Dissociable Prefrontal-Cerebellar Networks Underlying Executive Function: Evidence from Resting State Functional Connectivity in the Human Connectome Project

Joseph M. Orr*[a,b], Trevor B. Jackson[a], Michael J. Imburgio[a] & Jessica A. Bernard*[a,b]

[a]Department of Psychological and Brain Sciences,

[b]Texas A&M Institute for Neuroscience,

Texas A&M University

College Station, TX 77843

*Corresponding Author:

Joseph M. Orr or Jessica A. Bernard

515 Coke Street

4235 TAMU

College Station, TX 77843-4235

Email: joseph.orr@tamu.edu or

jessica.bernard@tamu.edu

Abstract

To date, investigations of executive function (EF) have focused on the prefrontal cortex (PFC), and prominent theories of EF are framed with respect to this brain region. Multiple theories describe a hierarchical functional organization for the lateral PFC, with anterior aspects controlling more abstract, higher-order behaviors (e.g., goal updating) and more posterior portions controlling more concrete, lower-order behaviors (e.g., response updating). However, recent evidence has indicated that the cerebellum (CB) also plays a role in EF. Posterior CB regions (Crus I & II) show structural and functional connections with the PFC, and further, resting networks including these CB regions are associated with individual differences in EF in healthy adults. However, it is unclear whether the cerebellum shows a similar functional gradient as does the PFC. To shed light on this issue we investigated high-resolution resting-state data from 225 participants in the Human Connectome Project. We compared the networks of Crus I, Crus II, and Lobule VI using standard GLM statistics. Demonstrating preliminary evidence for parallel PFC and cerebellar gradients, Crus I was functionally connected with anterior PFC, Crus II with middle PFC, and Lobule VI with posterior PFC. While no behavior was examined in the current study, the patterns of connectivity support the need for future functional neuroimaging investigations into functional gradients within the cerebellum. Moreover, the current results suggest that the cerebellum plays an important role in EF.

Introduction

As we navigate our day to day lives, intact executive function (EF) plays a critical role in educational, work, and home settings. EF allows for us to fluidly update our goals and the appropriate behavioral responses online. Indeed, across psychiatric disorders, EF deficits are a prominent feature and contribute to declines in quality of life. EF deficits are thought to be at the core of diseases such as schizophrenia [e.g., Kerns et al., 2008], depression [Snyder, 2013], and substance abuse [Volkow et al., 2011]; this underscores the importance of a clear and complete understanding of this critical cognitive domain. We know that the prefrontal cortex (PFC) plays a crucial role in EF [Miller and Cohen, 2001], and the prominent theories of the neural underpinnings of EF are focused on the PFC.

Nevertheless, the PFC does not act alone, and several cortical (e.g., parietal) and subcortical regions have strong connections with the PFC (e.g., thalamus and striatum). While PFC-thalamic and PFC-striatal loops are well characterized and integrated into theories of EF [Alexander et al., 1986; Masterman and Cummings, 1997], the connections between the PFC and cerebellum [Bernard et al., 2016; Kelly and Strick, 2003; Salmi et al., 2010], and their role in EF, are less understood. While the suggestion that the cerebellum may play a role in non-motor behavior is not a new idea [Leiner et al., 1986; Leiner et al., 1993; Schmahmann and Sherman, 1998], more recently there has been an increase in evidence to support this idea more directly. Investigations in non-human primates have revealed distinct closed-loop circuits connecting anatomically segregated regions of the cerebellum and motor and prefrontal cortices, respectively [Dum and Strick, 2003; Kelly and Strick, 2003], and these segregated circuits have also been replicated in the human brain with both structural [Bernard et al., 2016; Salmi et

al., 2010] and functional [Bernard et al., 2012; Bernard et al., 2014; Krienen and Buckner, 2009; O'Reilly, 2010] measures of brain connectivity. Nevertheless, there has been no work to date directly contrasting the connectivity of different cerebellar lobules, particularly those which may provide insight into cerebellar contributions to EF.

