Independent sources of spontaneous BOLD fluctuation along the visual pathway

* Jacco.deZwart@nih.gov

Jacco A. de Zwart*, Peter van Gelderen, Zhongming Liu, Jeff H. Duyn

Advanced MRI section, LFMI, NINDS, National Institutes of Health, Bethesda, MD, USA

Advanced MRI

Introduction

BOLD fMRI experiments of spontaneous brain activity in humans have generally found inter-hemispheric correlation between homologous regions. Reduced correlation with compromised or absent callosal fibers suggests the importance of a direct neural connection [1,2], although this may not always be the case [3]. In addition, subcortical areas could affect the observed cortical correlations. To investigate this, we studied spontaneous activity in the human visual system, including visual thalamic areas such as lateral geniculate nucleus (LGN), that have no direct inter-hemispheric connections, to investigate how this network behaves in absence of stimuli.

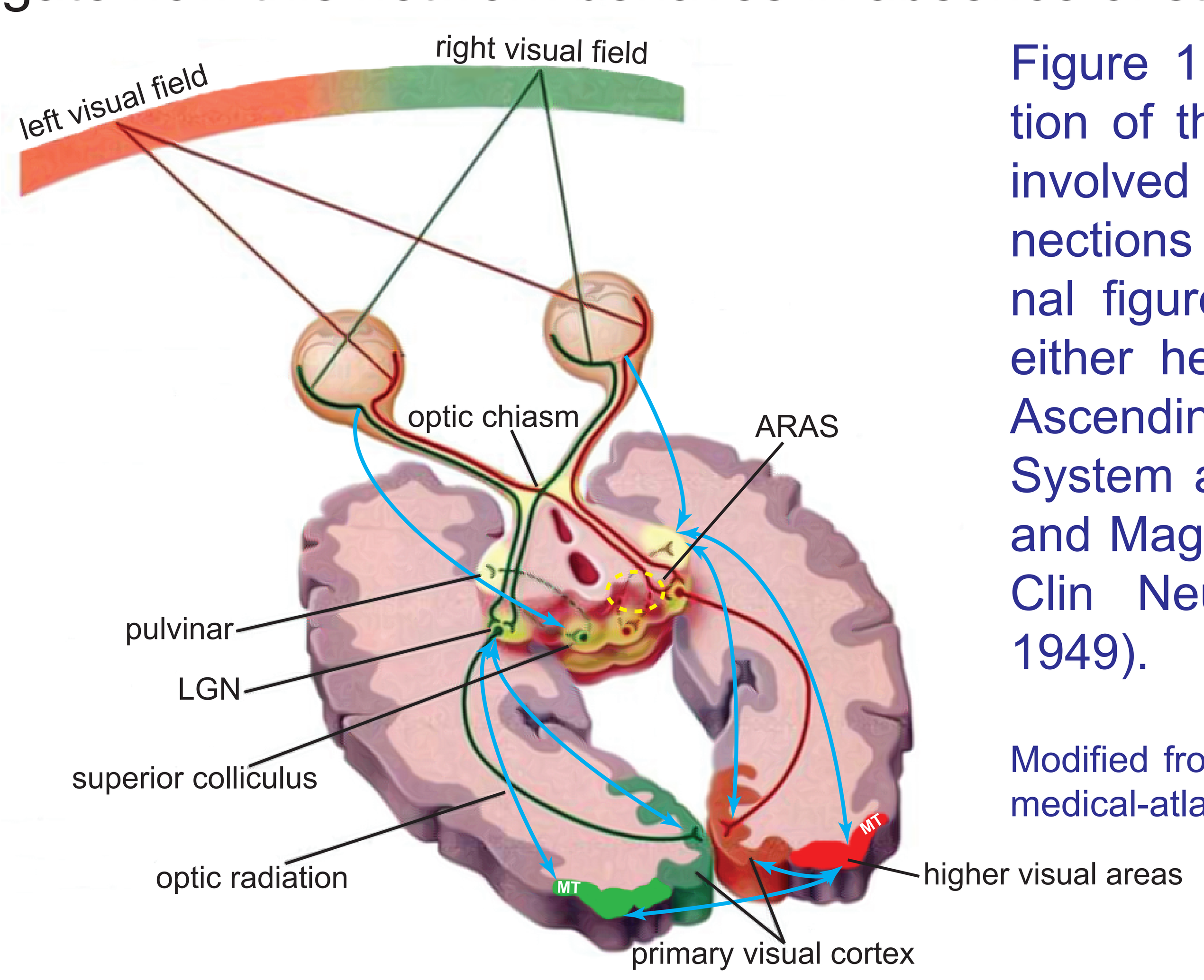

Figure 1: Schematic representation of the neuronal connections involved in human vision. Connections not present in the original figure are shown in blue in either hemisphere. ARAS is the Ascending Reticular Activation System as described by Moruzzi and Magoun (Electroencephalogr Clin Neurophysiol 1, 455-473, 1949).

Modified from http://www.edoctoronline.com/medical-atlas.asp?c=4&id=21964 after permission was requested.

