Study of Extra-visual Resting-state Networks in Pituitary Adenoma Patients With Vision Restoration

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Abstract

Background: Pituitary adenoma(PA) may compress the optic apparatus and cause impaired vision. Some patients can get improved vision rapidly after surgery. During the early time after surgery, however, the change of neurofunction in extra-visual cortex and higher cognitive cortex is still yet to be explored so far.

Objective: Our study is focused on the changes in the extra-visual resting-state networks in PA patients after vision restoration.

Methods:We recruited 14 PA patients with visual improvement after surgery. The functional connectivity (FC) of 6 seeds (auditory cortex (A1), Broca's area, posterior cingulate cortex (PCC)for default mode network (DMN), right caudal anterior cingulate cortex for salience network(SN) and left dorsolateral prefrontal cortex for executive control network (ECN)) were evaluated. A paired t-test was conducted to identify the differences between two groups.

Results: Compared with the preoperation counterparts, the PA patients with improved vision exhibited decreased FC with right A1 was identified in left insula lobule, right middle temporal gyrus and left postcentral gyrus, and increased FC in the right paracentral lobule; decreased FC with broca in left middle temporal gyrus, and increased FC in left Insula lobule and right thalamus; decreased FC with DMN in right declive, and right precuneus, and increased FC in right brodmann area 17, left cuneus and right posterior cingulate; decreased FC with ECN in right posterior cingulate, right angular and right precuneus; decreased FC with SN in right middle temporal gyrus, right hippocampus, and right precuneus, and increased FC in right fusiform gyrus, left lingual gyrus and right brodmann area 19.

Conclusions: The vision restoration may cause the response of cross-modal plasticity and the multisensory system related to A1 and broca. The DMN and SN may involve in top-down control on the subareas within vision cortex. The precuneus may involve in DMN, ECN and SN simultaneously.

Background

The experience-dependent plasticity exhibits the ability to shape the visual cortex and maintain its normal function. It is not only presented in the developing visual cortex, but also in the adult visual cortex [1]. Therapeutic interventions can also trigger plastic changes in the ageing visual cortex by restoring vision. The cataract surgery induced a use-dependent structural plasticity in the secondary visual cortex (V2) by restoring impaired vision and activity-dependent cortical plasticity was preserved in the ageing visual cortex [2]. The responses to motion in dorsal visual pathway bilaterally decreased and to faces in the right ventral visual pathway increased after visual restoration [3]. In those PA patients who had improved vision at about 3 months after the operation, the results showed that regional homogeneity (ReHo) decreased or increased within the visual cortex[4]. Most of these studies focused on the neuroplasticity change within the vision cortex, actually the visual restoration can lead to plasticity in the subareas of the multisensory and multimodal systems beyond the vision cortex[4].

The cross-modal plasticity refers to the capacity to develop structural and functional changes to execute other intact senses when loss of a sense input. For compensation, the brain develops or strengthens corticocortical or subcortical connections between the deprived and intact senses [5, 6]. The loss of vision from birth triggers a lot of compensatory plastic changes. The occipital cortex can be recruited by other non-visual inputs because of the cross-modal reorganization of the brain [7]. The primary visual cortex (V1) was found to process auditory signals in low-vision and blind individuals [7, 8, 9, 10, 11]. The visual cortex in congenitally blind humans can control speech function and semantic processing [12, 13]. The auditory cortex can also process vision in deaf adults [14, 15, 16]. Although many studies have showed cross-modal plasticity in the loss of a vision input, little has been reported about this neuroplastic change of the brain when vision recovery.

The visual cortex in congenitally blind humans exhibits decreased functional connectivity (FC) with the frontal motor, parietal somatosensory and temporal multi-sensory areas [17] and increased FC with the inferior frontal triangular areas [18]. Many studies show that the visual cortex dynamically interacts with higher cognitive areas [19, 20]. In pituitary adenoma (PA) patients with visual impairment, the author identified increased FC between the visual cortex and subareas in default mode network (DMN) and salience network (SN) [21]. Much of these studies exploring the connection between vision cortex and other higher cognitive areas mainly focused on early blind or low vision people. No study has been reported about this neuroplasticity change of the brain after vision restoration so far. The function connection changes between vision cortex and higher cognitive areas in patients with vision recovery remain unclear.

PA may compress the optic apparatus and cause impaired vision. The endoscopic transsphenoidal surgery is minimal invasive and do not damage the visual cortex and neighbouring areas. Some patients can get improved vision rapidly after surgery. During the early time after surgery, however, the change of neurofunction in extra-visual cortex and higher cognitive cortex is still yet to be explored so far. So we enrolled PA patients with improved vision at about 3 days after transsphenoidal operation. Our study is focused on the changes in the extra-visual resting-state networks in PA patients after vision restoration. Furthermore, it is aimed to explore the plasticity of the auditory, language and higher cognitive networks that extend beyond the visual cortex after vision improvement.

Materials And Methods

Subjects

14 PA patients with the visual damage were recruited in this study. All those patients underwent endoscopic transsphenoidal surgery and had improved vision rapidly after the surgery. The inclusion criteria consist: Age varied between 18 and 65 years; the corrected vision acuity was below 1.0 (20/20) before the operation, no ophthalmologic diseases or other intracranial lesions that disturbed the visual apparatus or cortex was found; vision recovery at the 3 day after surgery (the corrected vision acuity improved by more than 0.2 at least unilaterally) were required; and no severe electrolyte imbalance,

hypopituitarism or other complications occurred after surgery. This study was approved by the Ethics Committee of Hospital. Written informed consent was obtained from the patients.

Data Acquisition

The patients were scanned one day preoperatively and three days postoperatively on a 1.5 T MR system (Espree, Siemens Medical Solution, Erlangen, Germany) in the diagnostic room of iMRI brain suite[22]. We used foam pad to minimize head movement and earplugs to reduce surrounding noise during scanning. During the resting-state functional MRI (RS-fMRI) scan, we told the patients to remain motionless and keep their eyes closed and think nothing. RS-fMRI data were acquired using an echo-planar image pulse sequence (slice thickness = 4.5 mm, flip angle = 90°, and field of view [FOV] = 224 mm × 224 mm, TR: 2000 ms TE: 45 ms.)

Clinical And Neuro-ophthalmologic Assessments

The cognition of all patients was evaluated with the mini-mental state examination before surgery. The ophthalmologic examination was performed within 2 days prior to the operation and at about 3 days after the operation. The best-corrected visual acuity was measured for distance with the E chart and reported in the decimal scale. The ophthalmic fundus examination was made with a nonmydriatic retinal camera (Topcon, Japan).

Data Preprocessing

The RS-fMRI data was preprocessed with SPM8 ([http:// www.fil.ion.ucl.ac.uk/spm](http://www.fil.ion.ucl.ac.uk/spm)) and a pipeline analysis toolbox, DPARSF (<http://www.restfmri.net/>)[23]. The first ten volumes were deleted for signal equilibrium. The next data processes consisted of slice timing correction, head motion correction, normalization, smoothing, removing linear trend, filtering (0.01–0.08 Hz).