Paralleling the closed-loop circuitry of the cerebellum, lateral posterior regions of the cerebellum have been implicated in cognitive processing. Early work in patients with cerebellar lesions demonstrated both cognitive and affective deficits in patients with posterior cerebellar lesions [Schmahmann and Sherman, 1998]. More recently, work using functional imaging has suggested a corresponding functional topography in the cerebellum [e.g., E et al., 2012; Stoodley et al., 2012; Stoodley and Schmahmann, 2009]. Lateral posterior lobules of the cerebellum (Crus I, Crus II), show activation during the performance of cognitive tasks, including EF tasks. This parallels the regions of the structure showing both structural and functional connections with the PFC [Bernard et al., 2012; Bernard et al., 2016; Krienen and Buckner, 2009; O'Reilly et al., 2010; Salmi et al., 2010]. However, the specific contribution these posterior lobules make to cognitive behavior remains unknown. It has been suggested that much like in the motor domain, Crus I and Crus II of the cerebellum process internal models of thought, that aid in, and allow for organized and efficient cognition [Ito, 2008; Ramnani, 2006]. With that said, it may be the case that these regions differentially contribute to distinct components of EF, subserved by their connectivity patterns with the prefrontal cortex.

There are a number of theories describing the functional organization of the PFC. Many of these theories suggest that the PFC is organized in a rostral-caudal gradient of abstraction [Badre, 2008; O'Reilly, 2010], and as such, different regions of the PFC contribute to different components of EF. The most anterior aspects of the PFC (rostral

lateral prefrontal cortex; RLPFC) are thought to be involved in abstract higher order behaviors like the control of multiple goals, prospective memory, or using internal goals to guide task selection [Burgess et al., 2007; Koechlin and Hyafil, 2007; Orr and Banich, 2014]. Conversely, the more posterior regions of the PFC (i.e., premotor cortex and inferior frontal gyrus) are thought to be involved in more concrete behaviors related to action, including sensory or response selection [Banich, 2009]. Thus, an intact PFC, or intact PFC function is thought to be necessary for maintaining healthy EF. However, the PFC is unlikely to be acting alone. A network-based approach to understanding EF is crucial, and in particular, an eye towards the cerebellum is warranted.

To investigate cerebellar-prefrontal intrinsic functional connectivity, we utilized data from 225 unrelated participants in the Human Connectome Project (HCP), due to its large size and exceptional data quality—ultra-high resolution (0.7 mm isotropic) structural images and 4, 15-minute resting-state fMRI scans with 3 mm isotropic voxels preprocessed with cutting-edge methods for distortion and artifact correction. Data in the HCP comes from a healthy young adult (21-35 years) community sample. In addition to high quality imaging data, participants in the HCP completed a large battery of personality, demographic, and health questionnaires, as well as a cognitive battery. Nevertheless, the cognitive tasks employed were designed to assess broad cognitive abilities, and the tasks did not directly assess executive function. Therefore, we focused on just the resting-state fMRI data for the purposes of the current study. Cerebellar regions-of-interest were defined from the SUIT Probabilistic atlas [Diedrichsen et al., 2009]. We selected three lateral posterior cerebellar regions from the right hemisphere: Crus I, Crus II, and Lobule VI. Lobule VI was chosen as it has been shown to be functional connected to posterior prefrontal cortex [Bernard et al., 2012]. We predicted

that regions of the lateral posterior cerebellum would show connectivity patterns with the prefrontal cortex that parallel the rostral-caudal gradient of abstraction, suggesting that these lobules may subserve more specific components of EF.

Methods

Participants – HCP

Resting-state functional MRI (rfMRI) data from the S900 Release of Human Connectome Project (WU-UMN HCP Consortium), whose purpose is to "recruit a sample of relatively healthy individuals free of a prior history of significant psychiatric or neurological illnesses. The goal was to capture a broad range of variability in healthy individuals with respect to behavioral, ethnic, and socioeconomic diversity" [Van Essen et al., 2012, p. 2224]. Lifestyle and demographic data were collected alongside the imaging data and were used in this study to select for a sample meant to be representative of unrelated, non-clinical individuals across a variety of socioeconomic, behavioral, and ethnic backgrounds in order to maintain generalizability and control for any potential structural and functional similarities and differences linked to the factors above. Detailed descriptions of each variable used to eliminate participants are available here: https://wiki.humanconnectome.org (see HCP Data Dictionary Public – 500 Subject Release). Data were considered for this study only if the participant displayed right-handedness (Handedness>24), attained a high school degree (SSAGA_Educ>11), reported no family history of mental illness (FamHist_*_None = 1), did not meet the DSM4 criteria for Alcohol Abuse or Dependence (SSAGA_Alc_D4_Ab_Dx != 5; SSAGA_Alc_D4_Dp_Dx != 5), and did not meet the DSM criteria for Marijuana Dependence (SSAGA_Mj_Ab_Dep = 0). Data was further excluded if the participant reported more than 7 drinks per week for a female or 14 drinks per week for a male

([F]Total_Drinks_7days <8 OR [M]Total_Drinks_7days <15). Only one randomly selected participant from each family unit was used in order to account for any potential similarities in brain structure and function. These exclusions resulted in a sample size of 225 ranging in age from 22 to 36 years (92 males, 133 females; see Supplemental Material for a list of participants included).

