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Aging-related changes in the default mode network and its anti-correlated networks: A resting-state fMRI study

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ABSTRACT

Intrinsic brain activity in a resting state incorporates components of the task negative network called default mode network (DMN) and task-positive networks called attentional networks. In the present study, the reciprocal neuronal networks in the elder group were compared with the young group to investigate the differences of the intrinsic brain activity using a method of temporal correlation analysis based on seed regions of posterior cingulate cortex (PCC) and ventromedial prefrontal cortex (vmPFC). We found significant decreased positive correlations and negative correlations with the seeds of PCC and vmPFC in the old group. The decreased coactivations in the DMN network components and their negative networks in the old group may reflect age-related alterations in various brain functions such as attention, motor control and inhibition modulation in cognitive processing. These alterations in the resting state anti-correlative networks could provide neuronal substrates for the aging brain.

1. Introduction

Functions such as attention, problem solving, planning and fine motor skills commonly decline with the aging process. The study of intrinsic brain activity may be critical for understanding the physiological changes of the aging brain.

The synchronic low frequency fluctuations (LFFs) in blood oxygen level-dependent (BOLD) functional magnetic resonance imaging (fMRI) signals among spatial distant brain nodes imply brain networks that act cooperatively [3,14]. Within these intrinsically correlated networks, a so-called "default mode network" (DMN) has drawn the most attraction. The DMN shows consistently higher level organizations during rest than during a wide range of cognitive tasks (task negative) [11,14,29]. The DMN is involved in monitoring internal and external environment, memory and self-related functions [18,22,30].

External attention demanding tasks engage extensive dorsal and/or ventral attention networks. The attention networks, or so-called task-positive networks, presented strong negative temporal correlations with the DMN during resting state, these anti-correlated networks are thought to reflect physiological basis [11,12,14]. Such competitive relationship can impact on behavioral performance and account for decline in attention-demanded task performance in old people [20,31,35]. However, recent evidence indicated that the DMN is not a homogenous network, and the anterior (ventral medial prefrontal cortex, vmPFC) and posterior components (posterior cingulate cortex, PCC) of the DMN have differential anti-correlated networks related to differential brain functions [1,6,11,34]. Granger causality analysis showed the PCC positive network and the vmPFC positive network exert greater influence on their anti-correlated networks than the other way around [34].

Abnormal LFFs correlations related to aging were found not only during task-directed studies but also in resting state fMRI [2,6,9,13,21,24,26]. A further study showed reduced functional connectivity in two resting-state networks respectively corresponding to the posterior and anterior components of the DMN, in older versus younger subjects [6]. The decreased regional LFFs homogeneity and reduced connectivity in motor-related brain regions were interpreted to contribute to the decline of motor function [37,38]. The intrinsic networks may well be the substrates of cognitive decline in aging.

Most of the studies reviewed above focus on the changes of functional connectivity within DMN, whereas the heterogeneity in the DMN may be ignored, especially for its anti-correlated networks. The relationship between the DMN components and its anti-correlated networks in the elderly in resting state is unclear. Therefore, we conceive that the intrinsic changes in the aging brain

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could be refined from aspects of the anterior and posterior components, while a further question is how the negatively correlated networks underpinning attentional function change during resting state. In the current study, we determine the resting state functional connectivity of the reciprocal networks in the young and old groups using a method of temporal correlation analysis referring to the method that Uddin et al. [34] had applied. The DMN sub-networks (PCC positive and vmPFC positive) and their anti-networks (PCC negative and vmPFC negative) were compared between groups.

2. Materials and methods

2.1. Subjects and procedure

Two groups of right-handed healthy subjects matched on education years and gender participated in this study: (1) 18 young subjects recruited from young university students (aged 22–33, mean 23.9 ± 1.8, male 9, female 9), (2) 22 old subjects recruited from local community (aged 60–80, mean 69.8 ± 5.8, male 10, female 12). All subjects had no abnormal findings from their structural brain MRI.

Imaging was performed on a 1.5 T GE Signa Excite MR scanner (GE Healthcare systems, Milwaukee, WI). A standard head coil was used. Before the fMRI scanning, subjects were instructed to lie quietly with their eyes closed, not to think of anything in particular. Functional images were acquired by using a gradient echo-planar imaging (EPI) sequence (TR 3000 ms, TE 40 ms, flip angle 90, slice thickness 6 mm, slice gap 0 mm, FOV 240 mm, matrix 64×64), each frame included contiguous 18 slices covering whole brain volume. The slices paralleled to anterior/posterior commissure. The EPI scan lasted 6 min 24 s. Finally, a T1 weighted 3D fast spoiled gradient echo sequence was acquired.

