Supplementary Information

Supplementary materials

Imaging data acquisition

Whole brain scans were acquired on the 3T MRI scanner (Siemens Prisma, Germany) with a 64-channel head coil at the Paris Brain Institute neuroimaging platform.

T1-weighted data

3D T1-weighted MP2RAGE sequence was acquired in sagittal orientation, at 1 mm isotropic voxels resolution, with an in-plane matrix of 232 x 256 and 176 slices, TR = 5000 ms, TE = 2.96 ms, TI = 700 / 2500 ms, flip angle = 4 / 5°, grappa acceleration factor 3. Dummy scan were automatically discarded by the sequence, fat signal was suppressed.

Resting-state data

Resting state functional images were acquired using a multi-echo echo-planar imaging (EPI) sequence (350 time points), with a multi-slice, multi-echo acquisition scheme (TR = 1.9s, TE = 17/36/56ms, iPAT acceleration factor 2, Multi-band 2, isotropic voxel size 3mm, phase encoding direction P>A). The shim box was equal to the acquired volume. An interleaved ascending (MultiSlice) slide order was used during scans acquisition. Scans were acquired with the eyes opened with fixation on cross. The subjects were monitored with eye tracker system to assure that they were not somnolent during data acquisitions.

Functional magnetic resonance imaging preprocessing

T1-weighted data

T1-weighted images were background denoised[1], segmented and normalized to the Montreal Neurological Institute (MNI) space using the Computational Anatomy Toolbox (CAT12) implemented in SPM12.

Resting-state data

Concerning the scanner-side preprocessing: the reconstructed matrix was equal to the acquired matrix, there was no prospective motion correction, we used a signal inhomogeneity correction

(option: "Prescan Normalize"), there was no distortion-correction. The preprocessing was performed using AFNI.[2] For slice-timing correction, the reference slice was the first slice (t=0), we used a heptic (7th order) Lagrange polynomial interpolation. The motion correction was performed using rigid body transformations, without susceptibility correction, the reference scan was fixed with the option “MIN_OUTLIER in afni_proc.py”. There was no intensity correction for BOLD. The despiking step was performed using the AFNI 3dDespike function. Subsequently, TEDANA combined signal across echoes and, used a principal component analysis to reduce the dimensionality of the dataset by removing thermal noise, and an independent component analysis decomposition to separate blood-oxygen-level dependent BOLD from non-BOLD components based on the echo time dependence of the BOLD component[3] (non-BOLD components were visually inspected for each individual). Then, using SPM12, denoised rs-fMRI images were co-registered to structural images using rigid body transformations, normalized mutual information and the 4th degree B-Spline interpolation method. The normalization to the MNI space was applied to the structural image and then to the rs-fMRI image. Finally, data were smoothed (FWHM = 4 mm) and filtered (0.01–0.1 Hz) using the CONN toolbox.[4]

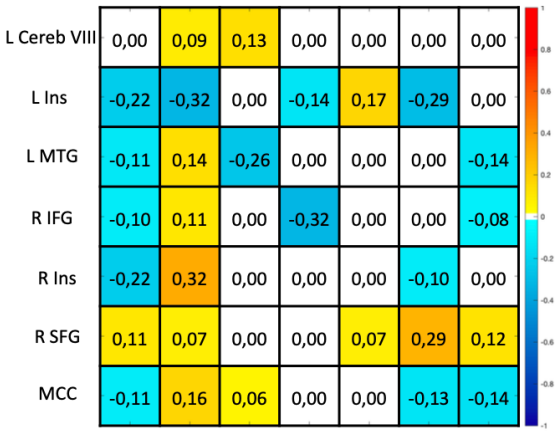
Optimal ICA decomposition

We tested the effectiveness of ICA decomposition in 20 to 30 components on our dataset in accordance with previous publications[5–9] as follows: after ICA analysis of each number of components, networks were identified using spatial matching correspondence using Dice coefficient to the templates of the same networks from the Yeo 7-Networks atlas.[10] Then the mean of the Dice coefficients was calculated for each number of components. The highest average matching to the template corresponded to the optimal ICA decomposition (Supplementary Table 1). For the CEN, when the right and left CEN were separated by ICA, we used the right CEN as it is usually described as lateralized on the right side. Also, network dynamics among the DMN, CEN and SN are more robust in the right hemisphere.[11,12] For each network of interest resulting from the optimal ICA decomposition, the threshold to fit with the Yeo template was applied and then was parcellated into distinct regions using CONN toolbox.

Hierarchical networks organization

To analyze the hierarchical network organization, we estimated a PEB (Parametric Empirical Bayes) model separately for each group (patients and healthy volunteers, HV), considering their own priors. The model parameter values were averaged and weighted by their model evidence, separately in each group. Then, in each PEB model, we computed the discrepancy between the absolute efferent and afferent connections[13] (with a posterior probability > 0.99) of each node.

For example, in patients, within the SN, the hierarchical strength of the cerebellum (|0| + |-0.22| + |-0.11| + |-0.10| + |-0.22| + |0.11| + |-0.11| - |0| - |0.09| - |0.13| - |0| - |0| - |0| - |0|) is greater than that of the R SFG (|0| + |-0.29| + |0| + |0| + |-0.10| + |0.29| + |-0.13| - |0.11| - |0.07| - |0| - |0| - |0.07| - |0.29| - |0.12|).



Hierarchical parametric empirical Bayes model of the Salience network in the group of patients.

Matrix A of each parameter in the model after Bayesian model averaging. Values and color represent the effect-size of each parameter. Only parameters with a posterior probability pp > 0.99 are displayed in color. The order of nodes remains consistent along the x and y axes. MTG = Middle temporal gyrus ; IFG = Inferior frontal gyrus ; SFG = Superior frontal gyrus ; MCC = Middle cingulate cortex ; Cereb = Cerebellum ; Ins = Insula ; L = Left ; R = Right. The charts were created using the Statistical Parametric Mapping toolbox (SPM12, Update Revision Number 7771, https://www.fil.ion.ucl.ac.uk/spm/), implemented in MATLAB (R2022a, Version: 9.12.0.2327980, Natick, Massachusetts: The MathWorks Inc, https://www.mathworks.com). The layout was done with Microsoft® PowerPoint software (version 16.87, https://www.microsoft.com).