HCP image acquisition and preprocessing

Details on data acquisition in the HCP sample are reported by Van Essen and colleagues [2012]. rfMRI data for each participant consisted of 2, 15-minute runs (1200 volumes, 720 ms TR, 2 mm isotropic voxels). Data were downloaded from the HCP S900 Release Resting State fMRI 1 FIX-Denoised (Extended) Package which included preprocessed data that had been registered and denoised using the FIX ICA-based automated method. Additional details on this pipeline are discussed in detail elsewhere [Glasser et al., 2013]. In additional to functional data, preprocessed T1 structural data were also downloaded. Structural scans had undergone gradient distortion correction, bias field correction, and registration to the 0.8 mm resolution MNI brain using Multimodal Surface Matching [Glasser et al., 2013; Glasser et al., 2016]. Structural images were used for tissue type segmentation for purposes of rfMRI data processing. Data underwent all additional processing and analysis using the CONN toolbox [v. 17e; Whitfield-Gabrieli and Nieto Castañón, 2012], a Matlab-based application designed for functional connectivity analysis. CONN was compiled as a standalone application for MATALB R2016b in centOS 6 running on a 128-core Intel Xeon Broadwell blade cluster. Preprocessing in CONN consisted of structural segmentation, smoothing (6mm FWHM), and artifact detection (global signal z-value threshold: 5, subject motion threshold: 0.9 mm). Data were then denoised with linear regression with confound

regressors for 5 temporal components each from the segmented CSF and white matter, 24 motion realignment parameters, signal and/or motion outliers, and the 1st order derivative from the effect of rest. Finally, data underwent linear detrending and bandpass filtering (0.01 – 0.1 Hz).

Functional Connectivity Analysis

Functional connectivity from right Crus I, Crus II, and Lobule VI to the rest of the brain was examined using a General Linear Model. ROIs were defined from the SUIT probabilistic cerebellum atlas [Diedrichsen et al., 2009], and thresholded at 50% probability. The location of these ROIs are shown in the insert of Figure 2. At the first-level, semipartial correlation measures were calculated from each ROI to the rest of the brain. At the group-level, connectivity measures were calculated as bivariate correlations, with group-level β's saved as Fisher-transformed correlation coefficients. The connectivity of each ROI was considered against the other two ROIs. Thus, 3 contrasts were defined: 1) Crus I > Crus II & Lobule VI, 2) Crus II > Crus I & Lobule VI, and 3) Lobule VI > Crus I & Crus II. Statistical maps were thresholded non-parametrically using a conservative thresholding approach, given the very large sample size; the cluster defining threshold was set to a FDR-corrected $p < .00001$, and the resulting clusters were thresholded to a cluster-mass FWE-corrected $p < .001$. The main results (Figure 1) were visualized using the HCP Connectome Workbench, with volumetric maps mapped to the HCP S900 Group Average Surface [Van Essen et al., 2017], and overlap maps (Figure 2) were generated in MRIcroGL.

Results

Connectivity from each ROI to the rest of the brain was contrasted with the other ROIs (Figure 1). Compared with Crus II and Lobule VI, Crus I showed greater

connectivity with dorsal anterior cingulate cortex, bilateral RLPFC, bilateral angular gyrus, bilateral anterior insula/ frontal operculum, bilateral caudate, bilateral inferior/middle temporal cortex, posterior cingulate, and precuneus (see Table 1). Compared with Crus I and Lobule VI, Crus II showed greater connectivity with inferior frontal cortex extending from the inferior frontal sulcus (IFS) to the inferior frontal junction (IFJ), as well as the posterior IPL and angular gyrus, posterior cingulate, and bilateral middle temporal cortex (see Table 2). Compared with Crus I & II, Lobule VI showed greater connectivity with bilateral sensorimotor cortex, inferior lateral occipital cortex, cuneus, and supplementary motor area (SMA) (see Table 3). The networks of the three ROIs are shown together on Figure 2. As these networks were defined from semipartial correlation, it is perhaps unsurprising that there was no overlap for any of the networks.

