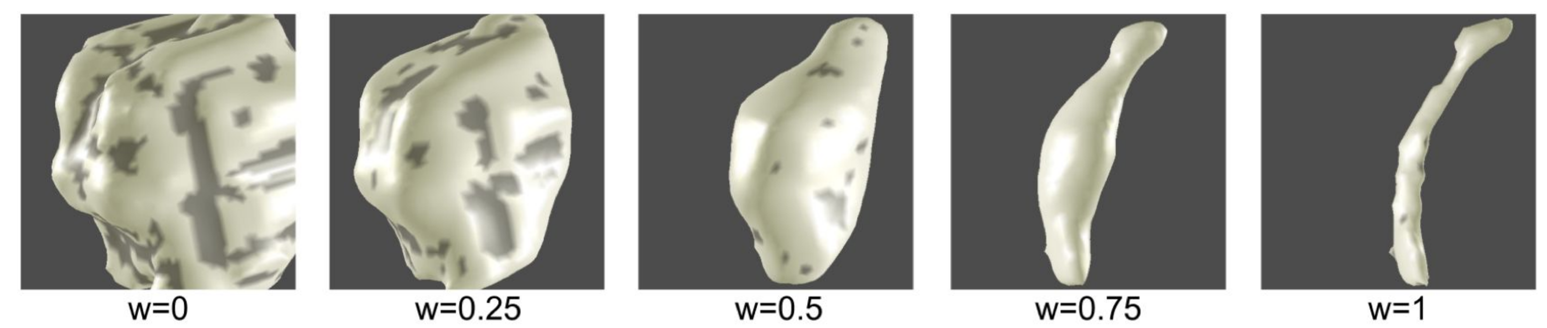
Image acquisition and preprocessing

- Acquired ultra-high field 9.4 Tesla MRI in 7 participants
- High-resolution (0.6-mm voxels) T1-weighted MRI provides detailed structural brain anatomy
- Functional MRI (point-spread function-corrected EPI; TR = 1.25 s) collected with 1 mm isotropic voxels over 26 slices, covering the colliculi and most of early visual cortex
- Brain regions initially segmented from the T1-weighted images using FreeSurfer, followed by manual adjustment in ITK–SNAP

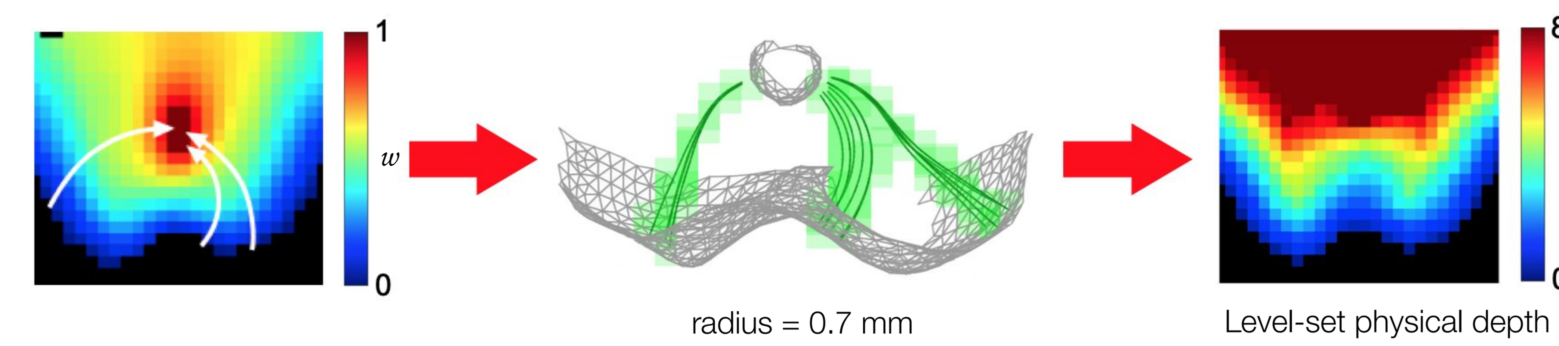


Generating streamline depth kernels

To quantify depth within the colliculi, we needed a robust representation of midbrain depth. We used a level-set algebraic approach [6] to map distinct points between the outer (collicular) and inner (cerebral aqueduct) surfaces of the dorsal midbrain with a normalized depth, w [7].