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Supplementary results

Supplementary Table 1. Dice coefficients of the different ICA decompositions

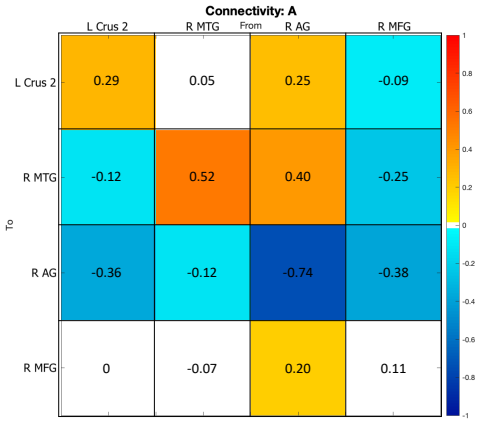
	20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
CEN	0.524	0.509	0.514	0.503	0.492	0.5	0.495	0.493	0.494	0.505	0.482
DAN	0.503	0.472	0.528	0.387	0.37	0.414	0.406	0.242	0.213	0.589	0.522
DMN	0.459	0.521	0.487	0.422	0.475	0.519	0.422	0.291	0.509	0.217	0.242
LN	0.219	0.246	0.377	0.321	0.384	0.339	0.338	0.366	0.395	0.384	0.318
SMN	0.558	0.526	0.522	0.524	0.479	0.537	0.524	0.512	0.489	0.425	0.42
SN	0.285	0.351	0.457	0.263	0.436	0.333	0.421	0.207	0.389	0.395	0.292
Mean	0.425	0.438	**0.481**	0.403	0.439	0.440	0.434	0.352	0.415	0.419	0.379
SD	0.139	0.114	0.057	0.102	0.052	0.091	0.067	0.128	0.112	0.126	0.112

CEN = Central executive network ; DAN = Dorsal attention network ; DMN = Default mode network ; LN = Limbic network ; SMN = Sensorimotor network ; SN = Salience network ; SD = Standard deviation

Supplementary Table 2.

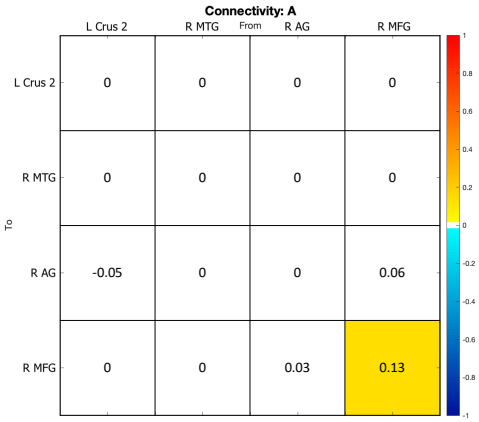
Modules	Network	ROI	Coordinates (MINI)
Psychomotricity	DAN	L SPL	-33, -38, 53
		R SPL	34, -38, 54
		L MTG	-51, -66, -3
		R MTG	54, -59, -5
		R MOG	42, -80, 20
		L Precentral	-53, 6, 30
		R Precentral	56, 9, 28
		L Cerebellum VIII	-34, -45, -42
	SMN	SMA	1, -25, 62
		Vermis III	1, -47, -17
		L Oper	-40, -24, 17
		R Oper	41, -23, 17
Affectivity	LN	L PHC	-30, -1, -34
		R PHC	34, 2, -34
	SN	L Insula	-50, -17, 13
		R Insula	52, -14, 13
		MCC	1, -29, 53
		L MTG	-48, -70, 12
		R IFG	45, 43, 4
		R SFG	13, -3, 67
		L Cerebellum VIII	-31, -49, -52
Internal thought	DMN	MedFG	0, 50, 32
		L AG	-49, -61, 30
		R AG	54, -57, 30
		Precuneus	-2, -53, 29
		L MTG	-57, -10, -26
		R MTG	57, -5, -32
		L Crus1-2	-30, -81, -36
		R Crus1-2	31, -81, -35
Executive thought	CEN	R MFG	38, 36, 26
		R AG	47, -53, 45
		R MTG	64, -31, -15
		L Crus2	-37, -73, -45

DAN = Dorsal attention network ; SMN = Sensorimotor network ; LN = Limbic network ; SN = Salience network ; DMN = Default mode network ; CEN = Central executive network ; SMA = Supplementary motor area; Oper = Rolandic operculum ; SPL = Superior parietal lobule ; MTG = Middle temporal gyrus ; MOG = Middle occipital gyrus ; IFG = Inferior frontal gyrus ; SFG = Superior frontal gyrus ; MCC = Middle cingulate cortex ; PHC = Parahippoccampal cortex ; MFG = Middle frontal gyrus ; AG = Angular gyrus ; medFG = extended Median frontal region ; L = Left ; R = Right.



All Subjects

CEN



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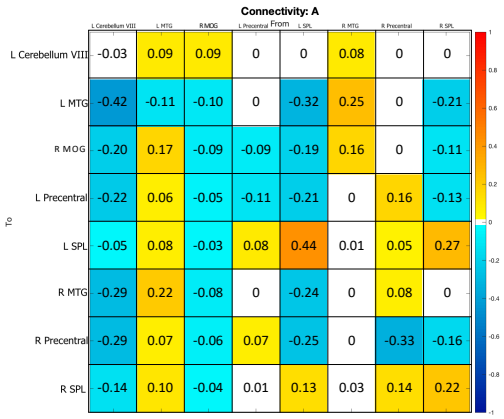
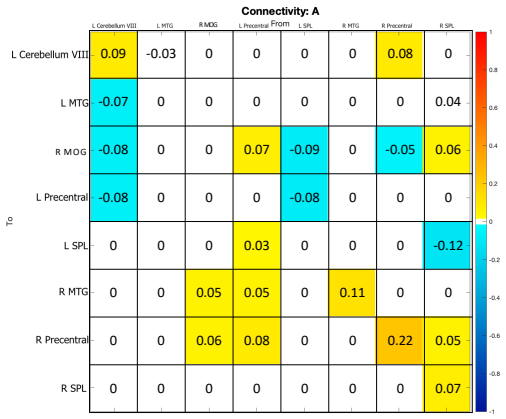


All Subjects

DAN



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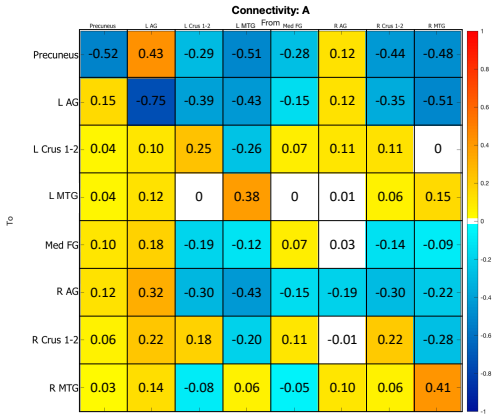
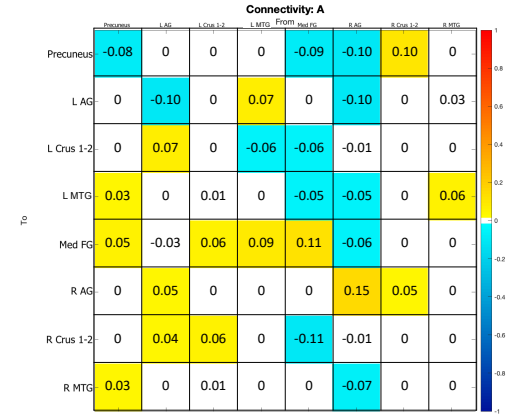