[Figures 1 & 2 about here]

[Tables 1-3 about here]

Discussion

The goal of this study was to test the hypothesis that cerebellar-prefrontal connections are organized along a gradient. Across several domains, it has been demonstrated that the lateral prefrontal cortex is organized along a rostral-caudal gradient of abstraction, with anterior PFC associated with the most abstract levels of processing (e.g., long-term goals and integrating information across time levels) and posterior PFC associated with concrete information such as stimuli and responses. While the current study was limited in that only resting state fMRI was considered, the findings suggest that such a gradient of abstraction may be present in the cerebellum. There is limited evidence from task-based fMRI to support this hypothesis, however. To

our knowledge, previous studies of levels of abstraction in EF have not focused on the cerebellum. The cerebellum is frequently not imaged due to limitations in coverage with standard imaging protocols. Moreover, standard spatial smoothing kernels employed in most cortical/whole-brain fMRI preprocessing pipelines (e.g., 6-8 mm FWHM) may be too large to allow for the separation of neighboring lobules [Bernard et al., 2012; Bernard and Seidler, 2013]. Nevertheless, the suggestion that such a functional gradient exists in the cerebellum is supported by a number of previous studies [e.g., Balsters et al., 2013; Stoodley et al., 2012; Stoodley and Schmahmann, 2009].

We found that Crus I was connected to the RLPFC more strongly than Crus II and Lobule VI. This is in line with our prior work which investigated the connectivity of each cerebellar lobule, but did not compare the networks of different lobules [Bernard et al., 2012]. There is evidence to suggest that Crus I is involved in higher-order cognitive processing, in concert with anterior prefrontal cortex. We have previously shown that Crus I and the rostral lateral prefrontal cortex are activated when participants perform voluntary task switching, a task that requires them to select tasks according to abstract, internally maintained task goals [Orr and Banich, 2014]. The rostral lateral prefrontal cortex has also been linked to prospective memory, i.e., remembering to perform an action after a delay [Burgess et al., 2003]. Several studies of prospective memory have shown activation of Crus I [Burgess et al., 2003; Reynolds et al., 2009]. Further, when examining individuals who don't show multitasking costs, aka "supertaskers", Medeiros-Ward and colleagues [2014] found that Crus I showed a group-by-load effect along with the rostral lateral prefrontal cortex.

While a number of studies have implicated a role of Crus I in executive function, there is less evidence for a role of Crus II. In an fMRI meta-analysis, Stoodley &

Schmahmann [2009] found strong activation overlap in Crus II during language tasks. The current findings support a link between Crus II and language, as Crus II was connected with language-related regions of posterior inferior frontal gyrus, including areas 45 and 47 of the Neubert ventral frontal probabilistic parcellation available in FSL's *fsleyes* viewer [Neubert et al., 2014]. However, Buckner and colleagues [2011] identified a connection between Crus II and the default mode network. If the center of gravity of the Right Crus II seed (from the SUIT atlas thresholded at 50%, coordinates: 26, -76, -42) is entered into *neurosynth* [Yarkoni et al., 2011], top meta-analytic terms associated with the region include "past", "socially", and "autobiographical". Nevertheless, the functional connectivity and meta-analytic connectivity maps for the same region from *neurosynth* (http://neurosynth.org/locations/?y=-76&x=26&z=-42) contains left posterior inferior frontal gyrus cortex. Thus, while several lines of evidence support a role for Crus II in language, further studies are needed to clarify the nature of this role.

While we predicted that Lobule VI would should show connectivity with posterior prefrontal cortex, the connectivity was more posterior in primary motor cortex, rather than premotor cortex. Prior studies have demonstrated connectivity between Lobule VI and premotor cortex [Bernard et al., 2012]. The conflicting results here may however be due to the nature of our analyses where we directly compared Lobule VI with Crus I and II. As seen in Figure 2, both Crus I and II also have areas of connectivity with dorsal and ventrial pre-motor cortical regions, and thus it may be the case that the greater connectivity for Lobule VI is with more primary motor cortical regions. However, it is also notable that the sample here is at much higher resolution and has a significantly larger sample than prior work [Bernard et al., 2012]. Reineberg and Banich [2016]