2.2. Data preprocessing and analysis

FMRI data preprocessing was performed with SPM5 (http://www.fil.ion.ucl.ac.uk/spm). The first four volumes were discarded. Images were corrected for the slice-timing and then were realigned for head movement correction. One young and two older subjects were excluded under the criterion with head translation exceeding 1.5 mm or head rotation exceeding 1.5°. Afterwards, the functional images were normalized by T1 weighted 3D image unified segmentation algorithm. T1 weighted 3D images

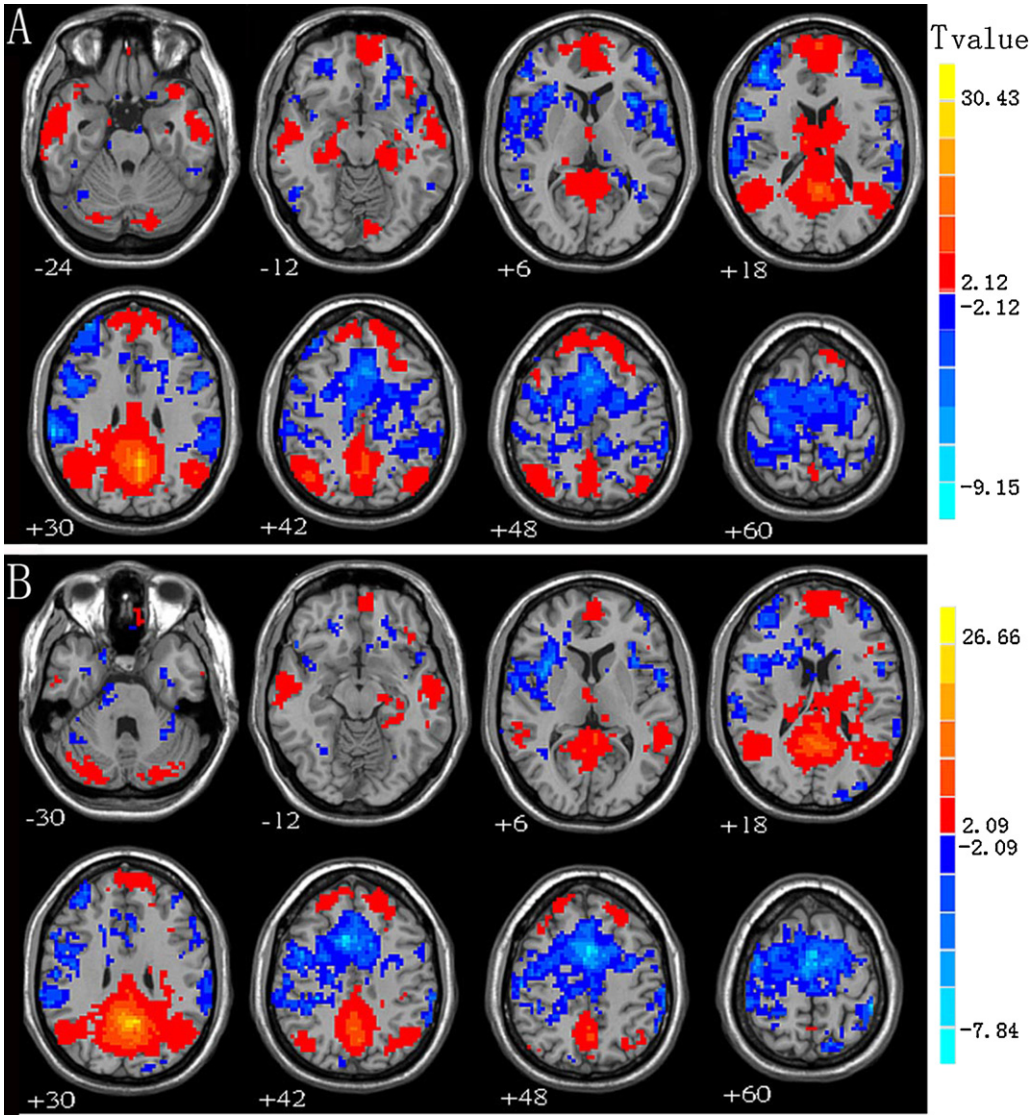

Fig. 1. Within-group maps of PCC positive and negative networks for the young and old groups. A: young group; B: old group. Red color represents positive correlations. Blue color represents negative correlations. Left is left. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

