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Clinical study

Development of the functional connectivity of the frontoparietal mirror neuron network in preschool Children: An investigation under resting state

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ABSTRACT

Previous task-related imaging studies in adults have demonstrated that there is a frontoparietal mirror neuron system (MNS) that preferentially engages in self-recognition. However, the development of the MNS during preschool (age 3–5 years) has not been thoroughly examined. In this study, we investigated the development of the MNS by examining the correlations in spontaneous fluctuations of the functional magnetic resonance imaging (fMRI) blood oxygen level-dependent (BOLD) signal in healthy, 3–5-year-old preschool children (n = 30, 15 in each group). Using a ROI-based (inferior frontal gyrus) functional connectivity analysis, we identified a right lateralized MNS during rest in both groups with a positive correlation between the inferior frontal gyrus and inferior parietal lobule. A significant increase in the functional connectivity of the MNS was observed in the older group. Our results suggest that the spontaneous functional connectivity of the MNS is shaped at as early as 3 years of age and undergoes age-related development within the preschool period.

1. Introduction

The mirror neuron system (MNS), which underlies self-recognition, is present only in higher-order primates [1,2] and plays a quintessential role in the development of social strategies in children, such as empathy, sympathy, intentional deception, mental state attribution, action observation, and synchronic imitation with playmates [3,4]. A growing body of neuroimaging studies on self-recognition in adults has generally investigated the neural basis of self-recognition, namely, how the brain gives rise to self. Strong evidence indicates that the right lateralized MNS, including a set of frontal and parietal regions, plays a key role in self-recognition [5–7]. The most striking finding involving the MNS was in a region of the right inferior frontal gyrus (IFG), which exhibited a greater activation during the processing of multimodal self-related stimuli, such as self-face [5,6,8–11], -body [12] and –voice [5]. This finding reflects the process of mapping the observed stimuli onto the self [13,14], the distinction between others and self [6], and sustained attention for processing of the self [11] or self-relevant stimuli [10]. These neural findings from the IFG are in strong agreement with clinical evidence from patients exhibiting delusional misidentification syndrome (DMS, a condition in which the patient thinks that the person in the mirror is an imposter or stranger), who also display lesions in the right frontal lobe [15]. Another brain region that comprises the mirror neuron system is the right inferior parietal lobule (IPL). Repetitive transcranial magnetic stimulation (rTMS) to the right IPL has been demonstrated to disrupt performance of a task involving the recognition of the subject's own face among morphed images of themselves and a familiar person [16]. This region has often been associated with self-awareness when self-related stimuli are presented [17], and clinical evidence indicates that lesions in this area often lead to the disruption of corporeal awareness, such as that observed in patients with anosognosia [18].

The functional anatomy of this frontoparietal MNS, which is vitally important for human self-recognition, has been inferred from the results of conventional task-based studies motivated by the idea that the brain is a system that primarily responds to task variables. An alternative approach to understanding the functional organization of the brain is the use of resting state functional magnetic resonance imaging (rs-fMRI), which assumes that the brain is active even in the absence of a task and driven by internal dynamics. During the resting state, a high temporal coherence of low frequency (<0.08 Hz) fluctuations (LFFs) in an fMRI time series can be observed between spatially distinct, functionally related brain

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regions [19]. Recent brain function studies using rs-fMRI in both animals and humans have provided great support for this approach. For example, using rs-fMRI, functional connectivity has been observed between disparate brain regions that modulate common task paradigms, such as motor [19], visual [19], ligual [20], auditory [21], attention [22], and facial processing [23].

The assumptions and findings from rs-fMRI studies raise a new question regarding the neural basis of self-recognition in humans. Specifically, is the MNS underlying a human's self-recognition restricted to task-response patterns, or does it represent a more fundamental functional architecture in the internal dynamics of brain spontaneous activity? Furthermore, as the requirements for fMRI scanning are too strict for many young children (e.g., no head movement and the necessity for maintaining attention during scanning time-series), little is known about the development of MNS within preschool aged children. The advantage of rs-fMRI is that tasks or the presentation of stimuli are not needed, making it possible to address these questions even in very young children.