showed that individual difference in network dynamics at rest in Lobule VI were associated with working memory updating. Further, meta-analytic evidence suggests that this region is involved not only in working memory, but across motor tasks and learning, and in language as well [E et al., 2012; Stoodley & Schmahmann, 2009; Bernard & Seidler, 2013]. The seemingly diverse roles and contributions of Lobule VI suggest that it is a transition area of sorts such that there is involvement in more abstract higher order thinking to some degree, but also makes contributions to motor planning. Because much of the evidence in this regard comes from meta-analysis, it is not feasible to dissociate the more concrete motor-reliant execution aspects of these tasks from the more abstract processing. However, the stronger resting state associations with motor cortical regions that that we see with Lobule VI, particularly relative to Crus I and Crus II, suggest that perhaps the role of this cerebellar region is with respect to the more concrete aspects of motor response selection during the performance of higher order cognitive tasks. Future work specifically dissociating these levels of abstraction with respect to the cerebellum is clearly warranted in the future.

Here, using a large sample of individuals from the HCP, we carefully probed connectivity of cerebellar lobules with respect to one another, as a first step towards understanding cerebellar contributions to executive function. While past work has taken a targeted lobular approach [Bernard et al., 2012], looked at the cerebellum more generally [Habas and Cabanis, 2007; O'Reilly et al., 2010], or made comparisons framed by the prefrontal cortex [Krienen & Buckner, 2009], this cerebellar approach allows us to carefully interrogate connectivity patterns that are of potential importance to our understanding of EF. Broadly speaking, our results suggest that a gradient of abstraction may also be present in the cerebellum, paralleling what is see in the PFC

[e.g., Badre, 2008], likely subserved by the closed-loop circuitry linking these two disparate brain regions [Bernard et al., 2016; Kelly and Strick, 2003; Salmi et al., 2010; Strick et al., 2009]. While the exact role of the cerebellum in non-motor behavior remains unknown, it has been suggested that the structure acts to process internal models of thought [Ramnani, 2006; Ito, 2008], much as is done in the motor domain [e.g., Imamizu et al., 2000]. Across cerebellar lobules, the cytoarchitectonics remain the same, only the cortical connections change, suggesting a similar computation is being performed, just on distinct inputs [Ramnani, 2006; Ito, 2008]. With damage and disease, one would therefore experience deficits in thought and processing, such as those seen in patients with schizophrenia [Andreasen et al., 1996; Andreasen et al., 1998], or those with cerebellar infarct [Schmahmann and Sherman, 1998]. Given the complex nature of EF, as well as its importance in the completion of activities of daily living, maintaining this domain is critically important. Here, the suggestion that the cerebellum engages with the PFC in a manner that parallels the gradient of abstraction in the PFC means that we now have additional areas of investigation for understanding EF, or its breakdown in the case of disease. Further, this provides additional targets of intervention and remediation to improve these skills in impacted populations. Future work targeting the relative contributions of the cerebellum, and ideally its lobular subregions, taking advantage of non-invasive brain stimulation stand to provide important insights into the necessity of this region for EF, and its underlying domains of function.