All Subjects

DMN



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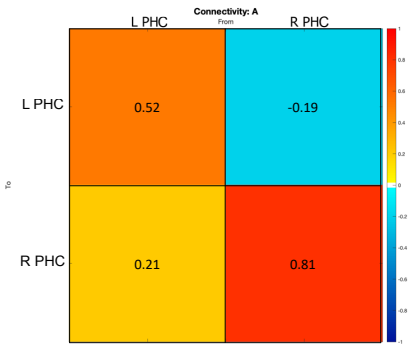
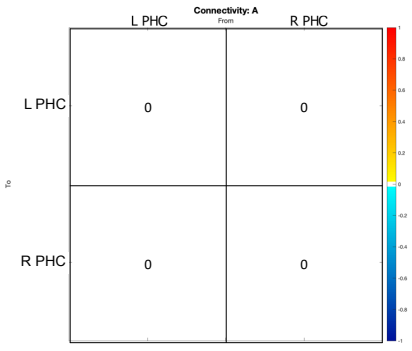
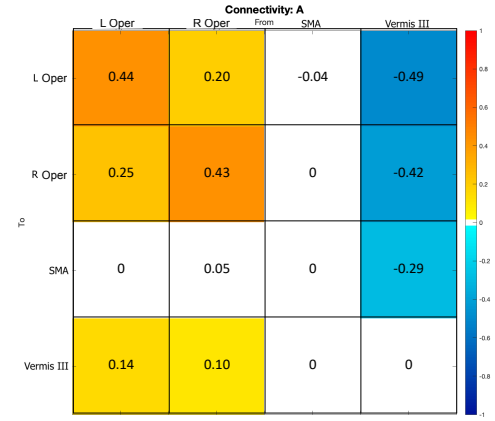


All Subjects

LN

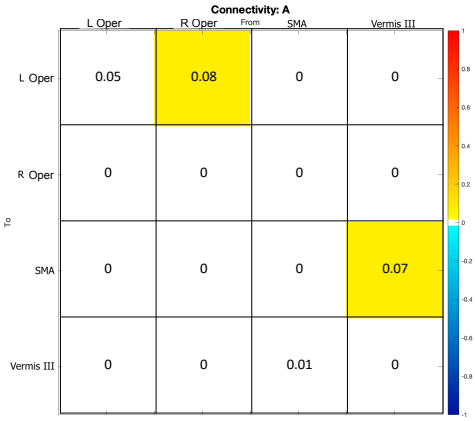


Patients > HV



All Subjects

SMN



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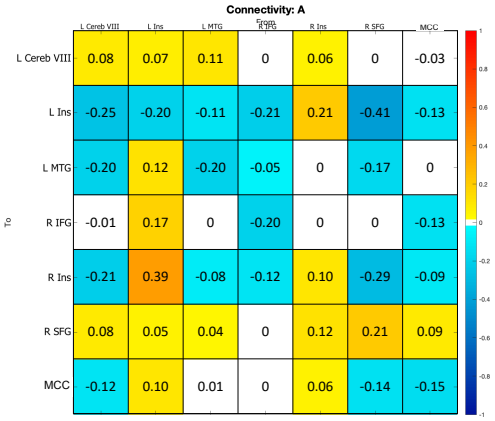

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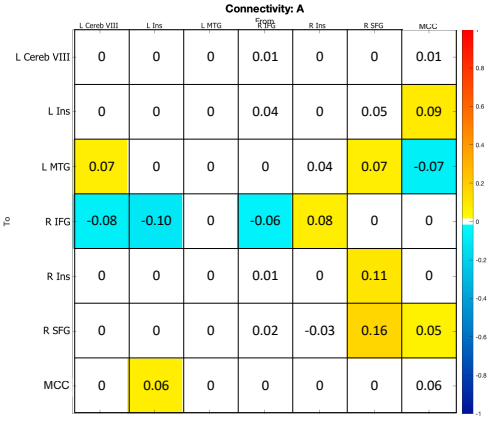
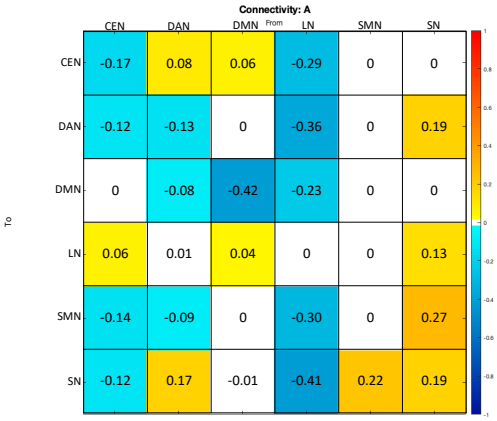
SN

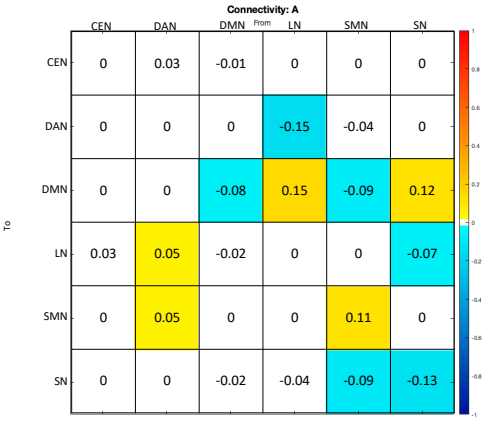


Patients > HV



All Subjects

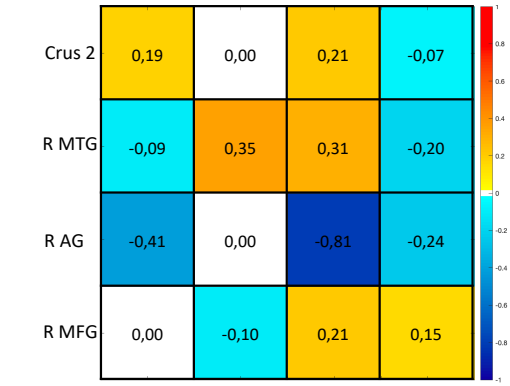
Networks



Patients > HV

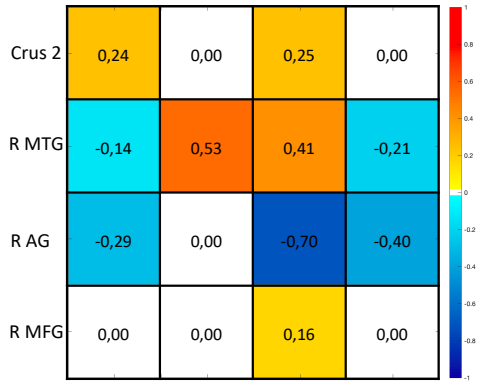
Supplementary Fig.1 Detailed hierarchical parametric empirical Bayes model across all subjects.