We hypothesized that the MNS of humans is not restricted to the evaluation of external stimuli, but rather represents a synchronized spontaneous network in the brain as previous rs-fMRI findings. Furthermore, as a previous study has shown that the concept of the self, which we know to be driven by the MNS, may be actively developing during the preschool stage [24–27], we hypothesized that an increased spontaneous neural activity across the MNS in older preschool-aged children compared to younger ones would be observed.

In the current study, we examined the spontaneous BOLD signal fluctuations of preschool-aged children (a 3- and 5-year-old group with 15 participants each) in the IFG, which is a region determined by previous studies to play a specific role in abstract self-representation. We first determined whether ongoing spontaneous activity can be observed in the MNS, and we subsequently focused in particular upon the development of the MSN between the ages of 3 and 5 years.

2. Methods

2.1. Participants

The final sample of 30 Chinese preschool children between 3 and 5 years of age (see Table 1) were recruited from several kindergartens in Nanshan District, Shenzhen City of Guangdong Province and compensated for their participation. MRI scanning was obtained from 6 additional participants, but these data were excluded from the final analyses because these participants woke up during scanning and were unwilling to continue. All the participants were right-handed with normal vision and were free of psychiatric disorders or medications. The *Chinnes-Binet scale* was used to test the participants' intelligence; no significant intellectual difference between the two groups was found (94.00 ± 2.62 *vs.* 97.40 ± 6.48, $t_{28} = 1.93$, $p > .05$, see also Table 1). The consent procedure was approved by the Academic Ethics Committee of Guangzhou University, and written informed consent was obtained from each participant's legal guardian.

Table 1
Participant characteristics.

	3 years group (n = 15)	5 years group (n = 15)
Sex (female/male)	8/7	7/8
Age (months, means ± SD)	36 ± 2	60 ± 2
Chinese Binet (scores, means ± SD)	94.00 ± 2.62	97.40 ± 6.48

2.2. Data acquisition

All MRI scanning was performed in afternoons or evenings. The day before scanning, the participants complied with our requirement to sleep later in the evening and woke up earlier in the morning than usual, under the assistance of their guardians. All participants were scanned at different times. The participants scanned on the same day were divided into pairs and asked to sleep successively for an interval of one hour. After falling asleep, the children were cuddled softly and moved to the MRI scanner by their kindergarten teacher. During the entire scan, the children were accompanied by their guardians and daycare teacher to increase the sense of security for the children. Finally, 6 participants were eliminated from the study because they woke up during scanning; thus, MRI data of 30 participants, 15 from each age group, composed the final sample. The experimental method was similar to that in previous resting-state studies associated with infants or preschool children [28,29].

All MRI scanning was performed with a 3T MRI scanner (Siemens Magnetom Trio A Tim System) using a 12-channel head coil, at Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences. Anatomical images were scanned using a fast spin echo (FSE) sequence and T1-weighted imaging with the following scan parameters: TR = 564 ms, TE = 9.1 ms, slice thickness = 2.5 mm, gap = 0.5 mm, slice number = 36, flipangle = 70°, field of view (FOV) = 200 mm × 200 mm, and matrix = 250 × 250. For functional images, T2*-weighted single-shot echo planar imaging (single-shot EPI) was used, and the parameters were as follows: TR = 2500 ms, TE = 30 ms, flip angle = 90°, slice thickness = 2.5 mm, gap = 0.5 mm, FOV = 200 mm × 200 mm, and matrix = 64 × 64. The entire brain was scanned in 36 slices, and the scan lasted 8 min. High-resolution three-dimensional structural images were acquired with a T1-weighted magnetization prepared rapid gradient echo (MPRAGE) sequence (TR/TE = 1900 ms/2.53 ms, flip angle = 9°; slice thickness = 1.0 mm, gap = 0 mm; FOV = 250 mm × 250 mm; matrix = 250 × 250). The whole scan for each child participant lasted 15 min.

