Cortical and subcortical proprioceptive contribution to oculomotor control in humans

D. Balslev[1], G. A. Keith[2], R. Hardaker[3], F. Crabbe[3], and A. Fracasso[3]

[1]School of Psychology and Neuroscience, University of St. Andrews, Scotland, UK [2]Imaging Centre of Excellence, University of Glasgow, Scotland, UK [3]School of Psychology and Neuroscience, University of Glasgow, Scotland, UK

SUMMARY

- **With 7T fMRI we identified cortical and subcortical somatosensory (ocular proprioceptive) activation in the oculomotor network.**
- **The study supports a role of proprioception in the control of eye movements**
- **We demonstrate the feasibility of brain + brainstem data acquisition at 7T**

Background

Accurate vision requires precise control of eye position. The extraocular muscles (EOM) have stretch receptors that inform the central nervous system about the rotation of one's own eyes in the orbits. Unlike the skeletal muscles where the role of proprioception in the fine control of movement is clear, the role of proprioception in the control of eye movements has been questioned.

Behavioural studies in humans support such a role[1-3], however, behavioural and electrophysiological studies in the macaques do not[4-6]. Unlike macaques[7], humans possess numerous muscle spindles in their EOMs[8]. Because of this difference in anatomy, a difference in function can be presumed.

To find out whether the human oculomotor network responds to proprioceptive feedback we used fMRI.

Data acquisition was optimised for parallel brainstem and brain imaging, while the behavioural task was identical to that used to map the oculoproprioceptive projection in previous fMRI studies that focused on either the brain[9] or brainstem[3].

References

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Methods

Behavioural Tasks

1.Passive (when cued by a sound, the participant pushed briefly the right eyeball medially with their right index finger which touched the eyelid at outer canthus). Components: passive eye movement (proprioception), finger movement, eyelid cutaneous stimulation

2. Touch (when cued by a sound, the participant touched the eyelid at the same location without moving the eyeball.) Components: cutaneous eyelid stimulation, finger movement.

3. Active (when cued by a sound, the participant moved both eyes to one side and back) Components: active eye movement (proprioception and ocular motor command), inner eyelid stimulation

4. *Rest* (the participant listened to sounds)

Contrast

Eye proprioception= (*passive – rest*) AND (*active – rest*) NOT (*touch – rest*)

Design

Trials of the same type were grouped in blocks (1 block= 25 seconds). Each block started with a verbal instruction presented in headphones. The onset of a trial was cued by a sound. There were 24 blocks/run. The order of the 4 blocks was randomised, and the same sequence was repeated throughout the run e.g. PTARPTAR…). The order was counterbalanced across participants.

Participants

6 healthy, right-handed.

Data acquisition

7T Siemens MAGNETOM Terra
Head coil Nova Medical 1Tx, 32RX
Functional data were acquired using a multi-band 2D EPI sequence[10], optimized to focus on subcortical activation[11].
We also acquired a high-resolution MP2RAGE structural and short 2D-EPI scan with opposite phase encoding to correct for nonlinear geometric distortions.

	TR/TE (ms)	Image resolution (mm^3)	Acceleration	Slices	Flip angle (°)	BW/px (Hz)	Other	Acq. Time (mm:ss)
Dist. Corr.	2500/17	2*2*2	MB 2	62	72	1796	20 dynamics, PE: **R>>L**	01:11
2D EPI	2500/17	2*2*2	MB 2	62	72	1796	144 dynamics, PE: **L>>R**	06:21
MP2RAGE	4680/2.07	0.6*0.6*0.6	GRAPPA 3	256	5.0/6.0	250	TI1 840 ms, TI2 2370 ms	11:11

Statistical analysis *(SPM12)*

Random effects analysis: conjunction (*passive – rest*) **AND** (*active – rest*) threshold $p<0.05$ FDR **corrected** masked exclusively with (*touch – rest*) at $p<0.05$ uncorrected (whole brain and brainstem analysis).

Results

Subcortical

The stretch of the right lateral rectus muscle was associated with suprathreshold activity not only in the somatosensory but also in the oculomotor network. In the brainstem we found a response to proprioceptive stimulation in the left abducens and left trigeminal nucleus which connect with the extraocular muscles of the left eye. This confirms previous findings at 3T[3,7].

