The Vestibulocerebellum: New Insights from Large Resting State Connectivity

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Introduction

The parts of the cerebellar cortex that interact with the vestibular system are thought to compute an "internal model" of the expected sensory consequences of self-motion. Mismatches between actual and expected vestibular signals is required for the control of posture and awareness of self-motion.

Axonal fibre tracing studies in animal models have shown that tracer injections in the vestibular nuclei result in dense labelling of Lobules IX and X, often collectively referred to as the "vestibulocerebellum".

Figure 1: Tracers were injected into the semicircular canals. Large portions of primary vestibulocerebellar fibers terminated in the lateral vestibular and ventral uvula (Lobules IX and X).

The Vestibular Cortex

In animals, a network of neocortical areas including the parietoinsular vestibular cortex (PIVC) contains neurons that respond to vestibular stimulation. A meta-analysis of 28 human neuroimaging studies identified a number of homologous cortical areas that respond to vestibular stimulation (e.g. GVS and CVS) (see Figure 2). However, their relationships with the vestibulocerebellum, or wider parts of the cerebellar cortex, remain unknown.

We used resting state fMRI data to map the connectivity between the vestibular cortex and the cerebellar cortex. We tested the hypothesis that each element of the cortical vestibular network influences activity in Lobules IX and X. We further explored the influence of the cortical vestibular system beyond these areas.

Methods

Timecourses from thirteen vestibular cortical coordinates were extracted and used as seeds of interest. We used rs-fMRI data from the Cam-CAN Data Repository. Seed-to-voxel analysis was conducted on 514 human subjects using the CONN Toolbox and SPM12.

EPI scans were realigned, normalised to the MNI template, smoothed with a Gaussian kernel of 4mm and the time courses denoised.

Time courses were used to construct general linear models (GLMs) for each subject.

Results

Correlated and anticorrelated activity of each vestibular cortical seed was identified using t contrasts (FWE, p<0.05 corrected).

A conjunction analysis was performed across all the vestibular cortical seeds to identify common influence in the cerebellum (FWE, p<0.05 corrected).

Within Lobules IX and X, no voxels were commonly influenced. However, there were statistically significant conjunctions in Lobule HVIIA (Crus I and Crus II) for areas showing anticorrelations. We infer that these parts of the cerebellar cortex come under the common influence of all cortical vestibular seed locations.

Hierarchical Clustering was applied to 38 approximately evenly spaced voxels in Lobules IX and X and the 13 cortical vestibular seed voxels to identify cortico-cerebellar vestibular networks. Note: clusters are displayed at an uncorrected threshold.

Figure 3: Activity of each vestibular cortical seed mapped onto cerebellar flatmaps. Positively correlating activity is marked in red, and blue represents anticorrelated activity.

No positive connectivity was found between Lobules IX and X and the vestibular cortical seeds. Activity in most vestibular cortical seeds was anticorrelated with parts of Lobules IX and X.

Figure 4: Conjunction of anticorrelated activity across all vestibular cortical seeds mapped on a cerebellar flatmap.

Figure 5: (A) Four neocortical areas (BA6, PF, OP4 and Central Insula) appear to exhibit correlated activity with a set of four voxels in Lobule IX, while at the same time showing anticorrelated activity in another seven. An additional anticorrelated voxel was identified in the vestibulocerebellar hierarchical clustering. (B) These two sets of cerebellar voxels appear to be located in segregated areas of Lobule IX.

Summary

Lobules IX and X showed consistent patterns of anticorrelated activity with vestibular cortical seeds. Surprisingly, Lobules IX and X did not appear to be commonly influenced by parts of the cortical vestibular network. Hierarchical clustering revealed a subcomponent of the cortical vestibular system in which activity is correlated with one part of Lobule IX, while being anticorrelated with another.