Fc And Statistical Analysis

Regions of interest (ROIs) were taken from the literature[24, 25, 26, 27]. They were defined as 6-mm radius spheres in both hemispheres. We selected 6 seeds to assess FC (Table 1). These seeds were selected within the extra-visual area (auditory cortex (A1), Broca's area, posterior cingulate cortex (PCC)/ precuneus for the DMN, right caudal anterior cingulate cortex for the SN and left dorsolateral prefrontal cortex for the executive control network (ECN).

Table 1
Regions of interest (ROIs).

	Left hemisphere			Right hemisphere			Literature reference
	X	Y	Z	X	Y	Z	
AREAS							
A1/BA41	-42	-21	7	56	-13	8	Rademacher etal. 2001
Broca	-42	26	17				Binkofski et al. 2000
DMN	-4	-52	22				Laird et al. 2009
ECN	-32	41	13				Seeley et al. 2007
SN				4	16	33	Seeley et al. 2007

First, non-neuronal-related covariates, including six parameters of head motion correction, the average time courses of the whole brain (global mean signal), the average time courses within the white matter mask, and the average time courses within the cerebral spinal fluid (CSF) mask, were removed from the preprocessed data by linear regression analysis. Then the images were smoothed with a 6-mm FWHM Gaussian kernel. The individual r-maps were normalized to Z-maps by using Fisher's Z transformation. A paired t-test was used on the Fisher's Z maps to present significant differences in correlation between the two groups. The AlphaSim method was used to correct for multiple comparisons. The corrected value of $p < 0.05$ (uncorrected $p < 0.001$ and a minimum of 40 voxels in a cluster) was chose as the threshold.

Results

Studied population

14 patients (male/female 7:7) were included in the final analyses. Mean age was 46.3 (Range 24–62 years). The main demographic and clinical characteristics of the patients were listed in Table 2.

Table 2
The main demographic and clinical characteristics of the patients

No.	Age(Years)	Vision impairment Duration(months)	Visual acuity(preop/postop)	
			left	right
1	44	6	1/1	0.2/0.5
2	54	2	0.15/0.2	0.1/0.3
3	49	10	0.5/0.8	1/1
4	55	24	0.4/0.6	0.6/0.8
5	46	12	0.2/0.5	0.3/0.4
6	65	1	1/1	0.6/0.8
7	31	2	0.8/0.8	0.4/0.6
8	54	6	0.6/0.9	0.8/0.8
9	46	12	0.3/0.5	0.4/0.5
10	62	12	0.15/0.4	0.8/0.8
11	52	39	0.15/0.4	0.8/0.8
12	40	24	0.5/0.6	0.3/0.5
13	26	0.25	0.8/0.8	0.15/0.4
14	24	24	1/1	0.6/0.9

Rs-fmri Analysis

Differences in FC after surgery (auditory ROIs).

Compared with the preoperative counterparts, decreased FC with right A1 was identified in left insula lobule, right middle temporal gyrus and left postcentral gyrus (Fig. 1, Table 3). Increased FC with right A1 was identified in the right paracentral lobule(Fig. 1, Table 3).

Table 3
Group differences in FC (postoperative vs. preoperative)

Seed	Brain region	Peak intensity	Peak MNI coordinate			Cluster Size (voxels)
			x	y	z	
auditory (R)	Insula(L)	-8.0798	-36	-9	-12	61
	Middle Temporal Gyrus(R)	-6.7219	60	-21	-9	63
	Postcentral Gyrus(L)	-8.2551	-60	-12	18	47
	Paracentral Lobule(R)	8.1151	6	-42	51	80
broca	Middle Temporal Gyrus(L)	-7.8379	-60	-12	-15	56
	Insula(L)	7.3353	-36	-12	-6	56
	Thalamus(R)	8.8303	18	-12	9	62
DMN	Declive(R)	-8.282	3	-78	-30	73
	Brodmann area 17(R)	7.976	12	-105	-3	45
	Cuneus(L)	6.0238	-6	-87	15	49
	Posterior Cingulate(R)/BA 30	8.5754	18	-60	9	51
	Cingulate Gyrus(L)	-12.2874	-3	-18	27	48
	Precuneus(R)	-6.8185	9	-63	36	43
ECN	Posterior Cingulate(R)	-6.5355	9	-39	21	46
	Angular(R)	-8.0772	33	-57	30	80
	Precuneus(R)	-5.6647	9	-48	60	58
SN	Fusiform Gyrus(R)	6.9667	33	-69	-15	74
	Lingual Gyrus(L)/BA 19	5.9544	-9	-60	-3	64
	Middle Temporal Gyrus(R)	-6.5879	63	-39	-6	44
	Hippocampus(R)	-7.8909	33	-18	-9	92
	Brodmann area 19(R)	5.9635	42	-84	3	42
	Corpus Callosum(R)	-7.6753	15	9	24	44
	Precuneus(R)	-7.239	3	-63	24	51

Differences in FC after surgery (language ROIs).

Compared with the preoperative counterparts, decreased FC with broca was identified in left middle temporal gyrus(Fig. 2, Table 3). Increased FC with broca was identified in left insula lobule and right thalamus (Fig. 2, Table 3).

Differences in FC after surgery (DMN ROIs).

Compared with the preoperative counterparts, decreased FC with DMN was identified in right declive, left cingulate gyrus and right precuneus(Fig. 3, Table 3). Increased FC with DMN was identified in right brodmann area 17, left cuneus and right posterior cingulate/BA 30(Fig. 3, Table 3).

Differences in FC after surgery (ECN ROIs).

Compared with the preoperative counterparts, decreased FC with ECN was identified in right posterior cingulate, right angular and right precuneus(Fig. 4, Table 3).

Differences in FC after surgery (SN ROIs).

Compared with the preoperative counterparts, decreased FC with SN was identified in right middle temporal gyrus, right hippocampus, right corpus callosum and right precuneus(Fig. 5, Table 3). Increased FC with SN was identified in right fusiform gyrus, left lingual gyrus/BA 19 and right brodmann area 19(Fig. 5, Table 3).

Discussion

RS-fMRI is non-invasive measure of neuronal function when patients are at rest [28, 29]. FC is widely used in RS-fMRI studies. FC refers to the temporal correlation between spatially remote neurophysiological events [30]. FC analyses can offer high spatial resolution and high spatial specificity relative to where the corresponding changes in neurophysiological signals take place [31]. We investigated FC in extra-visual resting-state networks in pituitary adenoma patients with vision restoration using a seed-based approach with a priori defined ROIs. Our data revealed a mixture of increases and decreases in FC in the brain network.