Methods

Volunteers were scanned at 7 T: 5-min localizer block paradigm; 2 min eyes-open rest; 5-min eyes-closed (EC) rest. (See abstract for scan parameters.) The localizer (30/30-s on/off, 7.5-Hz full-field checkerboard) was used to identify left (L) and right (R) LGN and visual cortex (VIS). VIS ROI was split along brain midline. Image registration and physiological noise reduction (RETROICOR; cardiac & respiratory rate) was followed by cross-correlation (CC) of ROI-averaged temporal signal. ROIs of 3x3x3 voxels were placed in other thalamic nuclei of interest (e.g. Fig 1) based on an anatomical atlas [4].

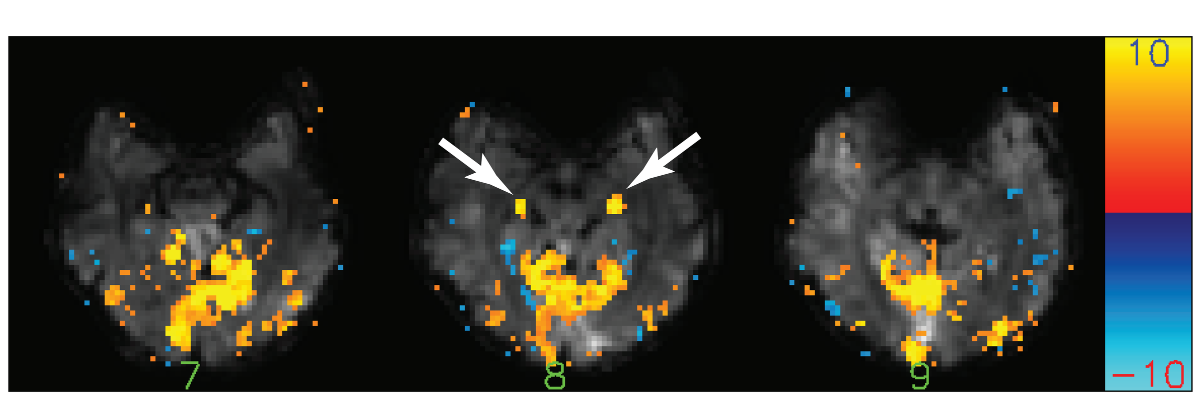

Figure 2: Example activation map for three slices of one volunteer. Arrows highlight bilateral LGN activation. Significance threshold: 4.96 ($p<0.05$ corrected).

Results

Fig 2 shows an example activation map for 3 slices of one volunteer. CC analysis showed that: 1) Significant CC between L and R VIS (0.95) exists during rest (Tab 1), as well as between L and R LGN (0.39), even though no known direct connection exists between LGNs. 2) Regression-based exclusion of VIS signal from LGN and vice-versa shows persistence of these correlations (Tab 1).

state	regressed out	cross correlation (SE over n=8)		
		$CC(LGN_L,LGN_R)$	CC(LGN,VIS)	$CC(VIS_L,VIS_R)$
EC rest	-	0.39 (0.07)	0.29 (0.07)	0.95 (0.01)
	VIS (from LGN)	0.35 (0.06)	-	-
	LGN (from VIS)	-	-	0.85 (0.03)
task	-	0.67 (0.07)	0.72 (0.04)	0.98 (0.00)
	VIS (from LGN)	0.36 (0.08)	-	-
	LGN (from VIS)	-	-	0.65 (0.03)
	paradigm	0.50 (0.07)	0.50 (0.05)	0.96 (0.00)
	$VIS_{avgresp}$ (from LGN)	0.49 (0.08)	0.25 (0.03)	-
	$LGN_{avgresp}$ (from VIS)	-	0.28 (0.03)	0.83 (0.03)

Table 1: Cross-correlation between nodes during rest and task. Signals listed in column 2 were regressed out to investigate partial correlation, yielding findings supported by the partial correlation coefficients (Fig 4).

Simulations indicate that this can be due to a bilateral LGN signal independent from VIS (e.g. input from retina or brain stem) and/or a signal in VIS not present in LGN. Global signal fluctuations or differences in SNR or fluctuation level were not the source of these findings. Other thalamic nuclei were investigated, some with no known involvement in vision (thalamic reference ≈ ventral medial nucleus), and Insula as a cortical reference (Tab 2). The inter-regional partial correlation matrix [5] was also computed (Fig 4). Pulvinar (higher-order visual area) and mediodorsal nucleus (alertness) showed coherences with LGN and VIS. Note that negative CC between thalamus and VIS, described previously [6], was not found here. Brain stem involvement (e.g. superior colliculus) needs to be further investigated.