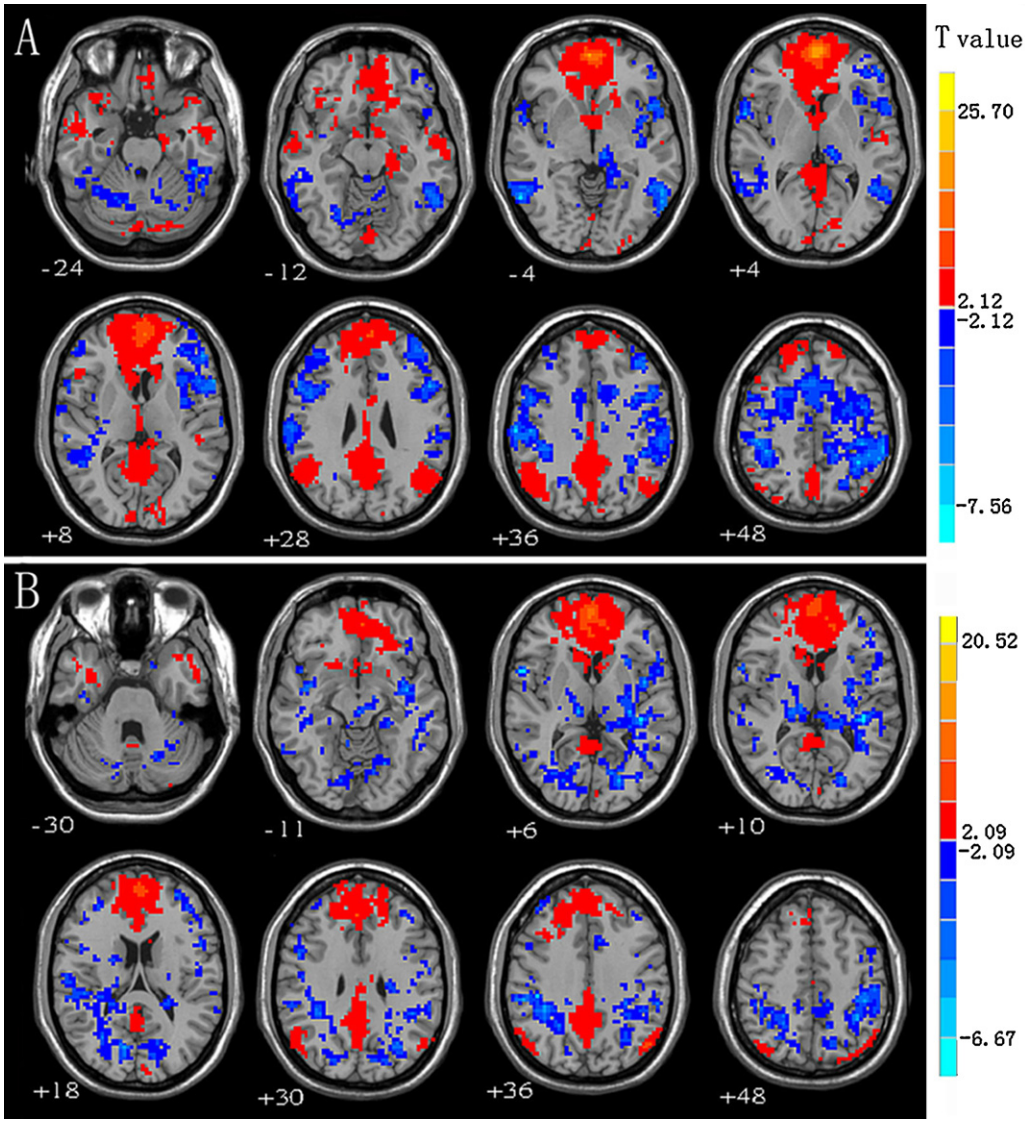

Fig. 2. Maps of vmPFC positive and negative networks within groups for the young and old. A: young group; B: old group. Red color represents positive correlations. Blue color represents negative correlations. Left is left. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

were segmented into modulated normalized three parts of gray mater, white matter and CSF. The normalized volumes were re-sampled to a voxel size of 3 mm × 3 mm × 3 mm in MNI space. Then the EPI images were spatially smoothed using isotropic Gaussian filter (4 mm FWHM).

Subsequent data processing and statistics analysis were performed using the Resting-state fMRI data Analysis Toolkit (REST V1.4, http://www.restfmri.net/forum/rest). Linear detrending and temporal bandpass filtering (0.01–0.08 Hz) were carried out. For the connectivity analysis, we created two spherical seed region of interest (ROI) in the PCC and vmPFC with radius of 6 mm containing 33 voxels, the ROI coordinates came from previous studies of De Luca et al. and Uddin et al. [7,34]. The functional data were then processed with a multiple regression analysis to limit nuisance covariates from head movement, global signal, white matter and cerebrospinal fluid. Pearson linear correlation coefficients between time series of each brain voxel's signal and the time series of the average signal of the seed region were calculated. A Fisher's *z*-transform was applied to improve the normality of these correlation coefficients.