2.3. Data preprocessing

Data preprocessing was carried out in AFNI (analysis of functional neuroimaging; http://afni.nimh.nih.gov) software [30]. The first 5 image acquisitions of the resting state were discarded because of spin saturation effects and adaptation of subjects to their immediate environment. The remaining 185 images were preprocessed, including:

a) Despiking (removal of extreme time series outliers using a hyperbolic tangent function, using 3dDespike in AFNI);
b) Spatial alignment (3D volume registration using least-squares alignment of 3 translational and 3 rotational parameters; 6 head movement parameters for each subject were saved into a 1D text, using 3dvolreg in AFNI);
c) Spatial normalization to Talairach coordinate space [31] referring to the methodology mentioned in previous resting-state studies in children [32,33]. Initially, the 3-year-old and 5-year-old children's templates (http://jerlab.psych.sc.edu/neurodevelopmentalmridatabase) were converted to AFNI native dataset format (3dcopy in AFNI), then MNI space was aligned to the Talairach space subjected to the intercommissural line (AC-PC) of Talairach. Children's templates were aligned to atlas's template (i.e., TT_N27, using align_epi_anat.py of AFNI's program) and subsequently spatially transformed to the Talairach space (@auto_tlrc in AFNI);

d) Subsequent resampling to 3 mm isotropic voxels was followed by spatial smoothing with 4 mm full-width at half maximum (FWHM; 3dmerge in AFNI);
e) Detrend linear and quadratic drift from the time series of each run (3dDetrend in AFNI);
f) A standard band pass filter (0.01–0.08 Hz) was then applied to the time series of each voxel to reduce the effect of low-frequency drifts and high-frequency noise [34–36], using 1dBandpass in AFNI;
g) Lastly, every voxel was normalized to its mean over the run (3dcalc in AFNI).

2.4. Definition of region of interest

Region of interest (ROI) was defined based on previous task-based studies of self-recognition (see Table 2). In all of these studies, participants were presented with a self-related stimulus such as self-face, -body or -voice and asked to perform a self-other discrimination task, with a consistent activation in the region of the right inferior gyrus (IFG). Thus, given its specific role in self-recognition found broadly in previous studies, the right IFG was used as the seed region in the examination of spontaneous BOLD correlation. Given that this study is the first one focusing on the resting-state and the IFG activated in previous studies was located in different Talairach coordinates, if the seed region were only based on one specific Talairach coordinate system, it would not be reliable or valid. Considering this, the Talairach coordinates of the IFG for functional connectivity analyses were determined by the following rules: first, the median coordinates of the IFG were calculated based on previous studies of IFG activation (for example, the x coordinates in previous studies were: 42, 48, 48, 44, 44, 42, 43, 50, and 46, thus midpoint x coordinates were located at 46); second, before the analyses of functional connectivity, the coordinates were transformed into high resolution 3D images (see Fig. 1) to check whether they were located in the IFG regions. The radii of the spheres used for functional connectivity analyses, were determined by this calculation: half of the longest distance in each dimensional coordinate (for example, the longest distance in x coordinate was 8 mm, thus the radius used was 4 mm). Lastly, right lateralized IFG regions (Talairach coordinate: $x = 46$, $y = 25$, $z = 12.5$) with different three-dimensional radii (4, 17, and 14.5 mm in x y and z axis respectively) generated the seed region in the current study. This calculation covered the activated extent of IFG in all previous studies associated with self-recognition, and, more importantly, excluded the Talairach coordinates of the seed region from the error that may be induced by different self-related stimuli, task requirements or contrast analyses.

2.5. Simple correlation analysis

a) The mean time series of the seed region was calculated by averaging across all voxels within the seed for each subject (3dmaskave in AFNI).
b) To reduce noise and correct for the effects of neuromodulatory strategies that might have influenced the signal at the whole-brain level, such as changes in respiration rate [37,38], we detrended the ROI data against the whole-brain (except for the seed region) time series data [38]. The voxel-wise detrending uses a linear least squares algorithm to remove components from the voxel time series (3dDetrend in AFNI).
c) To compute functional connectivity maps corresponding to a predefined seed ROI, the regional time course was correlated against all other voxels within the whole brain (3dDeconvolve in AFNI). To remove the confounding effects due to motion artifacts, the time-points with excessive head

Table 2
List of studies that reported activation in the right IFG during self-recognition.