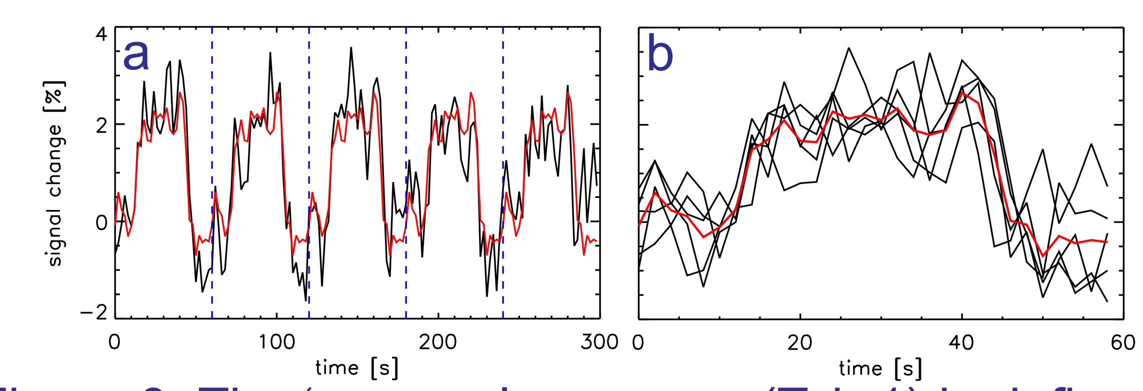

Figure 3: The 'avgresp' regressor (Tab 1) is defined by taking the mean ROI time course (e.g. in VIS, black in a), splitting it in the 5 task blocks (b, black), computing the mean (b, red) and repeating this 5 times (a, red).

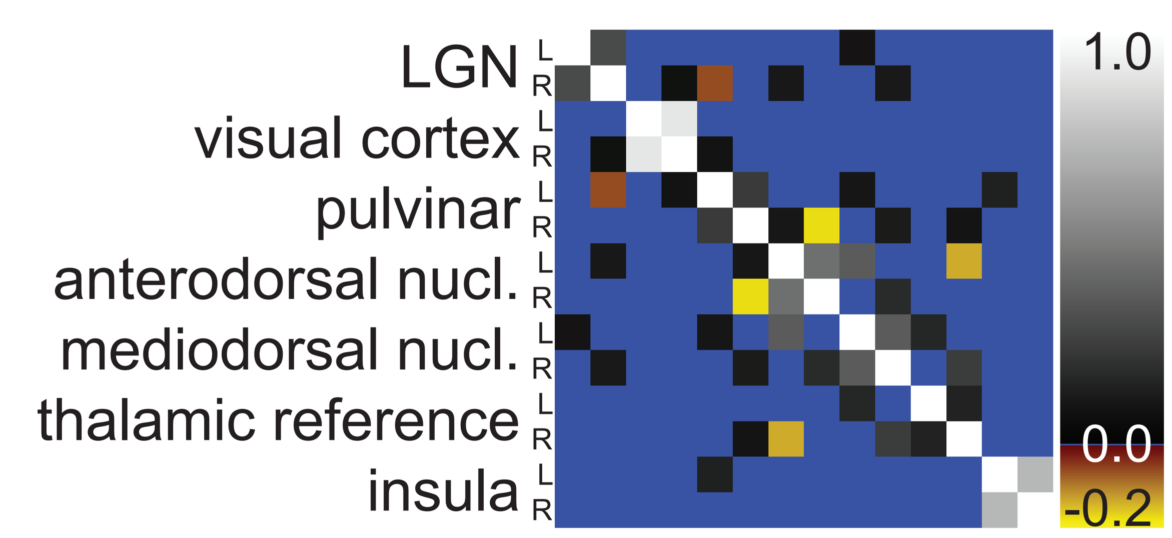

Figure 4: Inter-regional partial correlation matrix for all regions studied. (Partial correlation values in blue-shaded elements were not significant.)

SIG	cross correlation (SE over n=8)		
	$CC(SIG_L,SIG_R)$	CC(SIG,LGN)	CC(SIG,VIS)
LGN	0.39 (0.07)	-	0.29 (0.07)
visual cortex	0.95 (0.01)	0.29 (0.07)	-
pulvinar	0.42 (0.05)	0.23 (0.06)	0.37 (0.03)
thalamic reference	0.30 (0.07)	0.16 (0.06)	0.12 (0.07)
insula	0.82 (0.03)	0.09 (0.08)	0.47 (0.06)
anterodorsal nucleus	0.58 (0.10)	0.14 (0.04)	0.14 (0.10)
mediodorsal nucleus	0.65 (0.07)	0.31 (0.05)	0.20 (0.08)

Table 2: Correlation of various thalamic areas (and insula, as cortical reference) with VIS and LGN.

Conclusion

Correlated spontaneous activity exists between all visual system nodes studied, including those without monosynaptic connections. Correlations between bilateral LGN did not entirely arise from bilateral VIS activity or vice versa, suggesting that other pathways contribute to these. Potential contributors are other nodes of the visual pathway, either upstream or downstream from the areas studied.

References

[1] Johnston, J Neurosci 2008:28, 6453
[2] Quigley, Am J Neuroradiol 2003:24, 208
[3] Tyszka, J Neurosci 2011:31, 15154
[4] Morel 2007, Stereotactic atlas of the human thalamus and basal ganglia
[5] Salvador, Cereb Cortex 2005:15, 1332