Brain dynamics: synchronous peaks, functional connectivity, and its temporal variability

Supplementary Material

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Participants

Human Connectome Project dataset

The dataset was selected from the Mar 2017 public data release from the Human Connectome Project (HCP, N = 1200), WU-Minn Consortium. The sample included 1017 subjects (ages 22–35 years, 546 females) scanned on a 3-T Siemens connectome-Skyra scanner. Two resting state fMRI acquisitions on different days were used. The four resting-state runs of approximately 15 minutes each were acquired in separate sessions on two different days, with the eyes open with relaxed fixation on a projected bright cross-hair on a dark background. The WU-Minn HCP Consortium obtained full informed consent from all participants, and research procedures and ethical guidelines were followed in accordance with the Institutional Review Boards (IRB). The major parameters for the neuroimaging acquisition were as follows (Glasser, et al., 2013). Resting-state fMRI data were acquired using a 3T MRI scanner (Siemens) in a 15-min period in which the participants were awake in the scanner. A total of 1200 volumes of images were obtained (TR/TE: 720/33 ms, Flip angle 52 degree, matrix size: 104 90, FOV = 208 180 mm^2, slices 72). Further details of the subjects, and the collection and preprocessing of the data are provided at the HCP website (http://www.humanconnectome.org/) and in previous studies (Cheng, et al., 2018).

Data preprocessing

The HCP data pre-processing was carried out using FSL (FMRIB Software Library), FreeSurfer, and the Connectome Workbench software. All the data preprocessing procedures were performed by the Human Connectome Project (HCP) as described in (Glasser, et al., 2013). The data preprocessing included correction for spatial and gradient distortions and head motion, intensity normalization and bias field removal, registration to the T1 weighted structural image, transformation to 2 mm Montreal Neurological Institute (MNI) space, and the FIX artefact removal procedure(Navarro Schroder, et al., 2015; Smith, et al., 2013). Finally, the head motion parameters were regressed out and structured artefacts were removed by ICA+FIX processing (Independent Component Analysis followed by FMRIB's ICA-based X-noiseifier (Griffanti, et al., 2014; Salimi-Khorshidi, et al., 2014)). (We further note that the Pearson correlation between head motion (mean FD) and the frequency of synchronization events was 0.045 ($p = 0.149$), providing clear evidence that the synchronization events were not driven by head motions during the scanning. Further, we note that great care was taken as described above to regress out any effects that might be related to head motion.) The data preprocessing pipeline developed by FMRIB (Oxford University Centre for Functional MRI of the Brain) used here has been widely used in resting state fMRI studies (Colclough, et al., 2017; Navarro Schroder, et al., 2015; Smith, et al., 2015; Vidaurre, et al., 2018). This pipeline is efficient in removing noise, and regressing out the global signal etc is not involved (Griffanti, et al., 2014; Salimi-Khorshidi, et al., 2014).

Table S1. The anatomical regions defined in each hemisphere and their label in the automated anatomical labelling atlas AAL2 (Rolls, et al., 2015). The regions that have been redefined in AAL3 (Rolls, et al., 2020) are shown in italics. Column 4 provides a set of possible abbreviations for the anatomical descriptions.