Researchers	Task involved	Contrast	Talairach Coordinates		
			x	*y*	*z*
Devue et al. [8]	Self-face recognition	self *vs.* scrambled	42	34	6
		self *vs.* colleague	48	32	14
Uddin et al. [6]	Self-face recognition	self *vs.* familiar	48	42	−2
Kaplan et al. [5]	Self-face recognition	self *vs.* familiar	44	36	12
	Self-voice recognition	self *vs.* familiar	44	38	2
Platek et al. [43]	Self-face recognition	self *vs.* famous	42	8	27
Sugiura et al. [11]	Self-face recognition	A-C *vs.* A-P	43	12	6
		A-P	50	16	2
Oikawa et al. (2011)	Self-face recognition	self *vs.* stranger	46	32	6

Notes: In the studies of Sugiura et al. [11], A corresponds to active self-recognition, P corresponds to passive self-recognition and C corresponds to control tasks. Additionally, we excluded two coordinates reported in the studies of Morita et al. [10] and Hodzic et al. (2009) because these coordinates were located in regions other than IFG.

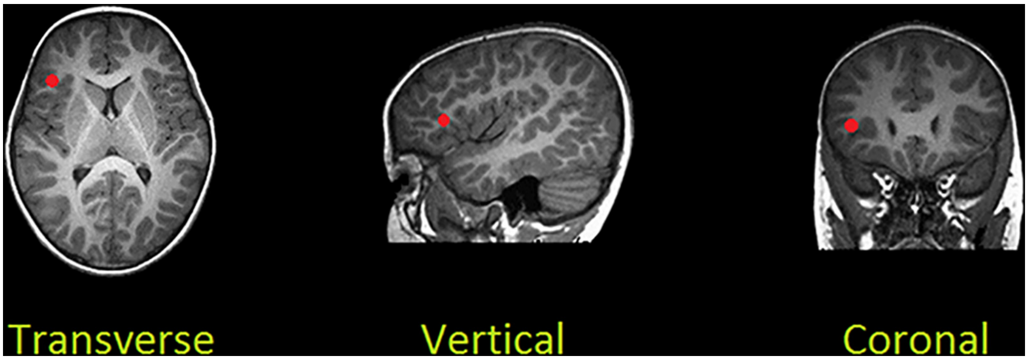

Fig. 1. Region of interest in inferior frontal gyrus of children in resting-state.

motion (>0.3 mm) were censored from each subject's time course; detailed information of the TRs censored is shown in Table 3. Furthermore, 6 head movement parameters obtained from realignment were taken as covariates.

d) Fisher's r-to-z transform was applied to these correlation coefficients [19] (3dcalc in AFNI).

2.6. Group analysis

Subsequently, the z scores were put into voxel-wise one-sample t-test to determine significant connectivity to the IFG in each group (3dttest++ in AFNI). Additionally, voxel-wise two-sample t-test was performed to detect the regions showing significant differences in connectivity between the two groups (3dttest++ in AFNI). A minimum cluster size of 23 voxels (621 mm^3) was determined through Monte Carlo simulations to correct for family-wise errors with a voxel-wise threshold at $t_{14} \geq 4.14$ ($p < .001$) and at $t_{28} \geq 2.145$ ($p < .05$) for the within- and between-groups test respectively. The significance maps were overlaid on an average of the Talairach-normalized high resolution 3D images from all subjects in this study. The locations of regions with significant connectivity to the IFG were identified by known neuroanatomical landmarks.

2.7. Laterality

For each participant, a laterality index (LI) was obtained from statistical maps. The calculation of LI was determined by the following expression: $LI = (L_{vol} - R_{vol})/(L_{vol} + R_{vol})$ [39,40]. In this expression, L represents the volume of the voxel activated above a certain threshold in the left hemisphere, while R represents the volume of the voxel activated above a certain threshold in the right hemisphere. The left hemispheric lateralization was defined as an $LI \geq 0.10$, while the right hemispheric lateralization was defined as an $LI \leq -0.10$. When the laterality indexes of 30 participants were obtained, a between-group comparison was performed using a two-sample t-test.

Table 3
The information of TRs censored from time series.