Individual *z*-maps underwent two-tailed one-sample *t* test to determine brain regions with significant positive or negative correlations to the seeds of PCC and vmPFC voxel by voxel, respectively. A threshold adjustment method based on Monte-Carlo simulations correction was used with a voxelwise $p < 0.01$, cluster size > 18 (486 mm^3), cluster connectivity criterion 5rmm, this yielded an AlphaSim correction threshold of $p < 0.05$. Before group comparison, union sets for PCC positive, PCC negative, vmPFC positive and vmPFC negative maps in both groups were calculated separately at a threshold of $p < 0.05$, corrected. These union sets were used for masking in subsequent between-group analysis. Individual *z*-maps underwent two-tailed two-sample *t* test for group comparison with a threshold adjustment method based on Monte-Carlo simulations correction at voxelwise $p < 0.05$, cluster size > 54 (1458 mm^3), cluster connectivity criterion 5rmm, this yielded an AlphaSim correction threshold of $p < 0.05$. The comparisons were performed for the PCC positive and negative correlations, vmPFC positive and negative correlations between the two groups, respectively. The individual modulated gray matter volumes were entered as covariates to regress out the confound of brain volume atrophy [28].

Herein when we delineate the network components, we will refer to the nodes positively and negatively correlated with the PCC seed as the PCC(+) and PCC(−) networks respectively. Similarly,

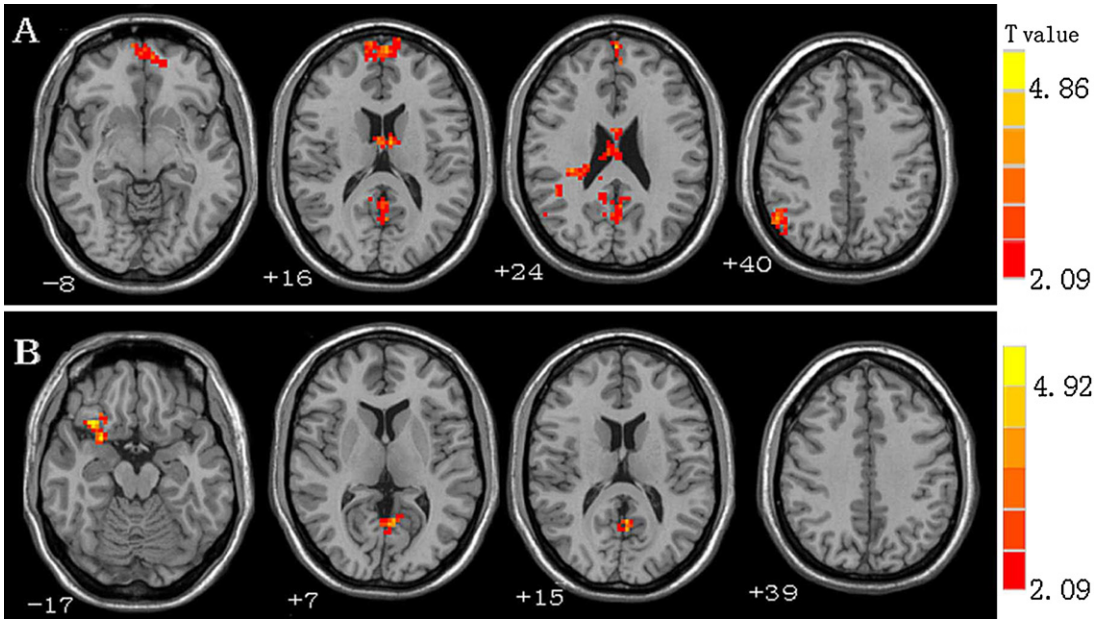

Fig. 3. Direct comparisons for the positive networks to PCC and MPFC between the young and old groups. A: PCC positive networks; B: vmPFC positive networks. Red color means young > old. Left is left. No increased connectivity for both components for old > young was found. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

the nodes correlated with the vmPFC seed are referred to as the vmPFC(+) and vmPFC(−) networks.

3. Results

3.1. Within group analysis

As showed in the PCC(+) maps, PCC positively correlated with the regions of vmPFC, bilateral medial temporal cortex (MTC), hippocampus, pulvinars, precuneus and inferior parietal cortex (IPC) in both group (Fig. 1, red color, A: young group; B: older group). For the PCC(−) network maps, the regions of dorsomedial prefrontal cortex, bilateral insula cortex, dorsolateral prefrontal cortex, medial cingulate cortex and central parietal cortex were involved (Fig. 1, blue color). Visual inspection indicated the PCC(+) and PCC(−) network maps in both groups were similar.