Matrix A of each parameter in the model after Bayesian model averaging. The left and the right charts represent respectively the effect of the entire group of participants and the between-group effect. Values and color represent the effect-size of each parameter. Only parameters with a posterior probability pp > 0.99 are displayed in color. DAN = Dorsal attention network ; SMN = Sensorimotor network ; LN = Limbic network ; SN = Salience network ; DMN = Default mode network ; CEN = Central executive network ; SMA = Supplementary motor area; Oper = Rolandic operculum ; SPL = Superior parietal lobule ; MTG = Middle temporal gyrus ; MOG = Middle occipital gyrus ; IFG = Inferior frontal gyrus ; SFG = Superior frontal gyrus ; MCC = Middle cingulate cortex ; PHC = Parahippoccampal cortex ; Cereb = Cerebellum ; Ins = Insula ; MFG = Middle frontal gyrus ; AG = Angular gyrus ; MedFG = extended Median frontal region ; L = Left ; R = Right. The charts were created using the Statistical Parametric Mapping toolbox (SPM12, Update Revision Number 7771, https://www.fil.ion.ucl.ac.uk/spm/), implemented in MATLAB (R2022a, Version: 9.12.0.2327980, Natick, Massachusetts: The MathWorks Inc, https://www.mathworks.com). The layout was done with Microsoft® PowerPoint software (version 16.87, https://www.microsoft.com).



DYT-*SGCE*

CEN



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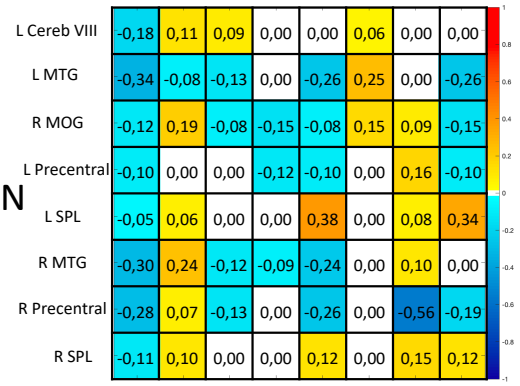
DYT-*SGCE*

DAN



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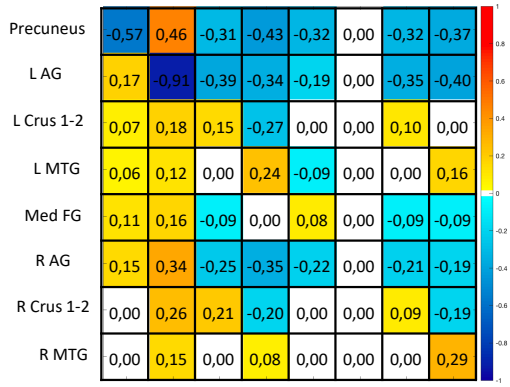
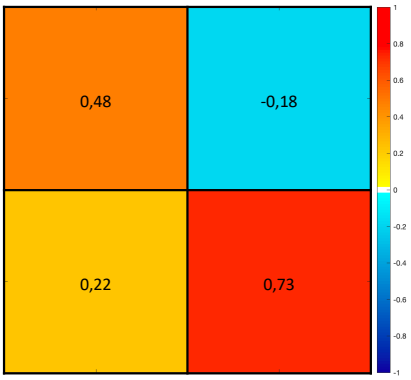


DYT-*SGCE*

DMN

HV



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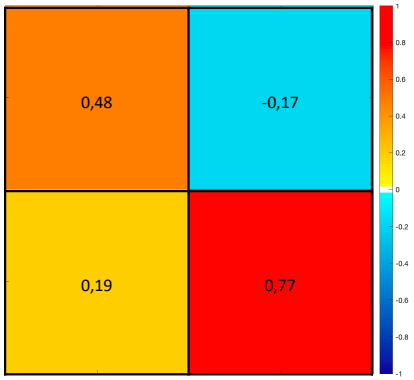
LN