Our data showed that the decreased FC with right A1 in the right middle temporal gyrus (MT). The results may imply that there was coexist neural connection between the right A1 and MT, and the FC decreased when vision restoration. The middle temporal complex (MT/MST) is area specialized for the procession of motion vision [32, 33, 34, 35]. Recent studies also show that the visual motion area MT+/V5 responds to auditory motion [36, 37]. In sighted individuals, MT/MST responds to motion perception in the visual modality, but not to sound [35]. In contrast, MT/MST of congenitally blind individuals responds to auditory and tactile motion [38]. So blindness can cause a multi-modal response in MT/MST. In early blind individuals who got partial visual restoration in adulthood, auditory motion responses within the MT/V5 area. So Saenz et al.[36]concluded that auditory and visual responses coexist after vision restoration. Jiang et al. [10] showed auditory motion responses increased in the MT area and decreased in the right planum temporale in sight-recovery subjects. So authors proposed that the cortical plasticity

that caused by early blindness is permanent and can persist even after visual restoration. The neuroplasticity may have an adaptive or maladaptive effect on restoration of the deprived sense [9]. Strelnikov, et al. [39] showed that synergy between the auditory and visual areas play a key role on the cross-modal plasticity. Alink, et al.[40]show that auditory motion complex and the visual motion area hMT/V5 + are involved in the generation of cross-modal dynamic capture illusion and the audiovisual integration occurs in early motion areas. Our results may imply that coexisting neural connection between the right A1 and MT + decreased after vision restoration. To the best of our knowledge, we do not find a possible reason for the decreased FC of the right A1 and MT+, more fMRI studies are needed in the future.

It is widely accepted that the occipital cortex of blind human is involved in language processing [13]. Braille reading in blind individuals triggers a large scale network of brain cortex, including posterior and medial occipital areas, fusiform gyrus, area hMT+, inferior temporal gyrus, inferior frontal, prefrontal, intraparietal sulcus, and somatosensory motor areas [41]. In congenitally blind subjects, the increased connectivity between visual cortex and Broca's area might relate to the role of the occipital cortex in semantic processing. [13, 42]. Deen, et al.[42]proposed that there is co-activation between the Broca's area and most of the occipital cortex. Ricciardi, et al. (2007) [38]showed that the increased FC between Broca's area and hMT + might be relate to the role of tactile flow processing in Braille reading. There are two explanations about the mechanisms of cross-modal plasticity in the occipital cortex. One is that the cross-modal plasticity arise through enhancing of existing bottom-up sensory connections from sensory areas, and sensory thalamic input during development can reorganize cortical function. The other is that cross-modal plasticity in blind adults is activated by top-down feedback from higher-order polymodal and amodal cortices. [43, 13].Our results may imply that FC between Broca and left middle temporal gyrus decreased after visual restoration. However, the mechanism resulting in functional alteration in Broca after vision restoration is still to be elucidated, more fMRI studies are needed in the future.

Our data show that the decreased FC with right A1 was identified in left insula lobule, left postcentral gyrus and increased FC with right A1 in the right paracentral lobule. Increased FC with Broca was identified in left insula lobule and right thalamus. The left insula lobule, left postcentral gyrus, right paracentral lobule, right thalamus are subareas of the multisensory system [44]. The multisensory system at the cortical locations consist of the frontal lobe, temporal lobe, parietal lobe and insular. The multisensory system at the subcortical locations involve the superior colliculus and basal ganglia [44, 45]. Insular lesions can result in a multisensory deficiency [46]. The anterior insular has connections with the orbital- frontal lobe, thalamus and limbic lobe. The posterior insular has connections with the frontal, temporal, parietal lobe and thalamus[47, 48]. The thalamus play a crucial role in multisensory integration processes [49]. It has been accepted that early sensory experience plays an important role in shaping the development of the neural circuitry underlying multisensory processes. In lid-sutured monkeys, studies showed that visual and multisensory areas lose responsiveness to visual stimulation [50, 51, 52]. In dark-reared cats, studies showed that multisensory neurons at cortical and subcortical sites cannot integrate cross-modal inputs [53, 54].In individuals with congenital dense bilateral cataracts, studies have revealed that their ability to integrate more complex cross-modal stimuli (e.g. speech input) is impaired [55, 56], despite a gain in reaction times for simple cross-modal stimuli (e.g. simultaneously presented light

flashes and noise bursts) as compared to their unimodal counterparts [57]. Some studies have proposed that superior temporal areas (particularly, the superior temporal sulcus) was critical sites for multisensory audio-visual integration [58, 59]. Calvert, et al.[58]have showed that multisensory audio-visual integration was within extrastriate visual areas. When brain receives streams of information from multiple sensory modalities, visual information was more frequently preferentially processed than the other sensory modalities. Multisensory information competes for preferential access to consciousness. In terms of multisensory competition, neural representations in the dominant sensory modality may suppress neural representations in the dominated modalities. Weissman, et al.[60]reported that enhanced prestimulus activity in the prefrontal cortex and decreased prestimulus activity in the DMN predicted better task performance. Some connectivity study about the visual and auditory activity showed that the sensory systems have dynamic interaction with the prefrontal cortex, the sensorimotor cortex, and the DMN during multisensory competition. The mechanism of multisensory competition is still unclear. One theory is the top-down control from the prefrontal cortex to dominate the outcome of multisensory competition. The other is the bottom-up processing in the sensory systems decide result of the winner. Huang, et al. [61]revealed that visual dominance originated from top-down control, while auditory dominance originated from altered sensory processing in the auditory cortex. Our data show that the functional connection between right A1 and left insula lobule and left postcentral gyrus decreased and between right A1 and right paracentral lobule increased. The functional connection between Broca and left Insula lobule and right thalamus increased. The study indicates that the visual restoration lead to different multisensory interactions within the cortical and subcortical regions, but the mechanism is not clear.

The DMN involves the PCC, medial prefrontal cortex and lateral parietal cortex. The DMN activates in the resting condition and de-activates in the task condition. This network plays a role in the detection and monitoring of environmental events and internal mentation[62, 63, 64]. Our data show that FC between DMN and right brodmann area 17 and left cuneus increased. When the DMN detect the decreased visual cortical activity, the decreased deactivation in DMN may likely occur. The strong DMN activity is related with reduced visual cortical excitability [65]. Our previous data show that the FC decreased in visual cortex after vision recovery (the results not presented in the paper), and this study reveal that decreased FC with right A1 and Broca in the right middle temporal gyrus. So it may be justified to propose that decreased visual cortex activity in some way incur decreased DMN deactivation (stronger activity). It was also assumed the compensatory mechanism arised as feedback connection by Top-down influences of DMN. However, the mechanism resulting in functional alteration in DMN after vision restoration is still to be elucidated. We also found a decrease in the FC between the DMN and the cerebellum (right declive). The cerebellum has an interaction with the frontal eye fields [66, 67] and take part in the control of eye movement [68, 69]. Our data propose that the vision improvement lead to the decreased function of the cerebellum with DMN.

The ECN gets activated when fMRI tasks include executive functions. It involves the dorsolateral prefrontal cortex and posterior parietal cortex[70, 71, 72]. This network activates when a task needs cognitive control and working memory[27]. Our data show that decreased FC with ECN was identified in right posterior cingulate, right angular and right precuneus after visual restoration. The posterior cingulate

/precuneus is a very important part of DMN. The angular gyrus(AG) plays role in language and semantic processing [73, 74] or spatial attention and orienting [75]. The AG was identified as an important parietal node of the DMN [76, 77, 78], and was reported with task-related deactivations [79]. So this result may indicate that there is contrary activity of the DMN and CEN after vision recovery. Consistent with our result, some study show that the DMN and CEN have antagonistic activity in resting state.[72]. Chen, et al. [80]found that the ECN has inhibitory control on DMN. Bauer, et al[81]showed that the ECN negatively regulates the DMN. Whitfield-Gabrieli, et al.[82]reported that the anticorrelations between DMN and ECN is associated with cognition hyperactivity such as complex working memory.