Group	Subject No.	TRs censored	Percentage censored (%)
3-year-old	1	17	9.18%
	2	4	2.16%
	3	19	10.27%
	4	0	0%
	5	8	4.32%
	6	4	2.16%
	7	6	3.24%
	8	0	0%
	9	0	0%
	10	6	3.24%
	11	57	30.81%
	12	6	3.24%
	13	56	30.27%
	14	6	3.24%
	15	4	2.14%
5-year-old	1	2	1.08%
	2	56	30.27%
	3	50	27.02%
	4	31	16.75%
	5	2	1.08%
	6	37	20%
	7	0	0%
	8	2	1.08%
	9	28	15.13%
	10	2	1.08%
	11	0	0%
	12	13	7.02%
	13	11	5.94%
	14	18	9.72%
	15	30	16.21%

Notes: The time-points with excessive head motion (i.e., >0.3 mm) were censored from data analysis. On average, 6.96% of TRs were excluded from 3-year-old subjects' data while 10.16% of TRs were excluded from 5-year-old subjects' data. No significant difference in the percentages of TRs censored between groups was found in the independent t-test (6.96 ± 2.59% *vs.* 10.16 ± 2.63%, mean with S.E; $t_{28} = -0.87$, $p > .05$, 2-tailed).

3. Results

3.1. Right IFG connectivity analyses within the 3- and 5-year-old groups

Maps of voxels whose time course was significantly correlated or anti-correlated with the time course of right IFG are shown in Table 4. In the 3-year-old group, the right IFG showed significant positive connectivity to a number of brain regions, including the right IFG (BA 47), left middle frontal gyrus (BA 9, 46), and right parietal lobule (BA 40). In the 5-year-old group, the right IFG showed significant positive connectivity to the following brain regions: bilateral IFG (BA 46, 47), right inferior parietal lobule (IPL; BA 40), right medial frontal gyrus (BA 8), middle temporal gyrus (BA 20), and right middle occipital gyrus (BA 19). The key finding was the positive functional connectivity between the IFG and IPL in both groups (see in Fig. 2A and B, presenting with SUMA software, http://afni.nimh.nih.gov/afni/suma), suggesting the frontoparietal mirror neuron system is evident in preschool children.

3.2. Difference in IFG connectivity between the 3- and 5-year-old groups

When comparing right IFG connectivity between the 3-year-old and 5-year-old groups, several regions, including the right superior parietal lobule (BA 7), left postcentral gyrus (BA 2), right IPL (BA 40), left postcentral gyrus (BA 40), and left occipital lobule (BA 31), showed significantly increased connectivity to the right IFG regions in the 5-year-old group; specific cluster locations are listed in Table 5.

3.3. Laterality within the 3- and 5-year-old groups

The significantly activated voxel of IPL was identified. The IPL was chosen because this region and the right IFG comprised the frontoparietal mirror neuron system in previous task-based studies. The result of between-group analyses for laterality index showed that there was no significant difference in laterality between the 3-year-old and 5-year-old groups ($t_{28} \leq 2.048$, $p > .05$, -0.59 ± 0.18 *vs.* -0.56 ± 0.16, see Table 6), but the LI scores imply that the functional connectivity was mostly right lateralized.

4. Discussion

The MNS model derived from previous studies was based upon patterns of neuron activity during the response to explicit self-recognition tasks. In these studies, the frontoparietal MNS was found to be preferentially activated during task processing. In the current study, we explored whether this functional organization is present even under resting state conditions; furthermore, we identified the potential differences in MNS function between two childhood age groups.

We made several key findings. First, we showed that the MNS observed in traditional fMRI studies could also be observed at rest, with the right IPL being positively correlated to the right IFG in both the 3- and 5-year-old groups. Secondly, we found that the spontaneous functional connectivity of the MNS was significantly

Table 4
Regions showing functional connectivity to right IFG in both groups (ifg ROI func…).

Group	Hemisphere	Brain Regions	BA	Vol (mm^3)	Talairach coordinates		
					x	*y*	*z*
3 years	R	Inferior Frontal Gyrus	47	20,142	50	17	−1
	L	Middle Frontal Gyrus	9	3483	−38	23	27
	L	Middle Frontal Gyrus	46	2268	−47	41	15
	R	Inferior Parietal Lobule	40	1161	50	−47	51
	R	Inferior Parietal Lobule	40	1053	56	−35	48
5 years	R	Inferior Frontal Gyrus	47	27,486	47	17	3
	L	Inferior Frontal Gyrus	46	12,474	−47	35	12
	R	Inferior Parietal Lobule	40	9450	32	−50	44
	R	Medial Frontal Gyrus	8	4509	5	20	45
	R	Middle Temporal Gyrus	20	2322	56	−32	−13
	R	Middle Occipital Gyrus	19	675	26	−86	9

Notes: BA, Brodmann's area; Vol, cluster volumn; *x*, *y*, *z*, coordinates of locations in Talairach space (Talairach and Tournoux 1988). Voxels with $t_{14} \geq 4.14$ ($p < .001$), and a minimum cluster size of 23 (621 mm^3) were considered to be significantly functionally correlated to the right IFG.