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Figures

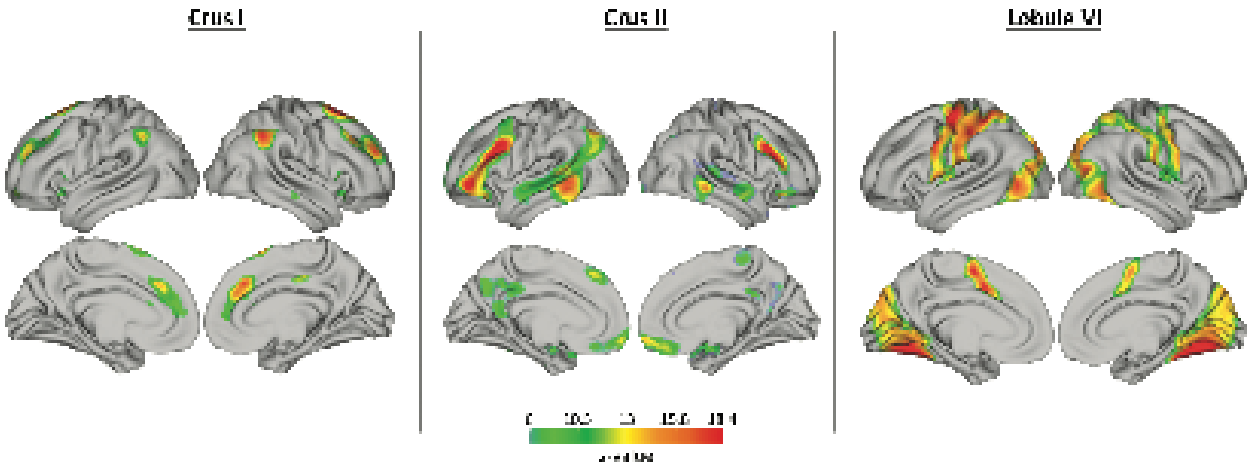


Figure 1. Cerebellar ROI networks. (Left panel) Cortical regions showing significantly stronger correlation with Right Crus I compared to Right Crus II and Right Lobule VI. (Middle panel). Cortical regions showing significantly stronger correlation with Right Crus II compared to Right Crus I and Right Lobule VI. (Right panel) Cortical regions showing significantly stronger correlation with Right Lobule VI compared to Right Crus I and Right Crus II.

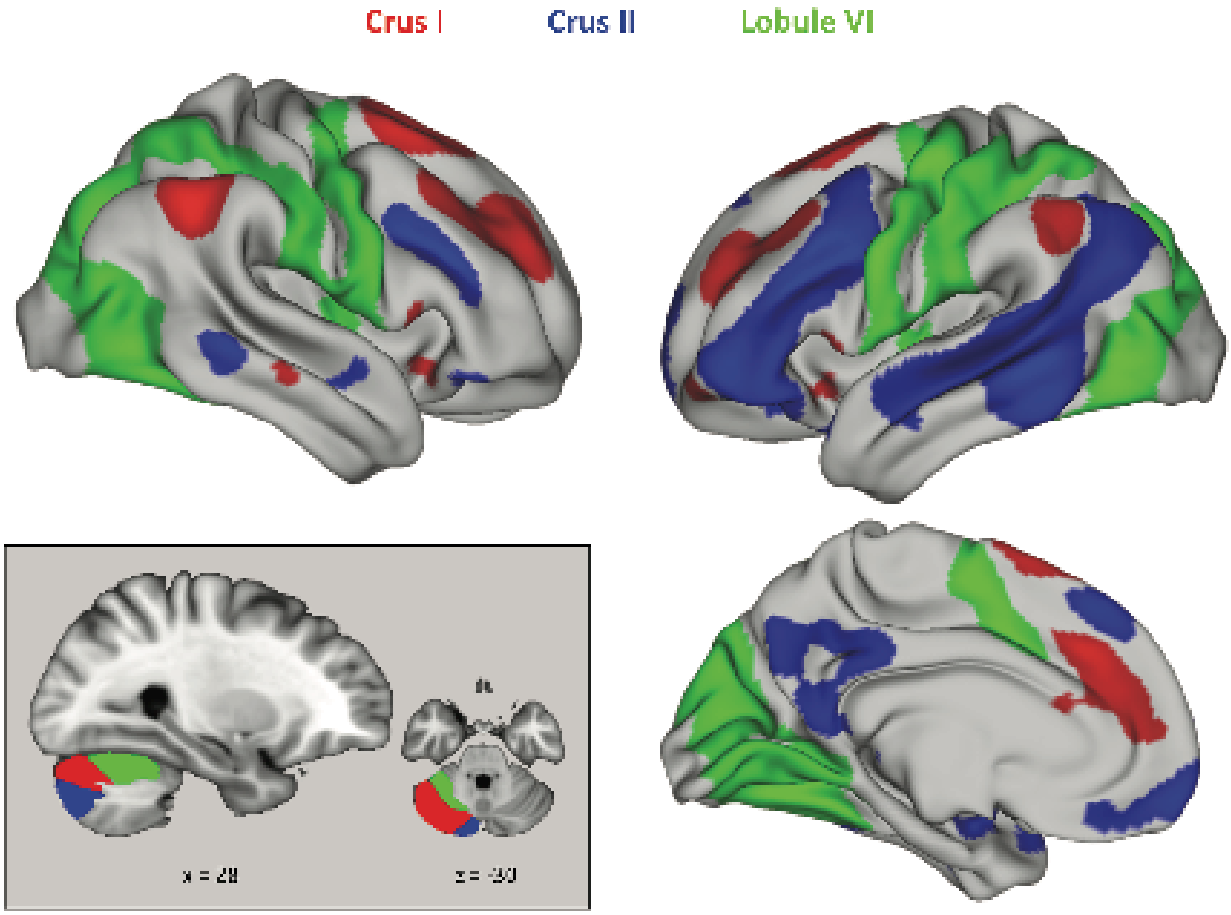


Figure 2. Overlay of ROI networks. Crus I networks are shown in Red, Crus II networks are shown in Blue, Lobule VI networks are shown in Green. The insert shows the location of the cerebellar ROIs in a sagittal and axial slice.