The analysis for vmPFC(+) networks in both group (Fig. 2A and B, red color) showed the constructions largely overlapped with those in the PCC(+) network. The vmPFC(−) network maps included bilateral dorsolateral prefrontal cortex, parietal cortex, posterior temporal cortex in both groups and additional regions in bilateral extra-striate cortex (bilateral middle occipital cortex, lingual gyrus, fusiform gyrus) in the old group as well as additional region of dorsomedial prefrontal cortex in the young group (Fig. 2A and B, blue color). Visual inspection showed that the areas in prefrontal cortex and posterior temporal cortex involved in the vmPFC(−) network maps reduced in the older group. An interesting finding is that vmPFC in the old group exhibited negative correlation with part of the bilateral occipital extrastriate areas, but showed positive correlation in the young group.

3.2. Comparisons between groups

Significant decreased connectivity in the four network components for the older group was illustrated in Figs. 3 and 4, and Table 1. For the PCC(+) network, the nodes including PCC, vmPFC and left angular gyrus showed reduced correlations (Fig. 3A, red color. Details are in Table 1). For the vmPFC(+) network, the regions of PCC and left inferior orbital frontal cortex showed reduced correlation with the vmPFC (Fig. 3B, red color. Details are in Table 1).

For the PCC(−) network, the regions of bilateral lateral middle and inferior frontal cortex, right supramarginal gyrus and right temporal–parietal conjunction cortex showed significant reduced connectivity with a feature of right lateralization in the old group (Fig. 4A, blue color. Details are in Table 1). For the vmPFC(−) network, the regions demonstrating reduced connectivity in the old group mostly involved supplementary motor cortex and left superior frontal gyrus in addition to the posterior portion of right inferior temporal gyrus (Fig. 4B, blue color. Details are in Table 1). Therefore the young group had significant higher absolute values of negative correlation coefficients in these negative network areas. Alterations in the PCC(−) and vmPFC(−) in the old groups showed differences in distribution, the former located laterally, the latter in midline (Fig. 4).

For the old group, the four network components did not show additional statistically significant increased connectivity, except that the bilateral visual cortex (Brodmann 17, 18, 19) and right superior temporal gyrus demonstrated increased negative connections for vmPFC(−) network (Fig. 4B, red color).

4. Discussion

The aim of this study is to explore the effects of normal aging on the co-operations within the DMN and their anti-networks. The brain areas comprising these positive and negative networks are coupled to PCC or vmPFC activity at resting state. Although previous task fMRI studies have revealed that older adults demonstrate greater or lesser activity depending on tasks, our findings further showed that the intrinsic neuro-networks as the substrates of cognition have altered in aging even at a state without any task load or stimuli.

Both the positive and negative networks showed significant disconnection in the old group while taking the differences in gray matter volume into account. Functional connectivity changes within DMN affected by age and attentional lapses resulted from abnormal activations in the PCC have been discussed in previous studies [6,9,11,21,26,35]. Focused attention and goal-directed

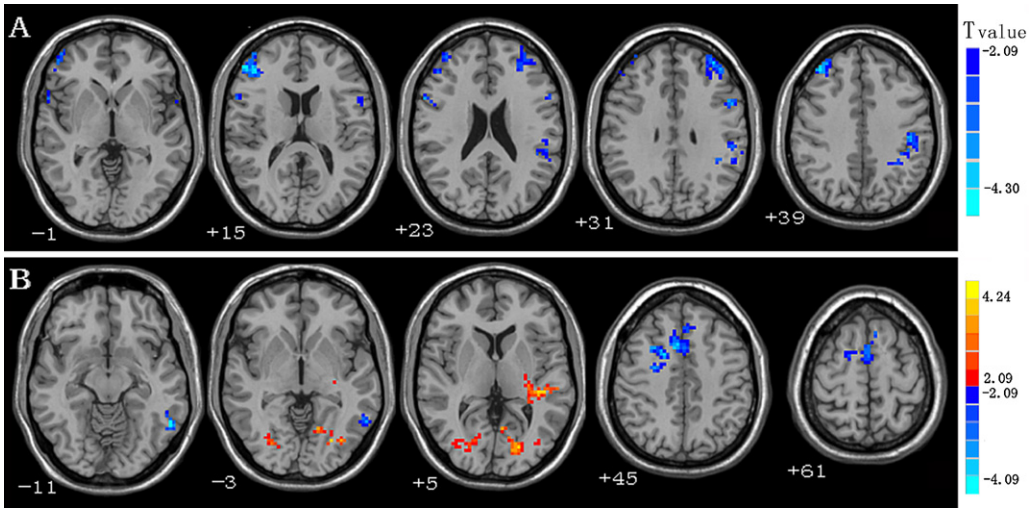

Fig. 4. Direct comparisons between the young and old groups for the negative networks to PCC and vmPFC. A: PCC negative networks; B: vmPFC negative networks. Blue color means increased negative correlations for young vs. old; red color means reduced negative correlations for young vs. old. Left is left. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

behavior are generally associated with intensive activity in both task-positive and task-negative networks [5,25]. Anti-correlations between these networks indicate that the networks are temporally modulated in opposite directions, the task-positive networks could be presented by the resting state negative correlations [10,12]. The interplay within these anti-correlated networks weakened in the elderly, which implied they function at a lower level at a state without any task. We speculate that the lower resting functional coordinations in the negative networks may actually serve to the abnormal activations during tasks in the elders.