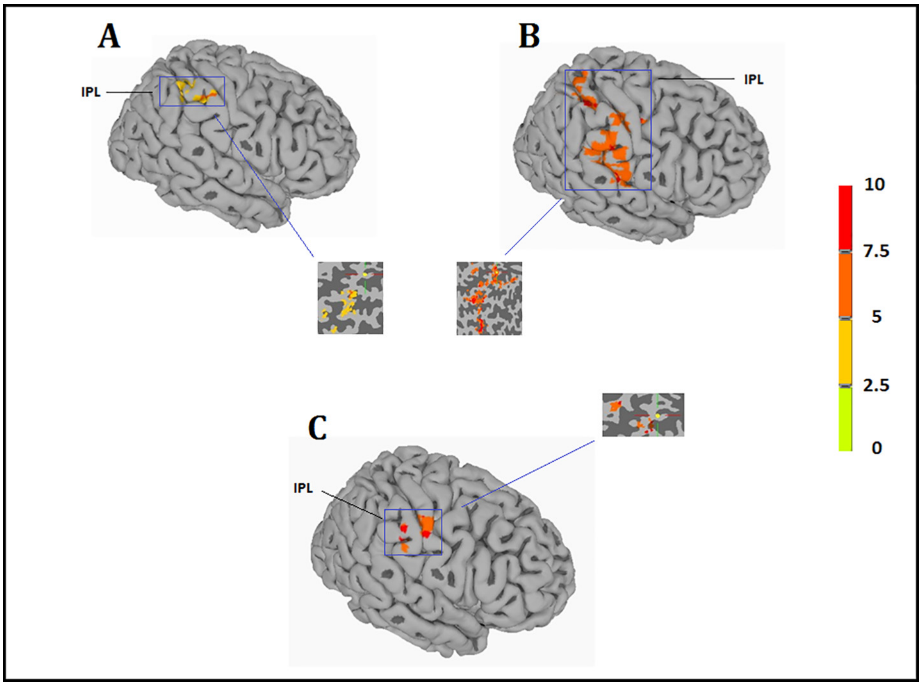

Fig. 2. The functional connectivity of frontoparietal MNS. (A) and (B) respectively correspond to the 3-year- and 5-year-old groups, voxel threshold was set at $t_{14} \geq 4.14$ ($p < .001$) with a minimum cluster size of 23 voxels (621 mm^3); (C) corresponds to right IPL (BA 40) showing significantly increased connectivity to the right IFG seed regions in the 5-year-old group relative to 3–year-old group, voxel threshold was set at $t_{28} \geq 2.145$ ($p < .05$) with a minimum cluster size of 23 voxels (621 mm^3); All corresponded to flattened images of right IPL.

Table 5
Regions showing increased functional connectivity to IFG in the 5-year-old group.

Brain regions	BA	Vol (mm^3)	Talairach coordinate		
			x	*y*	*z*
Right superior parietal lobule	7	4725	26	−56	60
Left postcentral gyrus	2	1620	−53	−29	57
Right inferior parietal lobule	40	1107	59	−32	39
Left postcentral gyrus	40	891	−29	−38	42
Left Occipital Lobule	31	837	−20	−71	18

Notes: The meanings of BA, Vol and Talairach coordinate are shown in Table 4. Voxels with $t_{14} \geq 2.145$ ($p < .05$), and a minimum cluster size of 23 (621 mm^3) were considered to be significantly functionally correlated to the right IFG.

increased in the 5-year-old group relative to the 3-year-old group. Finally, we observed that the synchronized spontaneous neural activity across the MNS displayed a right hemispheric lateralization.