The SN constitutes the dorsal anterior cingulate cortex, bilateral insula and presupplementary motor area. This network has a key role in regulating the dynamic changes in other networks. The SN has function in the commencement of control of cognition processes [83, 84, 85]. Our data show that increased FC with SN was identified in right fusiform gyrus, left lingual gyrus/BA 19 and right brodmann area 19. The results indicate that the vision restoration lead to enhanced FC of vision cortex with SN. There is anatomical connection between the visual cortex and the SN [86]. The SN was found to involve in top-down attentional control [87, 88]. Our previous data show that the FC decreased within visual cortex after vision recovery (the results not presented in the paper). This study reveal that decreased FC with right A1, Broca and SN in the right middle temporal gyrus. So decreased visual stimulation may result in the enhanced FC between the visual system and the SN. Our data show that decreased FC with SN in right hippocampus, right corpus callosum and right precuneus. The hippocampus is critical for learning, memory and cognition. The hippocampal region has been considered part of the DMN [77, 89]. The precuneus was key node of DMN. Our data show that FC between DMN and right brodmann area 17 and left cuneus increased. Studies reported that the SN drives the DMN during both resting state and tasks in healthy younger population [90, 91]. So the increased activity of DMN may lead to decreased influence of SN on DMN itself. Taken together, it is reasonable to posit that when decreased FC within visual cortex is detected, higher than normal SN and DMN activity is initiated to achieve the compensatory mechanism as feedback connection by top-down influences, then the correspondingly decreased SN activity on DMN occur in the brain network.

Our data show that decreased FC with DMN, ECN and SN was simultaneously identified in the right precuneus. Precuneus is an area with high metabolic rates compared to other networks during rest. Precuneus is widely accepted as the importance structure in the DMN as it assists in various behavioural functions[92, 93, 94]. Many studies showed that the precuneus play the vital role in autobiographical memory retrieval, emotional stimulus processing and reward outcome monitoring.[95, 96, 97]. Some studies showed that the SN play a role in the dynamic switching of antagonistic activity between the DMN and CEN in cognitively normal young brains [98, 99, 91].Multiple experiments have shown that DMN, SN, and CEN is respectively associated with mindfulness [100, 101, 102], and also interact with each other [100, 103]. During the active state of meditation, between-network connectivity of DMN, CEN and SN are increased [104, 105]. Our results imply that precuneus may involve in three networks and relate to between-network connectivity of DMN, CEN and SN after visual restoration, but the mechanism is not clear.

Conclusions

In conclusion, we show the changes of extra-visual resting-state networks in pituitary adenoma (PA) patients with visual restoration after transsphenoid surgery. The vision restoration may cause the response of cross-modal plasticity and the multisensory system related to A1 and broca. The DMN and SN may involve in top-down control on the subareas within vision cortex. The ECN and SN have decreased FC with DMN respectively. The precuneus may involve in DMN, ECN and SN simultaneously after visual restoration. However, more studies are needed to explore the mechanism of neural plasticity in extra-visual resting-state networks, as well as the mechanism of the interaction between the intra- and extra-visual networks in patients with specific visual diseases.

Abbreviations

FC

functional connectivity ; A1:auditory cortex; PCC:posterior cingulate cortex; DMN:default mode network; SN:salience network; ECN:executive control network; ReHo:regional homogeneity; PA:pituitary adenoma; ROIs:Regions of interest; FOV:field of view; RS-fMRI:resting-state functional MRI; CSF:cerebral spinal fluid; MT:middle temporal gyrus; MT/MST:middle temporal complex

Declarations

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Compliance with ethical standard

Ethical approva All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Competing Interests The authors declare that they have no conflict of interest.

Authors Contributions Not applicable

Consent to Participate: Not applicable

Consent to Publish Not applicable

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References

1. Chen, J., Yamahachi, H., & Gilbert, C.D. Experience-dependent gene expression in adult visual cortex. *Cereb Cortex*. 2010;20:650-660. <https://doi.org/10.1093/cercor/bhp131>.
2. Lou, A.R., Madsen, K.H., Julian, H.O., Toft, P.B., Kjaer, T.W., Paulson, O.B., ... Siebner, H.R. Postoperative increase in grey matter volume in visual cortex after unilateral cataract surgery. *Acta Ophthalmol*. 2013; 91:58-65. <https://doi.org/10.1111/j.1755-3768.2011.02304.x>
3. Giulia, D., Franco, L., Mona, H.D., Armonda, B., & Olivor, C. Recovering sight in adulthood leads to rapid neurofunctional reorganization of visual functions. *J Vis*. 2012;12:1279. <https://doi.org/10.1167/12.9.1279>
4. Qian, H.Y., Wang, X.C., Wang, Z.Y., Wang, Z.M., Liu, P.N., & Wang, Z.C. Changes in the Vision-related Resting-state Network in Pituitary Adenoma Patients After Vision Improvement. *Chin Med J (Engl)*. 2015;128:1171-1176. <https://doi.org/10.4103/0366-6999.156106>.
5. Klinge, C., Eippert, F., Roder, B., & Buchel, C. Corticocortical connections mediate primary visual cortex responses to auditory stimulation in the blind. *J. Neurosci*. 2010;30:12798-12805. <https://doi.org/10.1523/JNEUROSCI.2384-10.2010>.
6. Beer, A.L., Plank, T., & Greenlee, M.W. Diffusion tensor imaging shows white matter tracts between human auditory and visual cortex. *Exp. Brain Res*. 2011;213:299-308. <https://doi.org/10.1007/s00221-011-2715-y>.
7. Kupers, R., & Ptito, M. Compensatory plasticity and cross-modal reorganization following early visual deprivation. *Neurosci. Biobehav. Rev*. 2014;41:36-52. <https://doi.org/10.1016/j.neubiorev.2013.08.001>
8. Watkins, K.E., Shakespeare, T.J., O'Donoghue, M.C., Alexander, I., Ragge, N., Cowey, A., & Bridge H. Early auditory processing in area V5/MT+ of the congenitally blind brain. *J. Neurosci*. 2013;33:18242-18246. <https://doi.org/10.1523/JNEUROSCI.2546-13.2013>
9. Heimler, B., Weisz N., & Collignon O. Revisiting the adaptive and maladaptive effects of crossmodal plasticity. *Neuroscience*. 2014;283:44-63. <https://doi.org/10.1016/j.neuroscience.2014.08.003>
10. Jiang, F., Stecker, G.C., Boynton, G.M., & Fine, I. Early blindness results in developmental plasticity for auditory motion processing within auditory and occipital cortex. *Front. Hum. Neurosci*. 2016;10:324. <https://doi.org/10.3389/fnhum.2016.00324>
11. Dormal, G., Rezk, M., Yakobov, E., Lepore, F., & Collignon, O. Auditory motion in the sighted and blind: early visual deprivation triggers a large-scale imbalance between auditory and “visual” brain regions. *Neuroimage* 2016;134:630-644. <https://doi.org/10.1016/j.neuroimage.2016.04.027>
12. Roder, B., Stock, O., Bien, S., Neville, H., & Rosler, F. Speech processing activates visual cortex in congenitally blind humans. *Eur. J. Neurosci*. 2002;16:930– <https://doi.org/10.1046/j.1460-9568.2002.02147.x>
13. Bedny, M., Pascual-Leone, A., Dodell-Feder, D., Fedorenko, E., & Saxe, R. Language processing in the occipital cortex of congenitally blind adults. *Proc. Natl. Acad. Sci. U.S.A*. 2011;108: 4429-4434.