NO.	ANATOMICAL DESCRIPTION	LABEL aal2.nii.gz	POSSIBLE ABBREVIATION
1,2	Precentral gyrus	Precentral	PreCG
3, 4	Superior frontal gyrus, dorsolateral	Frontal_Sup	SFG
5, 6	Middle frontal gyrus	Frontal_Mid	MFG
7, 8	Inferior frontal gyrus, opercular part	Frontal_Inf_Oper	IFGoperc
9, 10	Inferior frontal gyrus, triangular part	Frontal_Inf_Tri	IFGtriang
11, 12	IFG pars orbitalis,	Frontal_Inf_Orb	IFGorb
13, 14	Rolandic operculum	Rolandic_Oper	ROL
15, 16	Supplementary motor area	Supp_Motor_Area	SMA
17, 18	Olfactory cortex	Olfactory	OLF
19, 20	Superior frontal gyrus, medial	Frontal_Sup_Med	SFGmedial
21, 22	Superior frontal gyrus, medial orbital	Frontal_Med_Orb	PFCventmed
23, 24	Gyrus rectus	Rectus	REC
25, 26	Medial orbital gyrus	OFCmed	OFCmed
27, 28	Anterior orbital gyrus	OFCant	OFCant
29, 30	Posterior orbital gyrus	OFCpost	OFCpost
31, 32	Lateral orbital gyrus	OFClat	OFClat
33, 34	Insula	Insula	INS
35, 36	*Anterior cingulate & paracingulate gyri*	Cingulate_Ant	ACC
37, 38	Middle cingulate & paracingulate gyri	Cingulate_Mid	MCC
39, 40	Posterior cingulate gyrus	Cingulate_Post	PCC
41, 42	Hippocampus	Hippocampus	HIP
43, 44	Parahippocampal gyrus	ParaHippocampal	PHG
45, 46	Amygdala	Amygdala	AMYG
47, 48	Calcarine fissure and surrounding cortex	Calcarine	CAL
49, 50	Cuneus	Cuneus	CUN
51, 52	Lingual gyrus	Lingual	LING
53, 54	Superior occipital gyrus	Occipital_Sup	SOG
55, 56	Middle occipital gyrus	Occipital_Mid	MOG
57, 58	Inferior occipital gyrus	Occipital_Inf	IOG
59, 60	Fusiform gyrus	Fusiform	FFG
61, 62	Postcentral gyrus	Postcentral	PoCG
63, 64	Superior parietal gyrus	Parietal_Sup	SPG
65, 66	Inferior parietal gyrus, excluding supramarginal and angular gyri	Parietal_Inf	IPG
67, 68	SupraMarginal gyrus	SupraMarginal	SMG
69, 70	Angular gyrus	Angular	ANG
71, 72	Precuneus	Precuneus	PCUN
73, 74	Paracentral lobule	Paracentral_Lobule	PCL
75, 76	*Caudate nucleus*	Caudate	CAU
77, 78	*Lenticular nucleus, Putamen*	Putamen	PUT
79, 80	Lenticular nucleus, Pallidum	Pallidum	PAL
81, 82	*Thalamus*	Thalamus	THA
83, 84	Heschl’s gyrus	Heschl	HES
85, 86	Superior temporal gyrus	Temporal_Sup	STG
87, 88	Temporal pole: superior temporal gyrus	Temporal_Pole_Sup	TPOsup
89, 90	Middle temporal gyrus	Temporal_Mid	MTG
91, 92	Temporal pole: middle temporal gyrus	Temporal_Pole_Mid	TPOmid

93, 94	Inferior temporal gyrus	Temporal_Inf	ITG
95, 96	Crus I of cerebellar hemisphere	Cerebellum_Crus1	CERCRU1
97, 98	Crus II of cerebellar hemisphere	Cerebellum_Crus2	CERCRU2
99, 100	Lobule III of cerebellar hemisphere	Cerebellum_3	CER3
101, 102	Lobule IV, V of cerebellar hemisphere	Cerebellum_4_5	CER4_5
103, 104	Lobule VI of cerebellar hemisphere	Cerebellum_6	CER6
105, 106	Lobule VIIB of cerebellar hemisphere	Cerebellum_7b	CER7b
107, 108	Lobule VIII of cerebellar hemisphere	Cerebellum_8	CER8
109, 110	Lobule IX of cerebellar hemisphere	Cerebellum_9	CER9
111, 112	Lobule X of cerebellar hemisphere	Cerebellum_10	CER10
113	Lobule I, II of vermis	Vermis_1_2	VER1_2
114	Lobule III of vermis	Vermis_3	VER3
115	Lobule IV, V of vermis	Vermis_4_5	VER4_5
116	Lobule VI of vermis	Vermis_6	VER6
117	Lobule VII of vermis	Vermis_7	VER7
118	Lobule VIII of vermis	Vermis_8	VER8
119	Lobule IX of vermis	Vermis_9	VER9
120	Lobule X of vermis	Vermis_10	VER10

Table S2. The extra anatomical regions defined in AAL3 in each hemisphere and their label (Rolls, et al., 2020). Column 4 provides a set of possible abbreviations for the anatomical descriptions. In AAL3, the label shown in column 3 is followed by the number shown in column 1. In most cases, the first number in a row is for the left hemisphere, and the second number is for the right hemisphere. This does not apply to the raphe nuclei, which are midline structures.