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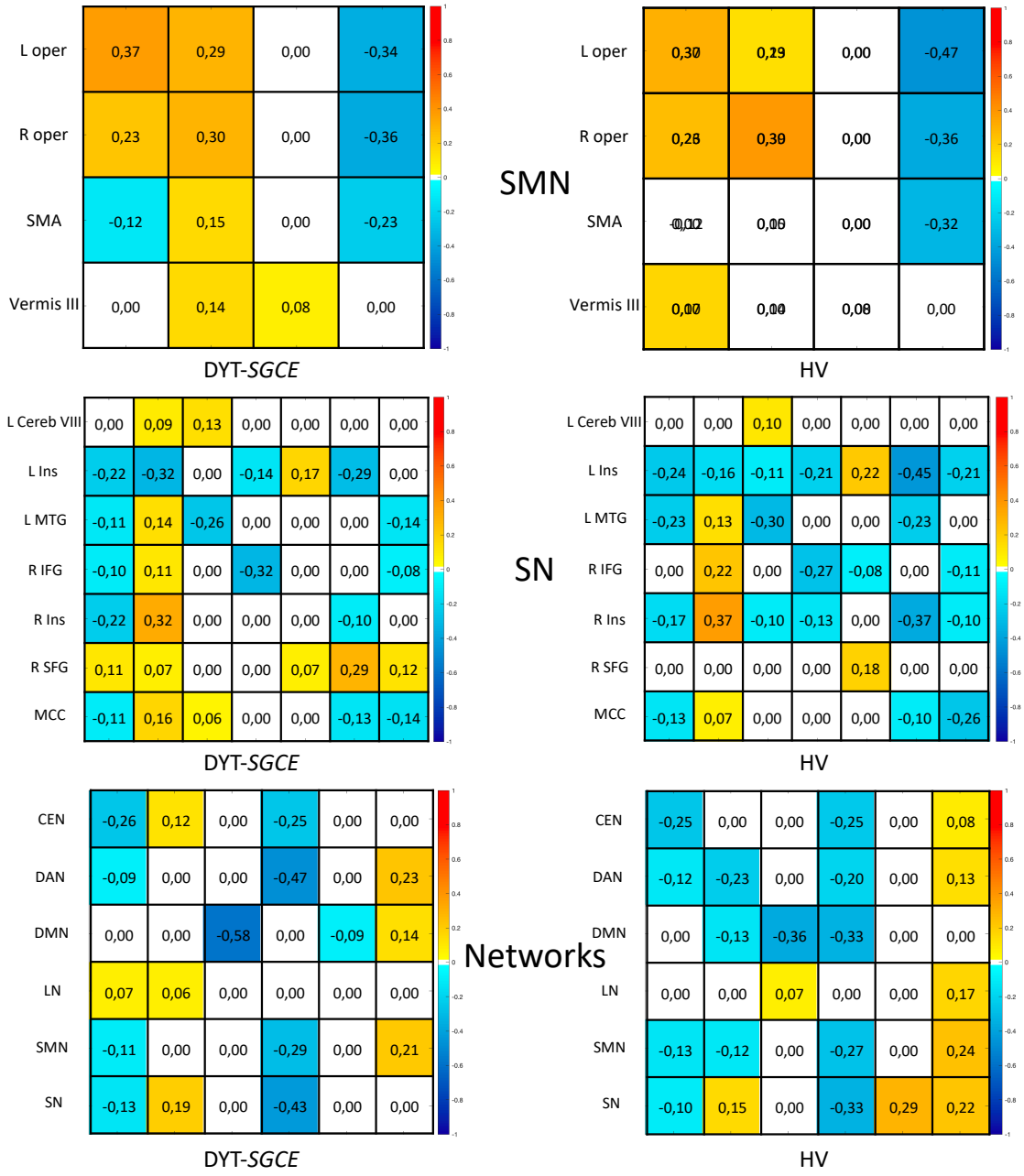
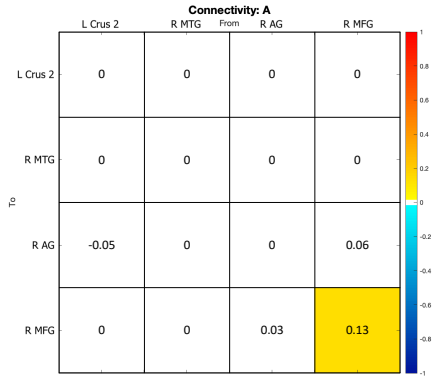


Supplementary Fig.2 Detailed hierarchical parametric empirical Bayes model in the groups of patients and healthy volunteers.

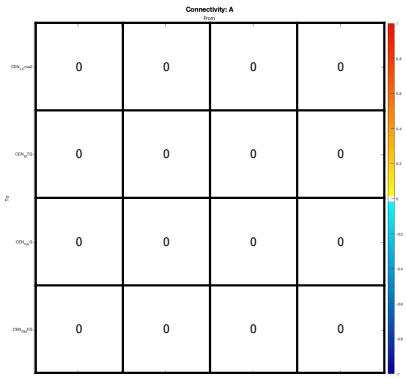
Matrix A of each parameter in the model after Bayesian model averaging. The left and the right charts represent respectively the effect of mean in the group of patients and in the group of healthy volunteers. The PEB models were run separately for each group. Values and color represent the effect-size of each parameter. Only parameters with a posterior probability pp > 0.99 are displayed in color. The order of nodes remains consistent along the x and y axes. DAN = Dorsal attention network ; SMN = Sensorimotor network ; LN = Limbic network ; SN = Salience network ; DMN = Default mode network ; CEN = Central executive network ; SMA

= Supplementary motor area; Oper = Rolandic operculum ; SPL = Superior parietal lobule ; MTG = Middle temporal gyrus ; MOG = Middle occipital gyrus ; IFG = Inferior frontal gyrus ; SFG = Superior frontal gyrus ; MCC = Middle cingulate cortex ; PHC = Parahippoccampal cortex ; Cereb = Cerebellum ; Ins = Insula ; MFG = Middle frontal gyrus ; AG = Angular gyrus ; MedFG = extended Median frontal region ; L = Left ; R = Right. The charts were created using the Statistical Parametric Mapping toolbox (SPM12, Update Revision Number 7771, https://www.fil.ion.ucl.ac.uk/spm/), implemented in MATLAB (R2022a, Version: 9.12.0.2327980, Natick, Massachusetts: The MathWorks Inc, https://www.mathworks.com). The layout was done with Microsoft® PowerPoint software (version 16.87, https://www.microsoft.com).

CEN

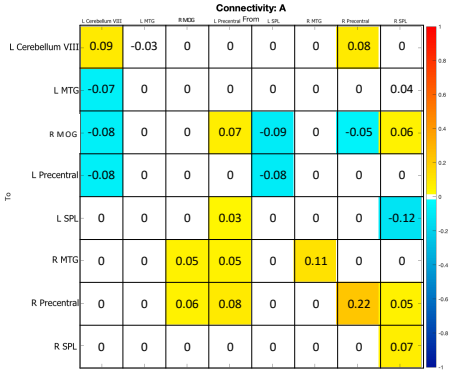


Patients > HV



Effect of FD (+)

DAN



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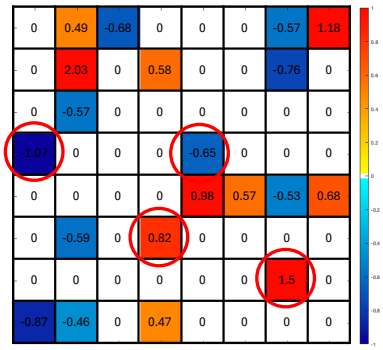
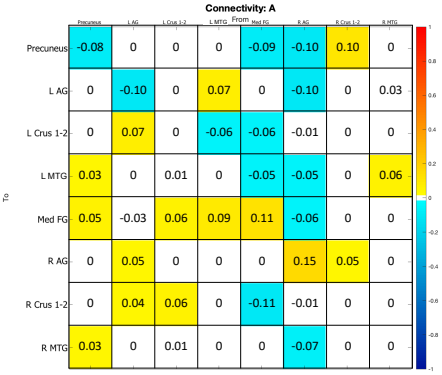
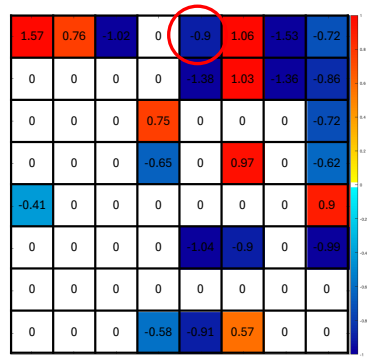