Our findings suggest the age-related disconnections are along the anterior–posterior gradient, coincided with previous studies like Andrews-Hanna et al. [2]. Moreover, our study extended the notion by looking across networks rather than just within the DMN. As previously noted, vmPFC(+) and PCC(+) networks have strong directional influence on vmPFC(−) and PCC(−). We speculate that the reduced integrity in the DMN in aging is responsible for the impaired large scale networks with antagonistic relationship.

Our analysis revealed that the alterations in the negatively correlated networks in the old group mainly distributed in bilateral dorsolateral and medial prefrontal cortex, such findings are consistent with the frontal lobe theory of aging, which suggests that many of age-related changes in cognition are due to particular vulnerability of frontal lobes to the neurochemical and structural changes that occur with age [4,16,36].

However, the alterations in negative networks for PCC and vmPFC in the old groups showed different features in distribution. The vmPFC(−) network displayed disconnection mainly in the midline regions in dorso-medial prefrontal cortex (mainly containing supplementary motor area, SMA), whereas the PCC(−) network demonstrated decreased functional connectivity in lateral regions of frontal cortex, and right lateralized supramarginal gyrus and inferior precentral sulcus. The SMA plays an important role in

Table 1
Main regions showing significant connectivity alterations in the PCC(+) network, PCC(−) network, vmPFC(+) network and vmPFC(−) networks between youths and elders.

Regions	MNI coordinates			Peak *T* score	Brodmann area
	x	*y*	*z*		
PCC(+) network					
L angular	−52	−59	40	3.94	39
PCC	0	−60	21	3.55	23, 30
Bilateral vmPFC	0	63	21	5.41	9, 10
vmPFC(+) network					
L inferior orbital frontal gyrus	−33	21	−18	4.34	38
PCC	4	57	16	3.51	23, 30
PCC(−) network					
L inferior frontal gyrus	−60	15	8	−4.18	6
R inferior frontal gyrus	60	9	9	−4.25	6
L inferior/middle frontal gyrus	−42	39	15	−4.34	45
R middle frontal gyrus	39	45	27	−3.70	46
R supramarginal gyrus	55	−37	27	−3.54	48
R inferior parietal lobule	42	−36	39	−3.10	40
vmPFC(−) network					
R middle occipital gyrus	18	−77	0	4.64	18, 19
L middle occipital gyrus	−23	−78	5	3.19	17, 18
R superior temporal gyrus	43	−28	9	4.63	41, 48
R inferior temporal gyrus	57	−54	−12	−4.48	37
Dorso medial prefrontal cortex	2	3	66	−4.19	6
	9	12	−45	−4.04	32
L superior frontal cortex	−20	6	52	−3.21	6

Thresholds were set at $p < 0.05$, AlphaSim corrected. PCC, posterior cingulated cotex; vmPFC, ventral medial prefrontal cortex; L, left; R, right.

planning, initiation, and execution of motor acts. Patients with SMA lesions are impaired in various kinematic parameters, such as velocity and duration of movement [33]. The impaired PCC(−) distribution largely overlapped with the ventral attention system with a feature of right lateralization. Our findings about the lateralization are consistent with previous studies [8,17,23].

An interesting observation was that the correlations between the seed of vmPFC and part of the occipital visual associated cortex presented positive connectivity in the young group, but negative connectivity in the old group. The altered regulation mechanism between vmPFC and visual cortex might reflect the reduced modulation between perceptual cortex and the higher-order cortex and contribute to the degraded visual attention function.

Our finding of the DMN alterations is similar to that seen in the disorders of aging such as AD and MCI when compared with normal aging [32,39]. Despite the fact that all of our old participants had normal mental status, it is not possible to know with certainty whether some individuals with incipient AD were included. We admit this to be one of the limitations in the present study.

There were some other limitations in our present work. The cause of negative correlations remains disputable [12,27]. Age-related vascular variation may have some effects on the BOLD signal [15,19]. The relationship between the alteration of resting state positive and negative networks and the behavioral performance need to be further investigated.

In summary, both the posterior and anterior network components in the DMN and their anti-correlated networks showed significantly reduced connectivity in the aging group. Our results suggest that the variations in the competitive relationship between the positive and negative networks in resting state may be helpful in understanding cognition decline in aging.