Surfaces of constant w smoothly morph from colliculus to cerebral aqueduct

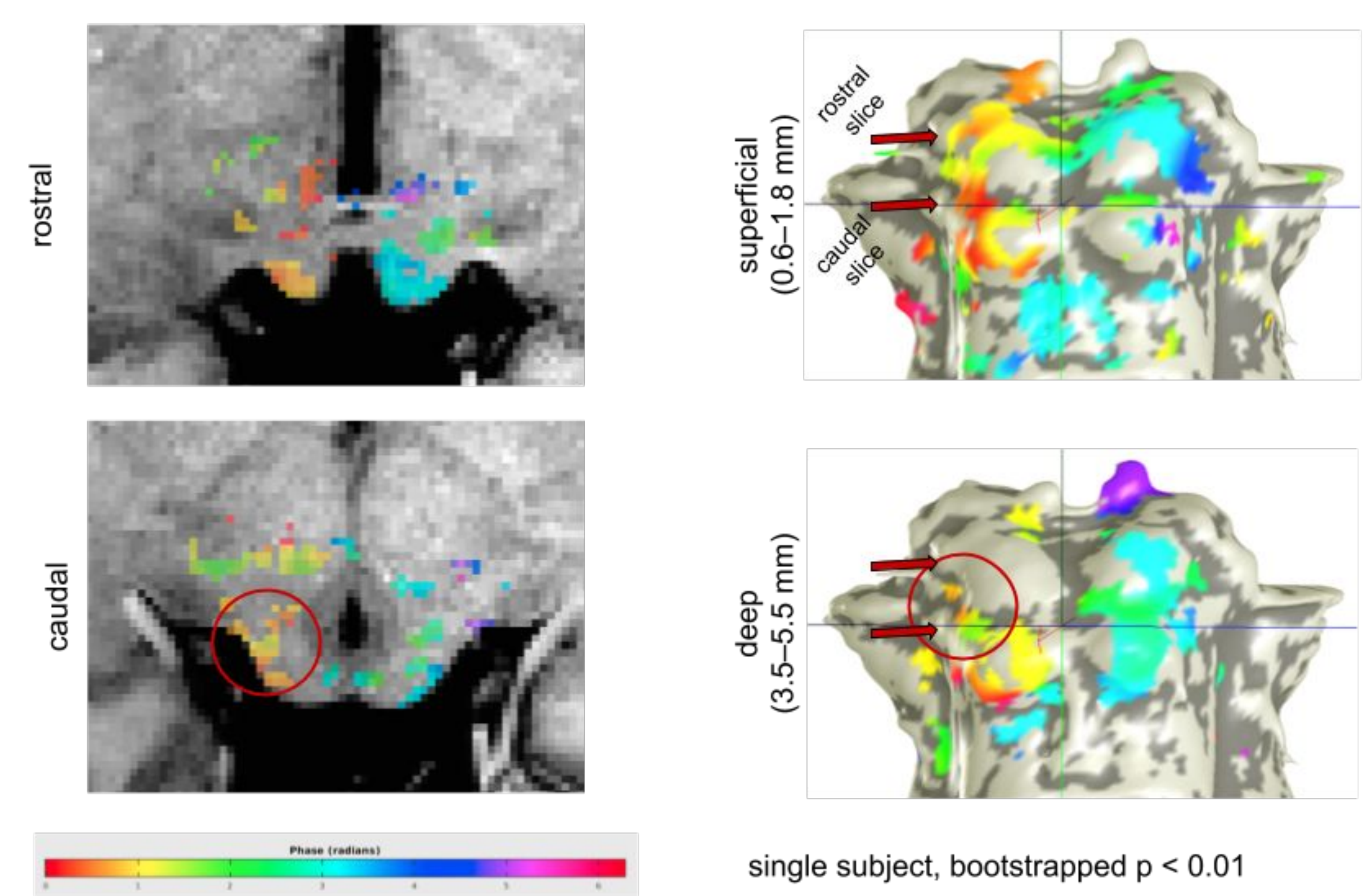


Ray tracing of ∇w from w=0 (brainstem) to w=1 (aqueduct)

Resample streamlines (dark green) to spatial resolution of data (light green)