Table 1. Structures connected with Right Crus I

Structures to which each center of mass belongs to:	Voxels	MAX Z	MAX X (mm)	MAX Y (mm)	MAX Z (mm)	COG X (mm)	COG Y (mm)	COG Z (mm)
68% Paracingulate Gyrus	13871	19.3	-14	16	70	0.0429	34.2	38.6
95% Right Crus I	3707	52.3	48	-60	-34	41.1	-63.9	-33.2
92% Left Crus I	3285	25.4	-50	-62	-32	-40.4	-63.8	-35.7
65% Angular Gyrus	1445	14.7	58	-52	48	54.4	-48.4	40.5
43% Angular Gyrus	1108	14.2	-50	-52	38	-53.7	-52.3	39.6
34% Insular Cortex, 17% Frontal Operculum Cortex	695	13.6	-44	16	2	-42	17.6	-2.84
95% Left Caudate	275	9.65	-16	20	8	-15.8	17.1	10.7
90% Cingulate Gyrus, posterior division	263	11.1	2	-22	42	1.73	-20.7	41.3
70% Middle Temporal Gyrus, posterior division	223	8.03	64	-20	-12	64.5	-21.2	-13.3
58% Frontal Orbital Cortex, 20% Insular Cortex	200	10.2	36	20	-12	35.3	20.6	-11.4
42% Inferior Frontal Gyrus, pars opercularis, 24% Inferior Frontal Gyrus, pars triangularis	191	9.46	50	18	2	50.2	18.2	4.24
95% Right Caudate	174	9.3	16	12	18	15.5	15.6	13.1
66% Frontal Pole	168	7.01	34	64	-8	32.6	58	-8.14
66% Inferior Temporal Gyrus, anterior division	137	6.72	-50	-2	-38	-51.4	-3.91	-35.1
43% Inferior Temporal Gyrus, anterior division, 25% Middle Temporal Gyrus, anterior division	109	6.85	50	0	-34	50.9	-1.01	-35.6
58% Middle Temporal Gyrus, posterior division	97	7.21	-64	-24	-14	-63.1	-24.4	-14.7
35% Precuneous Cortex	82	6.1	6	-56	72	5.96	-57.5	68.1
46% Precuneous Cortex	38	7.08	-8	-60	60	-8.31	-59.4	59.9

Table 2. Structures connected with Right Crus II

Structures to which each center of mass belongs to:	Voxels	MAX Z	MAX X (mm)	MAX Y (mm)	MAX Z (mm)	COG X (mm)	COG Y (mm)	COG Z (mm)
38% Middle Temporal Gyrus, temporooccipital part	7598	18.3	-66	-48	-10	-50.5	-50.5	11.3
14% Inferior Frontal Gyrus, pars triangularis	6451	24.5	-48	20	28	-41.5	25.9	10.3
77% Crus II	3477	61.5	12	-82	-36	16.5	-79.6	-39
52% Frontal Pole, 37% Frontal Medial Cortex	1280	13.8	-2	60	-12	-4.69	57	-7.68
22% Middle Frontal Gyrus	1064	14.4	44	18	30	45.6	24.4	23.7
77% Cingulate Gyrus, posterior division, 19% Precuneous Cortex	1004	11.6	-2	-38	34	-3.91	-51.6	30.6
41% Frontal Pole, 37% Frontal Orbital Cortex	562	14.9	40	36	-12	38.6	35.7	-13.6
54% Middle Temporal Gyrus, temporooccipital part, 22% Middle Temporal Gyrus, posterior division	543	11.1	68	-38	-8	65.9	-38.9	-4.14
64% Superior Frontal Gyrus	378	12.9	-4	34	48	-4.82	38.4	46.8
86% Lobule IX	178	12.8	10	-48	-44	6.07	-51.7	-45.4
39% Superior Temporal Gyrus, anterior division, 22% Middle Temporal Gyrus, anterior division	154	8.78	54	-4	-16	55.1	-2.19	-13
39% Temporal Pole, 15% Parahippocampal Gyrus, anterior division	69	8.45	28	2	-18	27.2	6.24	-20.7
72% Lateral Occipital Cortex, superior division	38	7.99	38	-68	44	38	-70	46.1
33% Precentral Gyrus, 28% Postcentral Gyrus	31	8.26	0	-32	62	0.0662	-31.4	61.2