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References

[1] J.R. Andrews-Hanna, J.S. Reidler, J. Sepulcre, R. Poulin, R.L. Buckner, Functional-anatomic fractionation of the brain's default network, Neuron 65 (2010) 550–562.
[2] J.R. Andrews-Hanna, A.Z. Snyder, J.L. Vincent, C. Lustig, D. Head, M.E. Raichle, R.L. Buckner, Disruption of large-scale brain systems in advanced aging, Neuron 56 (2007) 924–935.
[3] B. Biswal, F.Z. Yetkin, V.M. Haughton, J.S. Hyde, Functional connectivity in the motor cortex of resting human brain using echo-planar MRI, Magn. Reson. Med. 34 (1995) 537–541.
[4] T.S. Braver, D.M. Barch, A theory of cognitive control, aging cognition, and neuromodulation, Neurosci. Biobehav. Rev. 26 (2002) 809–817.
[5] M. Corbetta, G.L. Shulman, Control of goal-directed and stimulus-driven attention in the brain, Nat. Rev. Neurosci. 3 (2002) 201–215.
[6] J.S. Damoiseaux, C.F. Beckmann, E.J. Arigita, F. Barkhof, P. Scheltens, C.J. Stam, S.M. Smith, S.A. Rombouts, Reduced resting-state brain activity in the default network in normal aging, Cereb. Cortex 18 (2008) 1856–1864.
[7] M. De Luca, C.F. Beckmann, N. De Stefano, P.M. Matthews, S.M. Smith, fMRI resting state networks define distinct modes of long-distance interactions in the human brain, Neuroimage 29 (2006) 1359–1367.
[8] F. Dolcos, H.J. Rice, R. Cabeza, Hemispheric asymmetry and aging: right hemisphere decline or asymmetry reduction, Neurosci. Biobehav. Rev. 26 (2002) 819–825.
[9] F. Esposito, A. Aragri, I. Pesaresi, S. Cirillo, G. Tedeschi, E. Marciano, R. Goebel, F. Di Salle, Independent component model of the default-mode brain function: combining individual-level and population-level analyses in resting-state fMRI, Magn. Reson. Imaging 26 (2008) 905–913.
[10] M.D. Fox, M. Corbetta, A.Z. Snyder, J.L. Vincent, M.E. Raichle, Spontaneous neuronal activity distinguishes human dorsal and ventral attention systems, Proc. Natl. Acad. Sci. U. S.A. 103 (2006) 10046–10051.
[11] M.D. Fox, A.Z. Snyder, J.L. Vincent, M. Corbetta, D.C. Van Essen, M.E. Raichle, The human brain is intrinsically organized into dynamic, anticorrelated functional networks, Proc. Natl. Acad. Sci. U. S. A. 102 (2005) 9673–9678.
[12] M.D. Fox, D. Zhang, A.Z. Snyder, M.E. Raichle, The global signal and observed anticorrelated resting state brain networks, J. Neurophysiol. 101 (2009) 3270–3283.
[13] C.L. Grady, A.B. Protzner, N. Kovacevic, S.C. Strother, B. Afshin-Pour, M. Wojtowicz, J.A. Anderson, N. Churchill, A.R. McIntosh, A multivariate analysis of age-related differences in default mode and task-positive networks across multiple cognitive domains, Cereb. Cortex 20 (2010) 1432–1447.
[14] M.D. Greicius, B. Krasnow, A.L. Reiss, V. Menon, Functional connectivity in the resting brain: a network analysis of the default mode hypothesis, Proc. Natl. Acad. Sci. U. S. A. 100 (2003) 253–258.
[15] D.A. Handwerker, A. Gazzaley, B.A. Inglis, M. D'Esposito, Reducing vascular variability of fMRI data across aging populations using a breathholding task, Hum. Brain Mapp. 28 (2007) 846–859.
[16] T. Hedden, J.D. Gabrieli, Healthy and pathological processes in adult development: new evidence from neuroimaging of the aging brain, Curr. Opin. Neurol. 18 (2005) 740–747.
[17] C. Hommet, C. Destrieux, T. Constans, G. Berrut, Aging and hemispheric cerebral lateralization, Psychol. Neuropsychiatr. Vieil. 6 (2008) 49–56.
[18] M. Iacoboni, M.D. Lieberman, B.J. Knowlton, I. Molnar-Szakacs, M. Moritz, C.J. Throop, A.P. Fiske, Watching social interactions produces dorsomedial prefrontal and medial parietal BOLD fMRI signal increases compared to a resting baseline, Neuroimage 21 (2004) 1167–1173.
[19] S.S. Kannurpatti, M.A. Motes, B. Rypma, B.B. Biswal, Neural and vascular variability and the fMRI-BOLD response in normal aging, Magn. Reson. Imaging 28 (2010) 466–476.