Effect of FD (+)

DMN

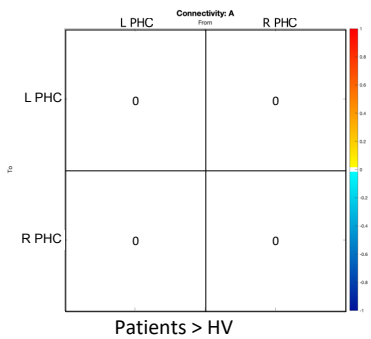


Patients > HV

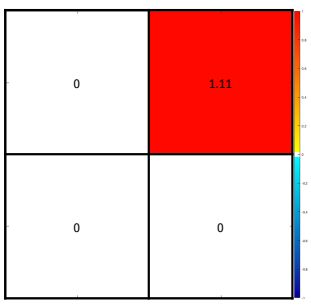


Effect of FD (+)

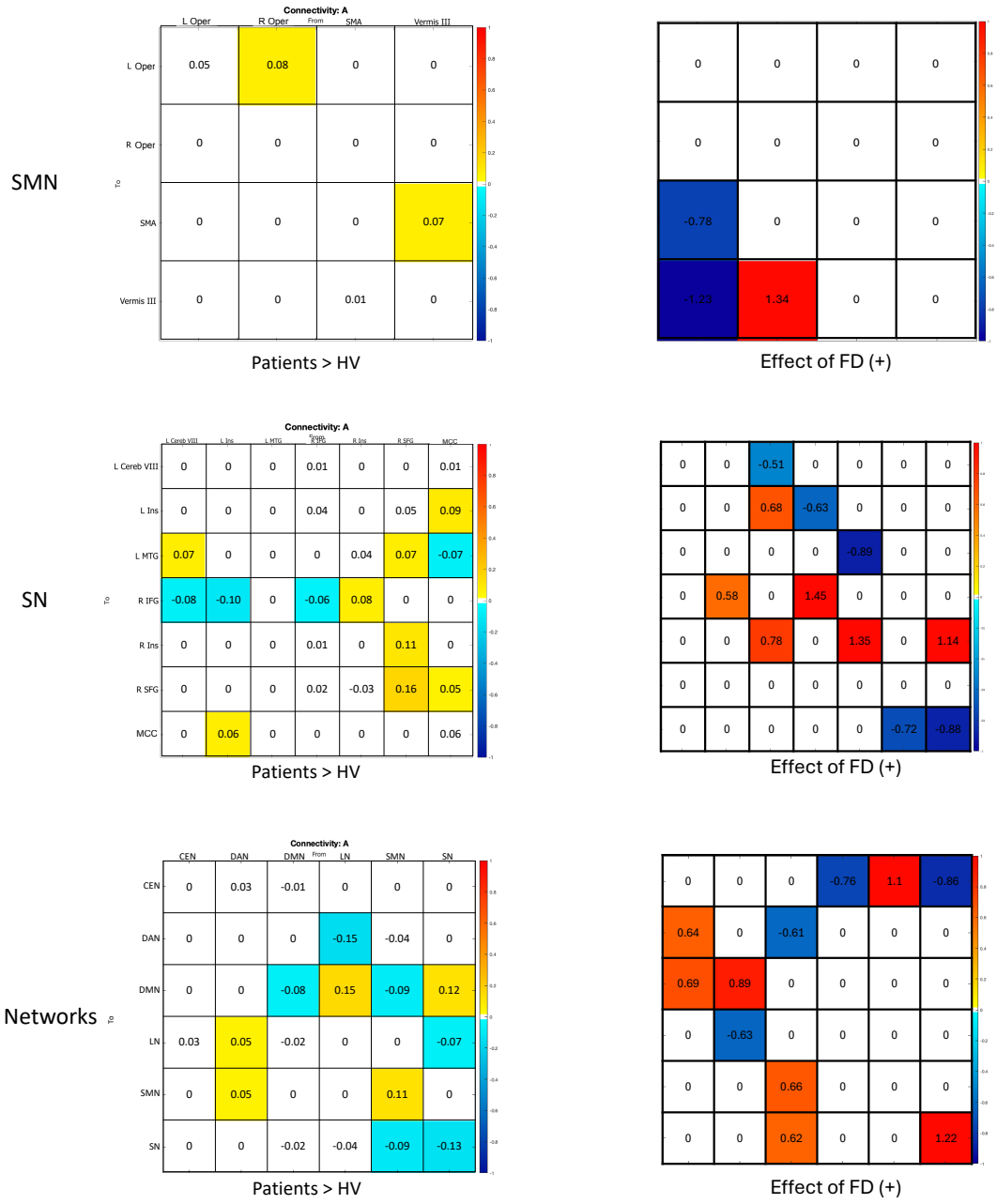
LN



Patients > HV



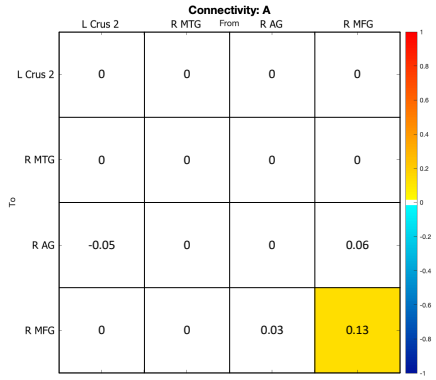
Effect of FD (+)



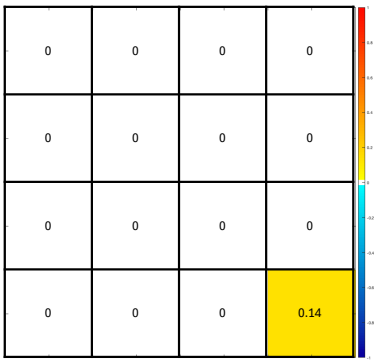
Supplementary Fig.3. Effects of group and framewise displacement on connectivity. Matrix A of each parameter in the model after Bayesian model averaging (nodes are in the same order on both the left and right charts). The left and the right charts represent respectively the between-group effect (positive values indicate "higher" for patients) and the effect of FD (positive values indicate "higher" when FD increases). Values and color represent the effect-size of each parameter. Red circles indicate connections with effects going in the same direction across the contrasts. Only parameters with a posterior probability pp > 0.99 are displayed in color. DAN = Dorsal attention network ; SMN = Sensorimotor network ; LN = Limbic network ; SN = Salience network ; DMN = Default mode network ; CEN = Central executive network ; SMA = Supplementary motor area; Oper = Rolandic operculum ; SPL = Superior parietal lobule

; MTG = Middle temporal gyrus ; MOG = Middle occipital gyrus ; IFG = Inferior frontal gyrus ; SFG = Superior frontal gyrus ; MCC = Middle cingulate cortex ; PHC = Parahippoccampal cortex ; Cereb = Cerebellum ; Ins = Insula ; MFG = Middle frontal gyrus ; AG = Angular gyrus ; MedFG = extended Median frontal region ; L = Left ; R = Right ; FD = Framewise displacement. The charts were created using the Statistical Parametric Mapping toolbox (SPM12, Update Revision Number 7771, https://www.fil.ion.ucl.ac.uk/spm/), implemented in MATLAB (R2022a, Version: 9.12.0.2327980, Natick, Massachusetts: The MathWorks Inc, https://www.mathworks.com). The layout was done with Microsoft® PowerPoint software (version 16.87, https://www.microsoft.com).