<https://doi.org/1073/pnas.1014818108>

14. Campbell, J., & Sharma, A. Cross-modal re-organization in adults with early stage hearing loss. *PLoS One* 2014;9:e90594. <https://doi.org/1371/journal.pone.0090594>
15. Stropahl, M., Plotz, K., Schonfeld, R., Lenarz, T., Sandmann, P., Yovel, G., ...Debener, S. Cross-modal reorganization in cochlear implant users: auditory cortex contributes to visual face processing. *Neuroimage* 2015;121:159-170. <https://doi.org/1016/j.neuroimage.2015.07.062>
16. Anderson, C.A., Wiggins, I.M., Kitterick, P.T., & Hartley, D.E.H. Adaptive benefit of cross-modal plasticity following cochlear implantation in deaf adults. *Proc. Natl. Acad. Sci. U.S.A.* 2017;114:10256-0261. <https://doi.org/1073/pnas.1704785114>
17. Yu, C., Liu, Y., Li, J., Zhou, Y., Wang, K., Tian, L., ...Li, K. Altered functional connectivity of primary visual cortex in early blindness. *Hum Brain Mapp.* 2008;29: 533-543. <https://doi.org/1002/hbm.20420>.
18. Liu, L., Yu, C.S., Liang, M., Li, J., Tian, L., Zhou, Y.,...Jiang T. Whole brain functional connectivity in the early blind. *Brain.* 2007;130: 2085-2096. <https://doi.org/1093/brain/awm121>.
19. Wen, X., Liu, Y., Yao, L., & Ding, M. Top-down regulation of default mode activity in spatial visual attention. *J Neurosci.* 2013;33: 6444-6453. <https://doi.org/1523/JNEUROSCI.4939-12.2013>
20. Mayhew, S.D., Ostwald, D., Porcaro, C., & Bagshaw, A.P. Spontaneous EEG alpha oscillation interacts with positive and negative BOLD responses in the visual-auditory cortices and default-mode network. *Neuroimage.* 2013;76: 362-372. <https://doi.org/1016/j.neuroimage.2013.02.070>
21. Qian, H., Wang, X., Wang, Z., Wang, Z., & Liu, P. Altered Vision-Related Resting-State Activity in Pituitary Adenoma Patients with Visual Damage. *PLoS One.* 2016;11: e0160119. <https://doi.org/1371/journal.pone.0160119>
22. Chen, X., Xu, B.N., Meng, X., Zhang, J., Yu, X.G., & Zhou, D.B. Dual-room 1.5-T intraoperative magnetic resonance imaging suite with a movable magnet: implementation and preliminary experience. *Neurosurg Rev.* 2012;35:95-109. <https://doi.org/10.1007/s10143-011-0336-3>.
23. Yan, C.G., & Zang, Y.F. DPARSF: A MATLAB Toolbox for "Pipeline" Data Analysis of Resting-State fMRI. *Front Syst Neurosci.* 2010;4: 13. <https://doi.org/3389/fnsys.2010.00013>. eCollection 2010.
24. Rademacher, J., Morosan, P., Schormann, T., Schleicher, A., Werner C., Freund H. J., & Zilles K. Probabilistic mapping and volume measurement of human primary auditory cortex. *Neuroimage* 2001;13:669-683. <https://doi.org/1006/nimg.2000.0714>.
25. Binkofski, F., Amunts, K., Stephan, K.M., Posse, S., Schormann, T., Freund, H.J.,...Seitz, R.J. Broca's region subserves imagery of motion: a combined cytoarchitectonic and fMRI study. *Hum. Brain Mapp.* 2000;11:273-285. [https://doi.org/10.1002/1097-0193\(200012\)11:4<273::AID-HBM40>3.0.CO;2-0](https://doi.org/10.1002/1097-0193(200012)11:4<273::AID-HBM40>3.0.CO;2-0).
26. Laird, A.R., Eickhoff, S.B., Li, K., Robin, D.A., Glahn, D.C., & Fox, P.T., Investigating the functional heterogeneity of the default mode network using coordinate-based meta-analytic modeling. *J. Neurosci.* 2009;29:14496-14505. <https://doi.org/doi:10.1523/JNEUROSCI.4004-09.2009>.
27. Seeley, W.W., Menon, V., Schatzberg, A.F., Keller, J., Glover, G.H., Kenna, H.,... Greicius, M.D. Dissociable intrinsic connectivity networks for salience processing and executive control. *J. Neurosci.* 2007;27:

- 2349-2356. <https://doi.org/doi:10.1523/JNEUROSCI.5587-06.2007>.
28. Fox, M.D, & Raichle, M.E. Spontaneous fluctuations in brain activity observed with functional magnetic resonance imaging. *Nat Rev Neurosci*. 2007;8:700-711. <https://doi.org/10.1038/nrn2201>.
 29. Pillemer, S., Holtzer, R., & Blumen, H.M. Functional connectivity associated with social networks in older adults: A resting-state fMRI study. *Soc Neurosci*. 2017;12:242-252. <https://doi.org/10.1080/17470919.2016.1176599>.
 30. Friston, K.J, Frith, C.D., Liddle, P.F., & Frackowiak, R.S. Functional connectivity: the principal-component analysis of large (PET) data sets. *J Cereb Blood Flow Metab*. 1993;13:5-14. <https://doi.org/10.1038/jcbfm.1993.4>.
 31. Shmuel, A., Yacoub, E., Chaimow, D., Logothetis, N.K., & Ugurbil, K. Spatio-temporal point-spread function of fMRI signal in human gray matter at 7 Tesla. *Neuroimage*. 2007;35:539-552. <https://doi.org/10.1016/j.neuroimage.2006.12.030>
 32. Dubner, R., & Zeki, S.M. Response properties and receptive fields of cells in an anatomically defined region of the superior temporal sulcus in the monkey. *Brain Res*. 1971;35:528–532. [https://doi.org/10.1016/0006-8993\(71\)90494-x](https://doi.org/10.1016/0006-8993(71)90494-x)
 33. Tootell, R.B., Reppas, J.B., Kwong, K.K., Malach, R., Born, R.T., Brady, T.J., ...Belliveau, J.W. Functional analysis of human MT and related visual cortical areas using magnetic resonance imaging. *J Neurosci*. 1995;15:3215–3230. <https://doi.org/10.1523/JNEUROSCI.15-04-03215.1995>
 34. de Jong, B.M., Shipp, S., Skidmore, B., Frackowiak, R.S., & Zeki S. The cerebral activity related to the visual perception of forward motion in depth. *Brain*. 1994;117:1039–1054. <https://doi.org/10.1016/j.brainres.2010.08.050>.
 35. Zihl, J., von Cramon, D., & Mai, N. Selective disturbance of movement vision after bilateral brain damage. *Brain*. 1983;106:313–340. <https://doi.org/10.1093/brain/106.2.313>
 36. Saenz, M., Lewis, L.B., Huth, A.G., Fine, I., & Koch, C. Visual Motion Area MT+/V5 Responds to Auditory Motion in Human Sight-Recovery Subjects. *J Neurosci*. 2008;28:5141–5148. <https://doi.org/10.1523/JNEUROSCI.0803-08.2008>
 37. Wolbers, T., Zahorik, P., & Giudice, N.A. Decoding the direction of auditory motion in blind humans. *Neuroimage*. 2010;56:681-687. <https://doi.org/10.1016/j.neuroimage.2010.04.266>
 38. Ricciardi, E., Vanello, N., Sani, L., Gentili, C., Scilingo, E.P., Landini, L., ...Pietrini, P. The effect of visual experience on the development of functional architecture in hMT+. *Cereb. Cortex* 2007;17: 2933-2939. <https://doi.org/10.1093/cercor/bhm018>
 39. Strelnikov, K., Rouger, J., Demonet, J.F., Lagleyre, S., Fraysse, B., Deguine, O., & P. Visual activity predicts auditory recover from deafness after adult cochlear implantation. *Brain* 2013;136:3682-3695. <https://doi.org/10.1093/brain/awt274>
 40. Alink, A., Singer, W., & Muckli, L. Capture of Auditory Motion by Vision Is Represented by an Activation Shift from Auditory to Visual Motion Cortex. *J Neurosci*. 2008;28:2690-2697. <https://doi.org/10.1523/JNEUROSCI.2980-07.2008>.

41. Burton, H., Snyder, A. Z., Conturo, T. E., Akbudak, E., Ollinger, J. M., & Raichle, M. E. Adaptive changes in early and late blind: a fMRI study of braille reading. *J. Neurophysiol.* 2002a;87: 589-607. <https://doi.org/1152/jn.00129.2002>
42. Deen, B., Saxe R., & Bedny, M. Occipital cortex of blind individuals is functionally coupled with executive control areas of frontal cortex. *J. Cogn. Neurosci.* 2015;27:1633-1647. https://doi.org/1162/jocn_a_00807.
43. Bedny, M., Konkle, T., Pelphrey, K.A., Saxe, R., & Pascual-Leone, A. Sensitive period for a multimodal response in human visual motion area MT/MST. *Curr Biol.* 2010;20:1900–1906. <https://doi.org/1016/j.cub.2010.09.044>
44. Cappe, C., Rouiller, E.M., & Barone, P. Multisensory anatomical pathways. *Hear Res.* 2009;258:28-36. <https://doi.org/10.1016/j.heares.2009.04.017>.
45. Brown, L.L., Schneider, J.S., & Lidsky, T.I. Sensory and cognitive functions of the basal ganglia. *Curr Opin Neurobiol.* 1997;7:157-163. [https://doi.org/10.1016/s0959-4388\(97\)80003-7](https://doi.org/10.1016/s0959-4388(97)80003-7).
46. Berthier, M., Starkstein, S., & Leiguarda, R. Behavioral effects of damage to the right insula and surrounding regions. *Cortex.* 1987;23:673-678. [https://doi.org/1016/s0010-9452\(87\)80057-6](https://doi.org/1016/s0010-9452(87)80057-6).
47. Chen, T., Michels, L., Supekar, K., Kochalka, J., Ryali, S., & Menon, V. Role of the anterior insular cortex in integrative causal signaling during multisensory auditory-visual attention. *Eur J Neurosci.* 2015;41:264-274. <https://doi.org/1111/ejn.12764>.
48. Frank, S.M., Baumann, O., Mattingley, J.B., & Greenlee, M.W. Vestibular and visual responses in human posterior insular cortex. *J Neurophysiol.* 2014;112:2481-2491. <https://doi.org/1152/jn.00078.2014>.
49. Tyll, S., Budinger, E., & Noesselt, T. Thalamic influences on multisensory integration. *Commun Integr Biol.* 2011;4:378-381. <https://doi.org/10.4161/cib.4.4.15222>.
50. Hyvärinen, J., Carlson, S., & Hyvärinen, L. Early visual deprivation alters modality of neuronal responses in area 19 of monkey cortex. *Neurosci Lett.* 1981a;26:239–243. [https://doi.org/1016/0304-3940\(81\)90139-7](https://doi.org/1016/0304-3940(81)90139-7)
51. Hyvärinen, J., Hyvärinen, L., & Linnankoski, I. Modification of parietal association cortex and functional blindness after binocular deprivation in young monkeys. *Exp Brain Res.* 1981b;42:1–8. <https://doi.org/1007/BF00235723>.
52. Carlson, S., Pertovaara, A., & Tanila, H. Late effects of early binocular visual deprivation on the function of Broadmann's area 7 of monkeys (*Macaca arctoides*) *Dev Brain Res.* 1987;33:101–11. [https://doi.org/1016/0165-3806\(87\)90180-5](https://doi.org/1016/0165-3806(87)90180-5)
53. Wallace, M.T., Perrault, T.J., Jr., Hairston, D., & Stein, B.E. Visual experience is necessary for the development of multisensory integration. *J Neurosci.* 2004;24:9580–9584. <https://doi.org/1523/JNEUROSCI.2535-04.2004>
54. Carriere, B.R., Royal, D.W., Perrault, T.J., Jr., Morrison, S.P., Vaughan, J.W., Stein, B.E., & Wallace, M.T. Visual deprivation alters the development of cortical multisensory integration. *J Neuropsychol.* 2007;98:2858–2867. <https://doi.org/1152/jn.00587.2007>