NO.	ANATOMICAL DESCRIPTION	LABEL AAL3.nii.gz	POSSIBLE ABBREVIATION
121, 122	Thalamus, Anteroventral Nucleus	Thal_AV	tAV
123, 124	Lateral posterior	Thal_LP	tLP
125, 126	Ventral anterior	Thal_VA	tVA
127, 128	Ventral lateral	Thal_VL	tVL
129, 130	Ventral posterolateral	Thal_VPL	tVPL
131, 132	Intralaminar	Thal_IL	tIL
133, 134	Reuniens	Thal_Re	tRe
135, 136	Mediodorsal medial magnocellular	Thal_MDm	tMDm
137, 138	Mediodorsal lateral parvocellular	Thal_MDl	tMDl
139, 140	Lateral geniculate	Thal_LGN	tLGN
141, 142	Medial Geniculate	Thal_MGN	tMGN
143, 144	Pulvinar anterior	Thal_PuA	tPuA
145, 146	Pulvinar medial	Thal_PuM	tPuM
147, 148	Pulvinar lateral	Thal_PuL	tPuL
149, 150	Pulvinar inferior	Thal_PuI	tPuI
151, 152	Anterior cingulate cortex, subgenual	ACC_sub	ACCsub
153, 154	Anterior cingulate cortex, pregenual	ACC_pre	ACCpre
155, 156	Anterior cingulate cortex, supracallosal	ACC_sup	ACCsup
157, 158	Nucleus accumbens	N_Acc	Nacc
159, 160	Ventral tegmental area	VTA	VTA
161, 162	Substantia nigra, pars compacta	SN_pc	SNpc
163, 164	Substantia nigra, pars reticulata	SN_pr	SNpr
165, 166	Red nucleus	Red_N	RedN
167, 168	Locus coeruleus	LC	LC
169	Raphe nucleus, dorsal	Raphe_D	RapheD
170	Raphe nucleus, median	Raphe_M	RapheM

References

Cheng, W., Rolls, E.T., Ruan, H., Feng, J. (2018) Functional connectivities in the brain that mediate the association between depressive problems and sleep quality. JAMA Psychiatry, 75:1052-1061.

Colclough, G.L., Smith, S.M., Nichols, T.E., Winkler, A.M., Sotiropoulos, S.N., Glasser, M.F., Van Essen, D.C., Woolrich, M.W. (2017) The heritability of multi-modal connectivity in human brain activity. Elife, 6.

Glasser, M.F., Sotiropoulos, S.N., Wilson, J.A., Coalson, T.S., Fischl, B., Andersson, J.L., Xu, J., Jbabdi, S., Webster, M., Polimeni, J.R., Van Essen, D.C., Jenkinson, M., Consortium, W.U.-M.H. (2013) The minimal preprocessing pipelines for the Human Connectome Project. Neuroimage, 80:105-24.

Griffanti, L., Salimi-Khorshidi, G., Beckmann, C.F., Auerbach, E.J., Douaud, G., Sexton, C.E., Zsoldos, E., Ebmeier, K.P., Filippini, N., Mackay, C.E., Moeller, S., Xu, J., Yacoub, E., Baselli, G., Ugurbil, K., Miller, K.L., Smith, S.M. (2014) ICA-based artefact removal and accelerated fMRI acquisition for improved resting state network imaging. Neuroimage, 95:232-47.

Navarro Schroder, T., Haak, K.V., Zaragoza Jimenez, N.I., Beckmann, C.F., Doeller, C.F. (2015) Functional topography of the human entorhinal cortex. Elife, 4:e06738.

Rolls, E.T., Huang, C.C., Lin, C.P., Feng, J., Joliot, M. (2020) Automated anatomical labelling atlas 3. Neuroimage, 206:116189.

Rolls, E.T., Joliot, M., Tzourio-Mazoyer, N. (2015) Implementation of a new parcellation of the orbitofrontal cortex in the automated anatomical labeling atlas. Neuroimage, 122:1-5.

Salimi-Khorshidi, G., Douaud, G., Beckmann, C.F., Glasser, M.F., Griffanti, L., Smith, S.M. (2014) Automatic denoising of functional MRI data: combining independent component analysis and hierarchical fusion of classifiers. Neuroimage, 90:449-68.

Smith, S.M., Beckmann, C.F., Andersson, J., Auerbach, E.J., Bijsterbosch, J., Douaud, G., Duff, E., Feinberg, D.A., Griffanti, L., Harms, M.P., Kelly, M., Laumann, T., Miller, K.L., Moeller, S., Petersen, S., Power, J., Salimi-Khorshidi, G., Snyder, A.Z., Vu, A.T., Woolrich, M.W., Xu, J., Yacoub, E., Ugurbil, K., Van Essen, D.C., Glasser, M.F., Consortium, W.U.-M.H. (2013) Resting-state fMRI in the Human Connectome Project. Neuroimage, 80:144-68.

Smith, S.M., Nichols, T.E., Vidaurre, D., Winkler, A.M., Behrens, T.E., Glasser, M.F., Ugurbil, K., Barch, D.M., Van Essen, D.C., Miller, K.L. (2015) A positive-negative mode of population covariation links brain connectivity, demographics and behavior. Nat. Neurosci., 18:1565-7.

Vidaurre, D., Abeysuriya, R., Becker, R., Quinn, A.J., Alfaro-Almagro, F., Smith, S.M., Woolrich, M.W. (2018) Discovering dynamic brain networks from big data in rest and task. Neuroimage, 180:646-656.