CEN

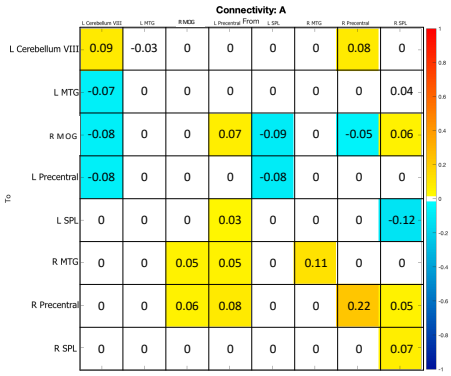


Patients > HV

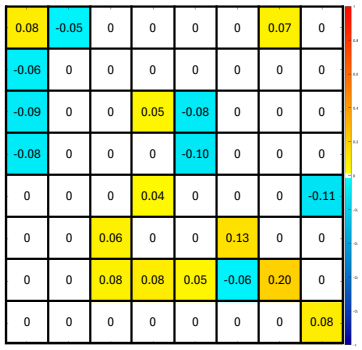


Patients > HV

DAN

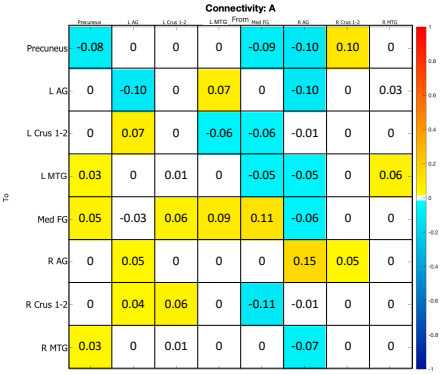


Patients > HV

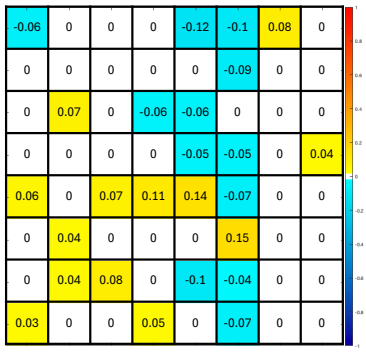


Patients > HV

DMN

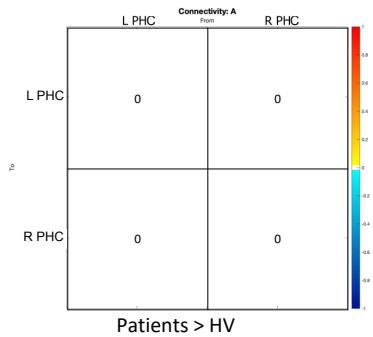


Patients > HV

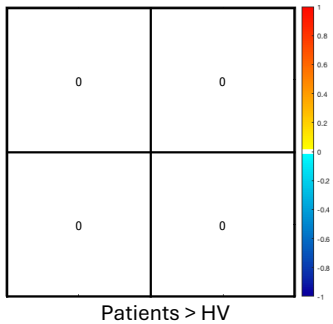


Patients > HV

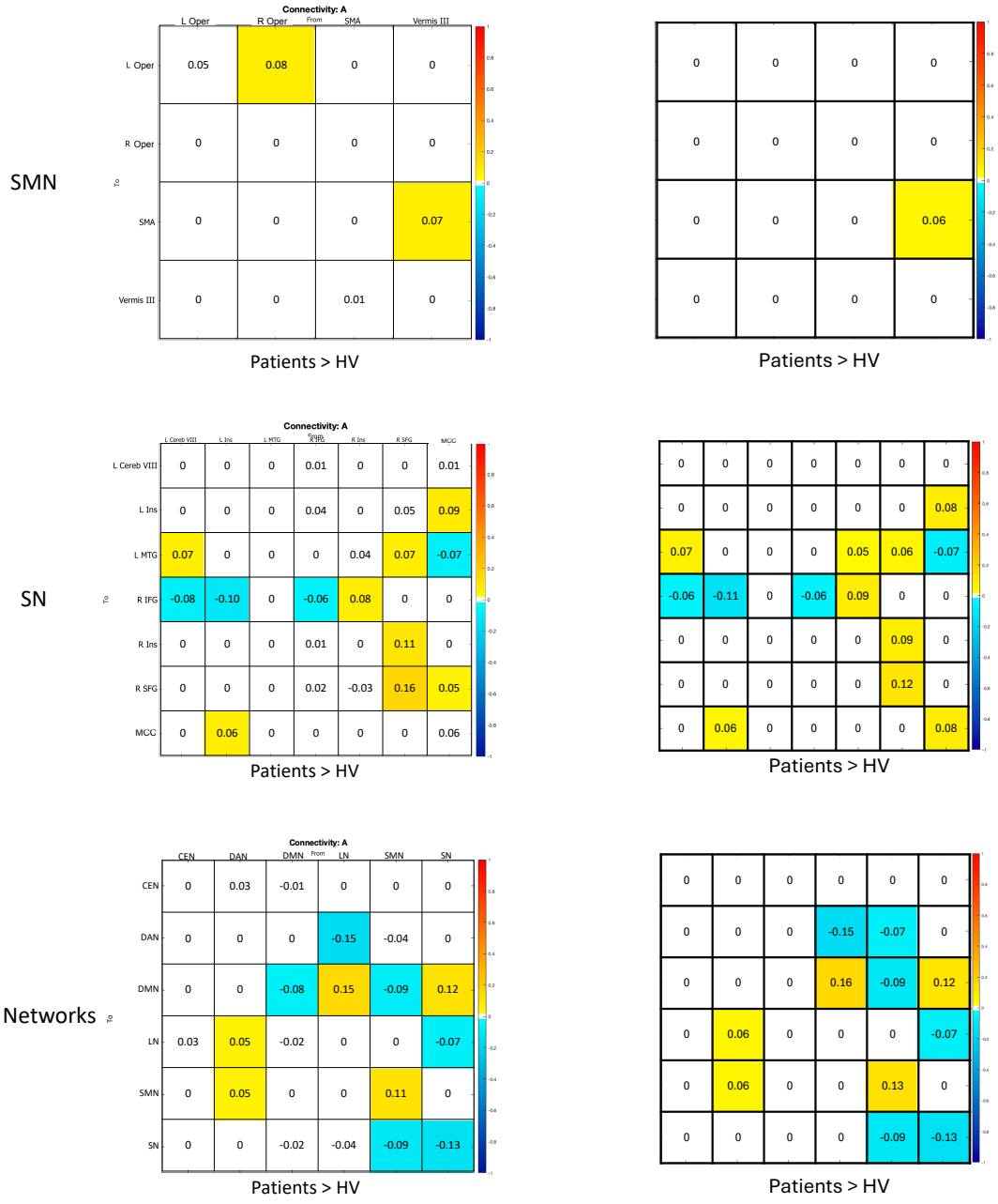
LN



Patients > HV



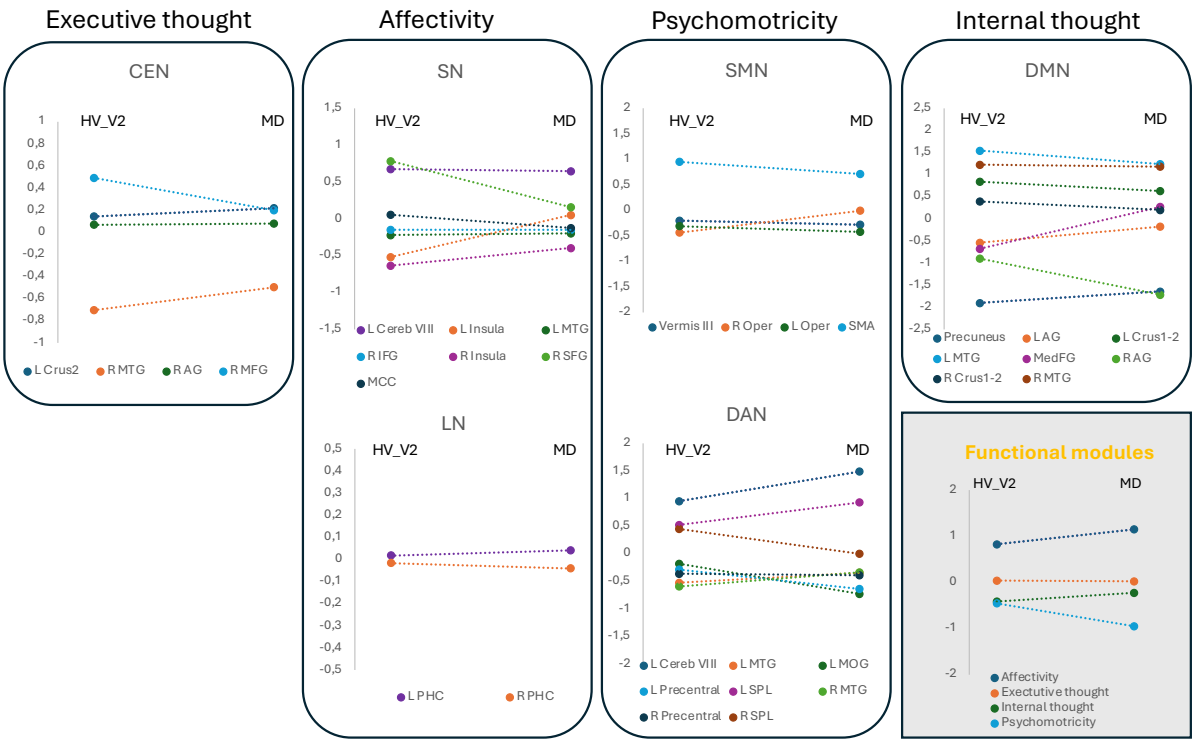
Patients > HV



Supplementary Fig.4. Effect of group depending on the exclusion of volunteers with psychiatric symptoms.

Matrix A of each parameter in the model after Bayesian model averaging (nodes are in the same order on both the left and right charts). The left and the right charts represent respectively the between-group effect of the initial analysis and of the same analysis after excluding the two volunteers with psychiatric symptoms. Values and color represent the effect-size of each parameter. Red circles indicate connections with effects going in the same direction across the contrasts. Only parameters with a posterior probability pp > 0.99 are displayed in color. DAN = Dorsal attention network ; SMN = Sensorimotor network ; LN = Limbic network ; SN =

Salience network ; DMN = Default mode network ; CEN = Central executive network ; SMA = Supplementary motor area; Oper = Rolandic operculum ; SPL = Superior parietal lobule ; MTG = Middle temporal gyrus ; MOG = Middle occipital gyrus ; IFG = Inferior frontal gyrus ; SFG = Superior frontal gyrus ; MCC = Middle cingulate cortex ; PHC = Parahippoccampal cortex ; Cereb = Cerebellum ; Ins = Insula ; MFG = Middle frontal gyrus ; AG = Angular gyrus ; MedFG = extended Median frontal region ; L = Left ; R = Right. The charts were created using the Statistical Parametric Mapping toolbox (SPM12, Update Revision Number 7771, https://www.fil.ion.ucl.ac.uk/spm/), implemented in MATLAB (R2022a, Version: 9.12.0.2327980, Natick, Massachusetts: The MathWorks Inc, https://www.mathworks.com). The layout was done with Microsoft® PowerPoint software (version 16.87, https://www.microsoft.com).



Supplementary Fig.5. Hierarchical organization of networks between groups after excluding volunteers with psychiatric symptoms.

Comparison of the hierarchical organization within each network and of functional modules between the groups of volunteers, after excluding the two volunteers with psychiatric disorders (HV_V2), and patients (MD). Nodes at the top act as drivers, while nodes at the bottom serve as sinks. Only connections that differed between groups were considered. DAN = Dorsal attention network ; SMN = Sensorimotor network ; LN = Limbic network ; SN = Salience network ; DMN = Default mode network ; CEN = Central executive network ; SMA = Supplementary motor area; Oper = Rolandic operculum ; SPL = Superior parietal lobule ; MTG = Middle temporal gyrus ; MOG = Middle occipital gyrus ; IFG = Inferior frontal gyrus ; SFG = Superior frontal gyrus ; MCC = Middle cingulate cortex ; PHC = Parahippoccampal cortex ; Cereb = Cerebellum ; Ins = Insula ; MFG = Middle frontal gyrus ; AG = Angular gyrus ; MedFG = extended Median frontal region ; L = Left ; R = Right.