[20] A.M. Kelly, L.Q. Uddin, B.B. Biswal, F.X. Castellanos, M.P. Milham, Competition between functional brain networks mediates behavioral variability, Neuroimage 39 (2008) 527–537.
[21] W. Koch, S. Teipel, S. Mueller, K. Buerger, A.L. Bokde, H. Hampel, U. Coates, M. Reiser, T. Meindl, Effects of aging on default mode network activity in resting state fMRI: does the method of analysis matter? Neuroimage 51 (2010) 280–287.
[22] K. Kompus, Default mode network gates the retrieval of task-irrelevant incidental memories, Neurosci. Lett. 487 (2011) 318–321.
[23] Z. Li, A.B. Moore, C. Tyner, X. Hu, Asymmetric connectivity reduction and its relationship to HAROLD in aging brain, Brain Res. 1295 (2009) 149–158.
[24] C. Lustig, A.Z. Snyder, M. Bhakta, K.C. O'Brien, M. McAvoy, M.E. Raichle, J.C. Morris, R.L. Buckner, Functional deactivations: change with age and dementia of the Alzheimer type, Proc. Natl. Acad. Sci. U. S. A. 100 (2003) 14504–14509.
[25] K.A. McKiernan, J.N. Kaufman, J. Kucera-Thompson, J.R. Binder, A parametric manipulation of factors affecting task-induced deactivation in functional neuroimaging, J. Cogn. Neurosci. 15 (2003) 394–408.
[26] D. Meunier, S. Achard, A. Morcom, E. Bullmore, Age-related changes in modular organization of human brain functional networks, Neuroimage 44 (2009) 715–723.
[27] K. Murphy, R.M. Birn, D.A. Handwerker, T.B. Jones, P.A. Bandettini, The impact of global signal regression on resting state correlations: are anti-correlated networks introduced? Neuroimage 44 (2009) 893–905.
[28] T.R. Oakes, A.S. Fox, T. Johnstone, M.K. Chung, N. Kalin, R.J. Davidson, Integrating VBM into the General Linear Model with voxelwise anatomical covariates, Neuroimage 34 (2007) 500–508.
[29] A. Pfefferbaum, S. Chanraud, A.L. Pitel, E. Muller-Oehring, A. Shankaranarayanan, D.C. Alsop, T. Rohlfing, E.V. Sullivan, Cerebral blood flow in posterior cortical nodes of the default mode network decreases with task engagement but remains higher than in most brain regions, Cereb. Cortex 21 (2011) 233–244.
[30] M.E. Raichle, A.M. MacLeod, A.Z. Snyder, W.J. Powers, D.A. Gusnard, G.L. Shulman, A default mode of brain function, Proc. Natl. Acad. Sci. U. S. A. 98 (2001) 676–682.
[31] E.J. Sonuga-Barke, F.X. Castellanos, Spontaneous attentional fluctuations in impaired states and pathological conditions: a neurobiological hypothesis, Neurosci. Biobehav. Rev. 31 (2007) 977–986.
[32] C. Sorg, V. Riedl, M. Muhlau, V.D. Calhoun, T. Eichele, L. Laer, A. Drzezga, H. Forstl, A. Kurz, C. Zimmer, A.M. Wohlschlager, Selective changes of resting-state networks in individuals at risk for Alzheimer's disease, Proc. Natl. Acad. Sci. U. S. A. 104 (2007) 18760–18765.
[33] A. Tankus, Y. Yeshurun, T. Flash, I. Fried, Encoding of speed and direction of movement in the human supplementary motor area, J. Neurosurg. 110 (2009) 1304–1316.
[34] L.Q. Uddin, A.M. Kelly, B.B. Biswal, F. Xavier Castellanos, M.P. Milham, Functional connectivity of default mode network components: correlation, anticorrelation, and causality, Hum. Brain Mapp. 30 (2009) 625–637.
[35] D.H. Weissman, K.C. Roberts, K.M. Visscher, M.G. Woldorff, The neural bases of momentary lapses in attention, Nat. Neurosci. 9 (2006) 971–978.
[36] R.L. West, An application of prefrontal cortex function theory to cognitive aging, Psychol. Bull. 120 (1996) 272–292.
[37] T. Wu, Y. Zang, L. Wang, X. Long, M. Hallett, Y. Chen, K. Li, P. Chan, Aging influence on functional connectivity of the motor network in the resting state, Neurosci. Lett. 422 (2007) 164–168.
[38] T. Wu, Y. Zang, L. Wang, X. Long, K. Li, P. Chan, Normal aging decreases regional homogeneity of the motor areas in the resting state, Neurosci. Lett. 423 (2007) 189–193.
[39] H.Y. Zhang, S.J. Wang, B. Liu, Z.L. Ma, M. Yang, Z.J. Zhang, G.J. Teng, Resting brain connectivity: changes during the progress of Alzheimer disease, Radiology 256 (2010) 598–606.