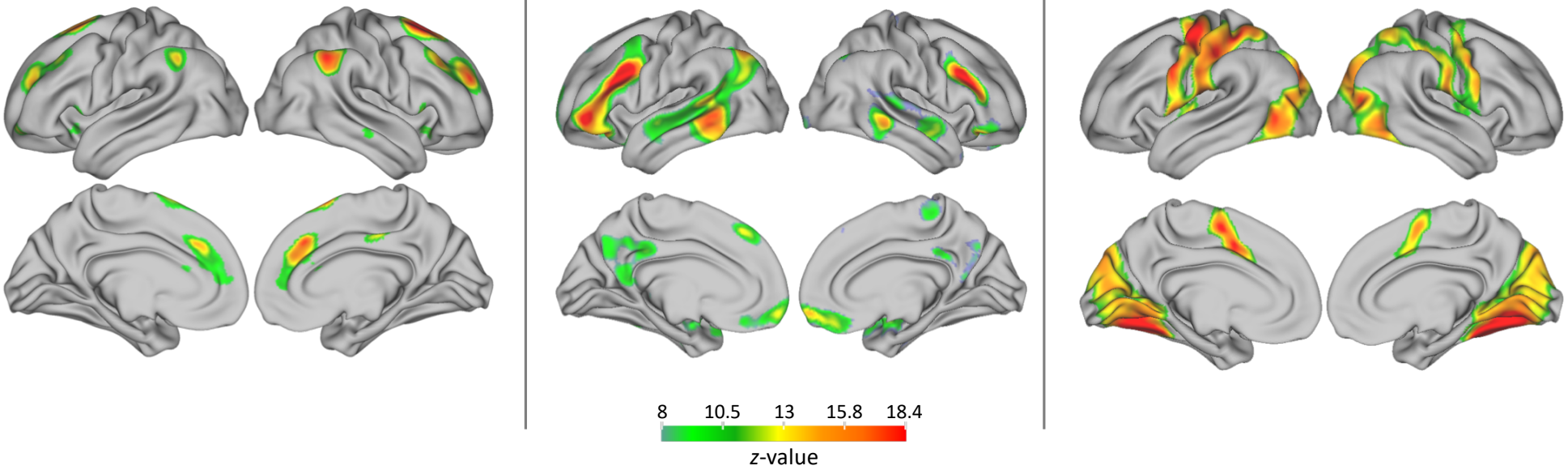
Table 3. Structures connected with Right Lobule VI

Structures to which each center of mass belongs to:	Voxels	MAX Z	MAX X (mm)	MAX Y (mm)	MAX Z (mm)	COG X (mm)	COG Y (mm)	COG Z (mm)
92% Lobule VI (max location due to cluster size)	22988	64.1	14	-64	-20	4.65	-65.1	-10.3
51% Postcentral Gyrus, 16% Precentral Gyrus	6557	23.7	-44	-10	60	-43.7	-19	43
47% Postcentral Gyrus, 13% Precentral Gyrus	2557	17.7	46	-4	58	47	-15.5	41.9
51% Juxtapositional Lobule Cortex (SMA)	1054	22	-2	-2	54	-0.921	3.1	50.1
54% Central Opercular Cortex, 15% Insular Cortex	294	16.5	44	0	12	42.6	1.53	8.77
92% Lobule VI (max location due to cluster size)	22988	64.1	14	-64	-20	4.65	-65.1	-10.3
51% Postcentral Gyrus, 16% Precentral Gyrus	6557	23.7	-44	-10	60	-43.7	-19	43
47% Postcentral Gyrus, 13% Precentral Gyrus	2557	17.7	46	-4	58	47	-15.5	41.9
51% Juxtapositional Lobule Cortex (SMA)	1054	22	-2	-2	54	-0.921	3.1	50.1
54% Central Opercular Cortex, 15% Insular Cortex	294	16.5	44	0	12	42.6	1.53	8.77

Crus I

Crus II

Lobule VI



Crus I Crus II Lobule VI