55. Putzar, L., Goerendt, I., Lange, K., Rösler, F., & Röder, B. Early visual deprivation impairs multisensory interactions in humans. *Nat Neurosci.* 2007;10:1243–1245. <https://doi.org/1038/nn1978>
56. Putzar, L., Hötting, K., & Röder, B. Early visual deprivation affects the development of face recognition and of audio-visual speech perception. *Restor Neurol Neurosci.* 2010b;28:251–257. <https://doi.org/3233/RNN-2010-0526>.
57. Putzar, L., Gondan, M., & Röder, B. Basic multisensory functions can be acquired after congenital visual pattern deprivation in humans. *Dev Neuropsychol.* 2012;37:697–711. <https://doi.org/1080/87565641.2012.696756>.
58. Calvert, G.A., Campbell, R., & Brammer, M.J. Evidence from functional magnetic resonance imaging of crossmodal binding in the human heteromodal cortex. *Curr Biol.* 2000;10:649–657. [https://doi.org/1016/s0960-9822\(00\)00513-3](https://doi.org/1016/s0960-9822(00)00513-3).
59. Stevenson, R.A., & James, T.W. Audiovisual integration in human superior temporal sulcus: inverse effectiveness and the neural processing of speech and object recognition. *NeuroImage.* 2009;44:1210–1223. <https://doi.org/1016/j.neuroimage.2008.09.034>
60. Weissman, D.H., Roberts, K.C., Visscher, K.M., & Woldorff, M.G. The neural bases of momentary lapses in attention. *Nat Neurosci.* 2006; 9:971–978. <https://doi.org/1038/nn1727>.
61. Huang, S., Li, Y., Zhang, W., Zhang, B., Liu, X., Mo, L., & Chen, Q. Multisensory Competition Is Modulated by Sensory Pathway Interactions with Fronto-Sensorimotor and Default-Mode Network Regions. *J Neurosci.* 2015;35:9064-9077. <https://doi.org/1523/JNEUROSCI.3760-14.2015>.
62. Gusnard, D.A., Raichle, M.E., & Raichle, M.E. Searching for a baseline: functional imaging and the resting human brain. *Nat Rev Neurosci.* 2001;2: 685-694. <https://doi.org/1038/35094500>
63. Sherman, L.E., Rudie, J.D., Pfeifer, J.H., Masten, C.L., McNealy, K., & Dapretto, M. Development of the default mode and central executive networks across early adolescence: a longitudinal study. *Dev Cogn Neurosci.* 2014;10: 148-159. <https://doi.org/1016/j.dcn.2014.08.002>.
64. Blakemore S-J. The social brain in adolescence. *Nat Rev Neurosci.* 2008;9:267-277. <https://doi.org/1038/nrn2353>
65. Moulder, J., Liu, Y., Huang, H., & Ding, M. Coupling between visual alpha oscillations and default mode activity. *Neuroimage.* 2013;68:112-118. <https://doi.org/10.1016/j.neuroimage.2012.11.058>.
66. Middleton, F.A., & Strick, P.L. Cerebellar projections to the prefrontal cortex of the primate. *Journal of Neuroscience.* 2001;21:700-712. <https://doi.org/10.1523/JNEUROSCI.21-02-00700.2001>.
67. Kelly, R.M., & Strick, P.L. Cerebellar loops with motor cortex and prefrontal cortex of a nonhuman primate. *Journal of Neuroscience.* 2003;23:8432-8444. <https://doi.org/10.1523/JNEUROSCI.23-23-08432.2003>.
68. Hayakawa, Y., Nakajima, T., Takagi, M., Fukuhara, N., & Abe, H. Human cerebellar activation in relation to saccadic eye movements: a functional magnetic resonance imaging study. *Ophthalmologica.* 2002;216:399-405. <https://doi.org/10.1159/000067551>.
69. Nitta, T., Akao, T., Kurkin, S., & Fukushima, K. Involvement of the cerebellar dorsal vermis in vergence eye movements in monkeys. *Cerebral Cortex.* 2008;18:1042-1057.

<https://doi.org/10.1093/cercor/bhm143>.

70. Binder, J.R., Frost, J.A., Hammeke, T.A., Bellgowan, P.S., Rao, S.M., & Cox RW. Conceptual processing during the conscious resting state. A functional MRI study. *J Cogn Neurosci*. 1999;11: 80-95.
<https://doi.org/1162/089892999563265>
71. Shulman, G.L., Corbetta, M., Fiez, J.A., Buckner, R.L., Miezin, F.M., Raichle, M.E., & Petersen, S.E. Searching for activations that generalize over tasks. *Hum Brain Mapp*.1997;5:317-322.
[https://doi.org/1002/\(SICI\)1097-0193\(1997\)5:4<317::AID-HBM19>3.0.CO;2-A](https://doi.org/1002/(SICI)1097-0193(1997)5:4<317::AID-HBM19>3.0.CO;2-A)
72. Fox, M.D., Snyder, A.Z., Vincent, J.L., Corbetta, M., Van Essen, D.C., & Raichle, M.E. The human brain is intrinsically organized into dynamic, anticorrelated functional networks. *Proc Natl Acad Sci U S A*. 2005;102:9673–9678. <https://doi.org/1073/pnas.0504136102>.
73. Binder, J.R., Desai, R.H., Graves, W.W., & Conant, L.L. Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cereb Cortex*. 2009;19:2767–2796.
<https://doi.org/1093/cercor/bhp055>.
74. Brownsett, S.L, & Wise, R.J. The contribution of the parietal lobes to speaking and writing. *Cereb Cortex*. 2009;20:517-523. <https://doi.org/1093/cercor/bhp120>.
75. Chambers, C.D., Payne, J.M., Stokes, M.G., & Mattingley, J.B. Fast and slow parietal pathways mediate spatial attention. *Nat Neurosci*. 2004;7:217–218. <https://doi.org/1038/nn1203>.
76. Raichle, M.E., MacLeod, A.M., Snyder, A.Z., Powers, W.J., Gusnard, D.A., & Shulman, G.L. A default mode of brain function. *Proc Natl Acad Sci USA*. 2001;98:676–682.
<https://doi.org/1073/pnas.98.2.676>.
77. Greicius, M.D., Krasnow, B., Reiss, A.L., & Menon, V. Functional connectivity in the resting brain: a network analysis of the default mode hypothesis. *Proc Natl Acad Sci USA*. 2003;100:253–258.
<https://doi.org/1073/pnas.0135058100>.
78. Uddin, L.Q., Kelly, A.M., Biswal, B.B., Castellanos F, & Milham MP. Functional connectivity of default mode network components: correlation, anticorrelation, and causality. *Hum Brain Mapp*. 2009;30:625–637. <https://doi.org/1002/hbm.20531>.
79. Wu, S.S., Chan, T.T., Majid, A., Caspers, S., Eickhoff, S.B., & Menon, V. Functional heterogeneity of inferior parietal cortex during mathematical cognition assessed with cytoarchitectonic probability maps. *Cereb Cortex*. 2009;19:2930–2945. <https://doi.org/1093/cercor/bhp063>.
80. Chen, A.C., Oathes, D.J., Chang, C., Bradley, T., Zhou, Z.W., Williams, L.M., ... Etkin A. Causal interactions between fronto-parietal central executive and default-mode networks in humans. *Proc Natl Acad Sci U S A*. 2013;110:19944–19949. <https://doi.org/1073/pnas.1311772110>.
81. Bauer C.C.C., Whitfield-Gabrieli, S., Díaz, J.L., Pasaye, E.H., & Barrios, F.A. From State-to-Trait Meditation: Reconfiguration of Central Executive and Default Mode Networks 6:ENEURO.0335-18.2019. <https://doi.org/10.1523/ENEURO.0335-18.2019>.
82. Whitfield-Gabrieli, S., Thermenos, H.W., Milanovic, S., Tsuang, M.T., Faraone, S.V., McCarley, R.W.,...Seidman, L.J. Hyperactivity and hyperconnectivity of the default network in schizophrenia and