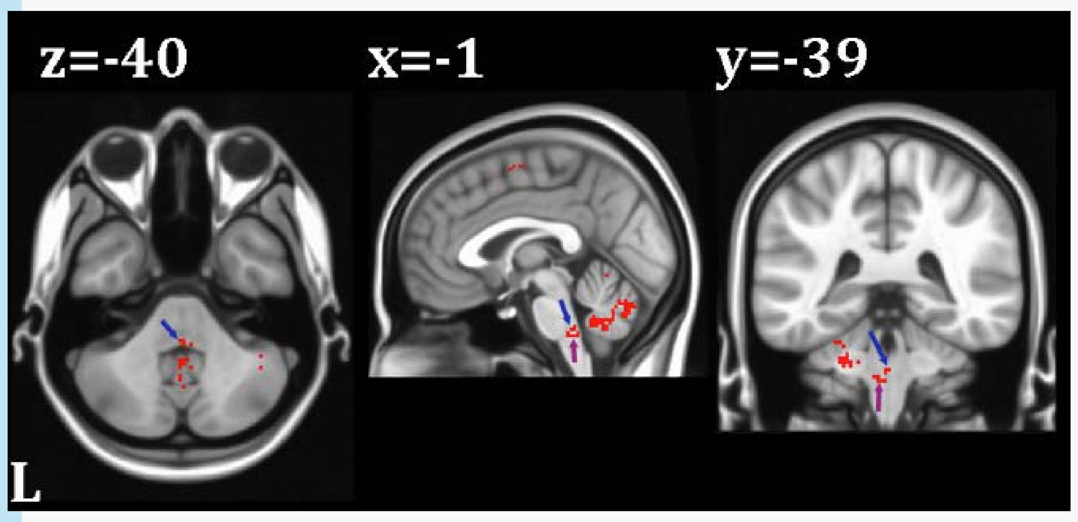

Figure 1. Subcortical ocular proprioceptive projection. Statistical parametric map for the conjunction (see Methods) on MNI template (ICBM) shown in three orthogonal projections through the left abducens nucleus (x, y, z) = (-1, -39, -40). **Blue arrows:** left abducens nucleus; **Purple arrows:** left spinal trigeminal nucleus. Anatomical localisation using Duvernoy atlas[12] and published MNI coordinates[13-15].

Cortical

We replicated the cortical activation identified previously and found additional foci in (oculo)motor structures, such as cerebellum and supplementary eye fields

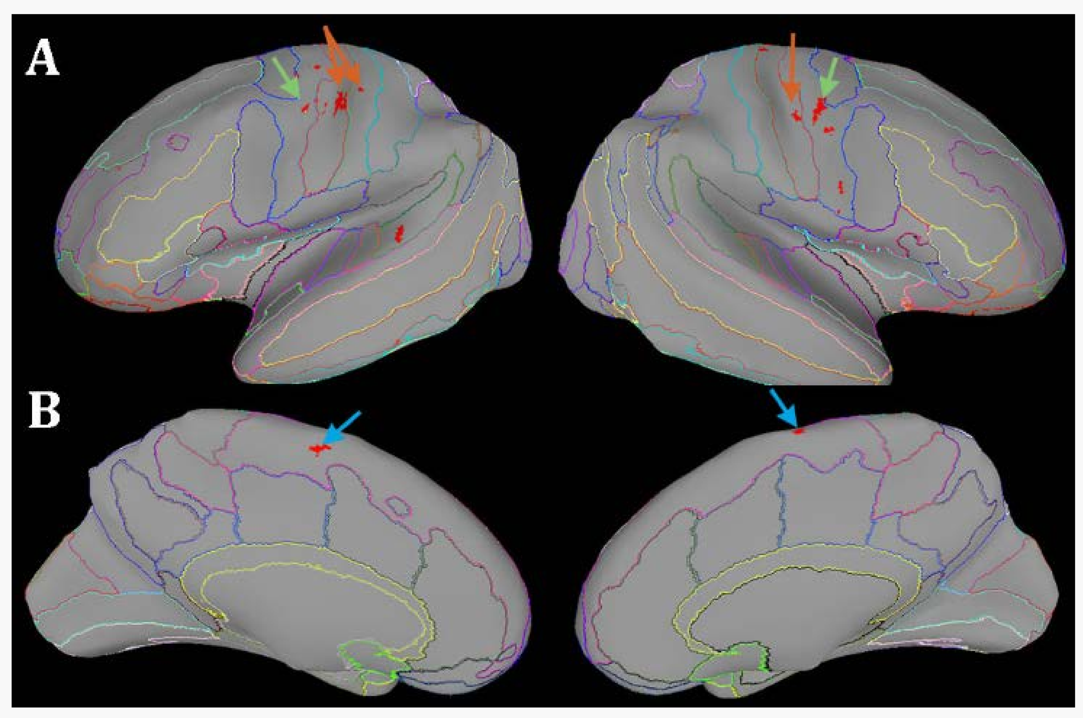

Figure 2. Cortical ocular proprioceptive projection. Statistical parametric map for the conjunction superimposed on an inflated MNI template. **A.** Lateral view **B.** Medial view. **Blue arrows:** Supplementary Eye Field; **Orange arrows:** Central sulcus- Area 3a/Postcentral gyrus – Area 2; **Green arrows:** Frontal Eye Field. Anatomical labels are according to[16-17].