Interpolate integrated path distance onto volume

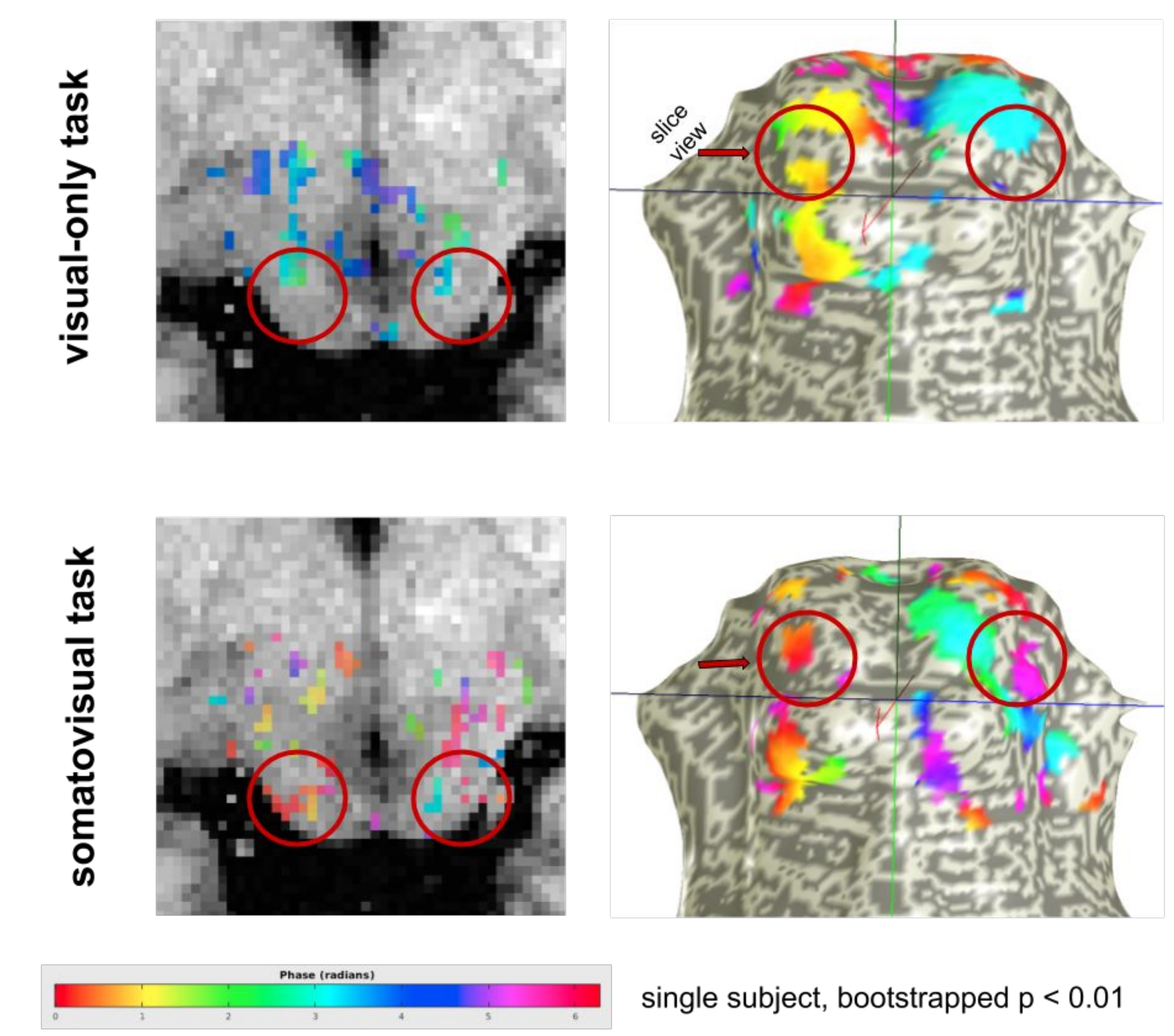
Somatovisual integration in deep superior colliculus



Depth-averaged phase values at two collicular depths (**hot** = early; **cool** = late; bootstrapped p < 0.01) at rostral and caudal levels of the superior colliculus in one participant.

Note the BOLD activation in the deep layers at the caudal level of the SC during the somatovisual task, in line with predictions from previous studies using invasive electrophysiology in mice [8].

Task dependence of deep caudal superior colliculus



Task-dependent phase coherence in deep caudal superior colliculus (projected to the collicular surface) shows areas with greater activation during somatovisual stimulation than visual-only stimulation.

Future directions

Using high resolution fMRI, we identified regions in SC that respond to somatovisual integration. These correspond to deep layers of the SC, which are believed to represent multisensory information onto a visuotopic map.

Overall, we found that ultra-high field fMRI is sensitive to somatosensory integration in deep layers of human SC, which to this point has only been accessible in animal models.

Using these methods, we will next ask:

- Does audio-visual integration in the superior colliculus use the same visual field maps as somatovisual integration?
- Are coordinate representations in SC visuotopic or body-centered?
  - If we alter the stimulation location, how does the locus of activation in the superior colliculus change?
  - How do the multisensory representations change when hand position is altered?

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