- in first-degree relatives of persons with schizophrenia. *Proc Natl Acad Sci USA*. 2009;106:1279–1284. <https://doi.org/1073/pnas.0809141106>.
83. Uddin, L.Q. Salience processing and insular cortical function and dysfunction. *Nat Rev Neurosci*. 2015;16: 55–61. <https://doi.org/1038/nrn3857>
 84. Ham, T., Leff, A., de Boissezon, X., Joffe, A., & Sharp, D.J. Cognitive control and the salience network: an investigation of error processing and effective connectivity. *J Neurosci* 2013;33: 7091–7098. <https://doi.org/1523/JNEUROSCI.4692-12.2013>.
 85. Menon, V., & Uddin, L.Q. Saliency, switching, attention and control: a network model of insula function. *Brain Struct Funct*. 2010;214: 655–667. <https://doi.org/1007/s00429-010-0262-0>.
 86. Uddin, L.Q., Supekar, K., Amin, H., Rykhlevskaia, E., Nguyen, D.A., Greicius, M.D., & Menon, V. Dissociable connectivity within human angular gyrus and intraparietal sulcus: evidence from functional and structural connectivity. *Cereb Cortex*. 2010;20:2636-2646. <https://doi.org/1093/cercor/bhq011>.
 87. Yantis, S. The neural basis of selective attention: cortical sources and targets of attentional modulation. *Curr Dir Psychol Sci*. 2008;17:86-90. <https://doi.org/1111/j.1467-8721.2008.00554.x>
 88. Rushworth, M.F. Intention, choice, and the medial frontal cortex. *Ann N Y Acad Sci*.2008;1124: 181-207. <https://doi.org/1196/annals.1440.014>
 89. Greicius, M.D., Srivastava, G., Reiss, A.L., & Menon, V. Default-mode network activity distinguishes Alzheimer's disease from healthy aging: evidence from functional MRI. *Proc Natl Acad Sci USA*. 2004;101:4637–4642. <https://doi.org/1073/pnas.0308627101>.
 90. Chand, G.B., & Dhamala, M. Interactions among the brain default-mode, salience, and central-executive networks during perceptual decision-making of moving dots. *Brain Connect*.2016a; 6:249–254. <https://doi.org/1089/brain.2015.0379>
 91. Sridharan, D., Levitin, D.J., & Menon, V. A critical role for the right fronto-insular cortex in switching between central-executive and default-mode networks. *Proc Natl Acad Sci U S A*. 2008;105:12569–12574. <https://doi.org/1073/pnas.0800005105>
 92. Hayden, B.Y., Nair, A.C., McCoy, A.N., & Platt, M.L. Posterior cingulate cortex mediates outcome-contingent allocation of behavior. *Neuron*. 2008;60:19–25. <https://doi.org/1016/j.neuron.2008.09.012>.
 93. Utevsky, A.V., Smith, D.V., & Huettel, S.A. Precuneus is a functional core of the default-mode network. *J Neurosci*. 2014;34: 932–940. doi: 10.1523/JNEUROSCI.4227-13.2014.
 94. Fransson, P., & Marrelec, G. The precuneus/posterior cingulate cortex plays a pivotal role in the default mode network: evidence from a partial correlation network analysis. *Neuroimage*. 2008;42: 1178–1184. <https://doi.org/1016/j.neuroimage.2008.05.059>
 95. Cavanna, A.E., & Trimble, M.R. The precuneus: a review of its functional anatomy and behavioural correlates. *Brain*. 2006;129: 564–583. <https://doi.org/1093/brain/awl004>.
 96. Maddock, R.J., Garrett, A.S., & Buonocore, M.H. Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task. *Hum Brain Mapp*.2003;18:30–41.

<https://doi.org/1002/hbm.10075>.

97. Maddock, R.J., Garrett, A.S., & Buonocore, M.H. Remembering familiar people: the posterior cingulate cortex and autobiographical memory retrieval. *Neuroscience*. 2001;104: 667–676.
[https://doi.org/1016/s0306-4522\(01\)00108-7](https://doi.org/1016/s0306-4522(01)00108-7)
98. Chand, G.B., & Dhamala, M. The salience network dynamics in perceptual decision-making. *Neuroimage* 2016b;134:85–93. <https://doi.org/1016/j.neuroimage.2016.04.018>.
99. Goulden, N., Khusnulina, A., Davis, N.J., Bracewell, R.M., Bokde, A.L., McNulty, J.P., & Mullins, P.G. The salience network is responsible for switching between the default mode network and the central executive network: replication from DCM. *Neuroimage*. 2014;99:180–190. <https://doi.org/1016/j.neuroimage.2014.05.052>
100. Kilpatrick, L.A., Suyenobu B. Y., Smith S. R., Bueller J. A., Goodman T., Creswell J. D.,...Naliboff, B.D. Impact of mindfulness-based stress reduction training on intrinsic brain connectivity. *Neuroimage*. 2011;56:290–298. <https://doi.org/1016/j.neuroimage.2011.02.034>
101. Hasenkamp, W., & Barsalou, L.W. Effects of meditation experience on functional connectivity of distributed brain networks. *Front. Hum. Neurosci*. 2012;6:38.
<https://doi.org/3389/fnhum.2012.00038>
102. Taylor, V.A., Daneault, V., Grant, J., Scavone, G., Breton, E., Roffe-Vidal, S.,...Beauregard, M. Impact of meditation training on the default mode network during a restful state. *Soc. Cogn. Affect. Neurosci*. 2013;8:4–14. <https://doi.org/1093/scan/nsr087>
103. Froeliger, B., Garland, E.L., Kozink, R.V., Modlin, L.A., Chen, N.-K., McClernon, F.J., ...Sobin, P. Meditation-state functional connectivity (msFC): strengthening of the dorsal attention network and beyond. *Evid Based Complement Alternat Med*.2012;2012:680407.
<https://doi.org/1155/2012/680407>
104. Brewer, J.A., Worhunsky, P.D., Gray, J.R., Tang, Y.Y., Weber, J., & Kober, H. Meditation experience is associated with differences in default mode network activity and connectivity. *Proc Natl Acad Sci USA*. 2011;108:20254–20259. <https://doi.org/1073/pnas.1112029108>
105. Jao, T., Li, C.W., Vértes, P.E., Wu, C.W., Achard, S., Hsieh, C.H., ...Bullmore, E.T. Large-scale functional brain network reorganization during Taoist meditation. *Brain Connect*. 2016;6:9–24.
<https://doi.org/1089/brain.2014.0318>

Figures

Figure 1

Brain areas exhibited significantly different FCs with the right A1 in PAs (postoperative vs preoperative).

Figure 2

Brain areas exhibited significantly different FCs with the broca in PAs (postoperative vs preoperative).

Figure 3

Brain areas exhibited significantly different FCs with the DMN in PAs (postoperative vs preoperative).

Figure 4

Brain areas exhibited significantly different FCs with the ECN in PAs (postoperative vs preoperative)

Figure 5

Brain areas exhibited significantly different FCs with the SN in PAs (postoperative vs preoperative).