Functional connectivity analyses showed that the right IPL (BA 40) was positively correlated to the right IFG in both groups. In previous studies, when participants were presented with the self-face, a typical co-activation of the right IPL and IFG was generally

Table 6
Functional laterality indexes.

	LI (mean ± SD)
All participants (n = 30)	−0.57 ± 0.23
3 years group (n = 15)	−0.59 ± 0.18
5 years group (n = 15)	−0.56 ± 0.16

Notes: $LI = (L_{vol} - R_{vol})/(L_{vol} + R_{vol})$, $LI \geq 0.10$ and $LI \leq -0.10$ were defined as left and right hemispheric lateralization respectively. There was no significant difference in laterality between 3-year-old and 5-year-old groups [$t_{28} \leq 2.048$ ($p > .05$)].

observed. Thus, this right frontoparietal network was considered to be a part of the MNS that preferentially engaged in self-recognition [5–7]. We have extended this finding in the present study by showing that the spontaneous functional connectivity between the IPL and the IFG is also observed during the resting state. Our results suggest that the frontoparietal MNS is not only driven by external demands but also represents a fundamental functional architecture in the internal dynamics of brain spontaneous activity.

Our results also show that the spontaneous functional connectivity of MNS was increased in the older, compared to the younger, age group suggesting that the frontoparietal MNS undergoes age-related development. This may support findings from previous behavioral studies that have indicated that the self-recognition ability of a 5-year-old child is greater than that of a 3-year-old child [24–27]. However, one limitation to the current study is the lack of behavioral tests. Including such tests in future studies, which would strengthen the correlation between behavioral performance and spontaneous functional connectivity of the MNS, will help to elucidate the nature of the synchronized spontaneous neural activity of MNS.

Notably, although previous task-based studies have reported a right-lateralization of the MNS [5–7], we directly quantified this laterality on the basis of spontaneous functional connectivity. We found that the functional connectivity of the MNS during rest was indeed right-lateralized; the presence of lateralization during the resting state is important because it suggests that hemispheric lateralization is not induced by task-involved processing but is a fundamental aspect of the patterning of spontaneous activity. Furthermore, this finding may also provide some explanation of the inconsistent findings and perspectives regarding hemispheric lateralization in previous task-based studies [5,6,41–45].

The current study demonstrates that the frontoparietal MNS, defined on the basis of explicit tasks with specific self-recognition demands, also exhibits ongoing spontaneous activity. An important and interesting question is why task-evoked and resting-state activity patterns are so similar. One striking idea is that internal ongoing spontaneous activity serves to organize and coordinate neural activity, and this organization and coordination would be more effective if regions were commonly co-modulated [22,46]. Another viewpoint is that the spontaneous activity of the frontoparietal MNS serves as a record or memory of previous use, allowing the regions that have been modulated together in a task to be correlated during resting conditions [47]. These viewpoints are mutually compatible and benefit our understanding of why the task-based activation patterns of the MNS can also be shown during spontaneous activity.

In summary, the current study identifies a right-lateralized MNS in preschool children on the basis of spontaneous activity, suggesting that the MNS, as defined in previous task-based studies, represents a fundamental functional architecture in the internal dynamics of spontaneous brain activity. Furthermore, this system is subject to age-related development in children between the ages of 3 and 5 years old. The finding that the MNS, as defined by self-face recognition tasks in traditional fMRI studies, was also functionally connected during rest invites a broader investigation of whether other functional networks (e.g., multisensory perception, learning and memory, dorsal/ventral visual system, and emotion) also possess properties of internal dynamics.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jocn.2019.07.070.

References

[1] Gallup GG. Chimpanzees: self-recognition. Science 1970;167(3914):86–7.
[2] Povinelli DJ, Gallup GG, Eddy TJ, Bierschwale DT, Engstrom MC, Perilloux HK, et al. Chimpanzees recognize themselves in mirrors. Anim Behav 1997;53(5):1083–8.
[3] Asendorpf JB, Baudonnière PM. Self-awareness and other-awareness: Mirror self-recognition and synchronic imitation among unfamiliar peers. Dev Psychol 1993;29(1):88.
[4] Gallup GG. Self-awareness and the emergence of mind in primates. Am J Primatol 1982;2(3):237–48.
[5] Kaplan JT, Aziz-Zadeh L, Uddin LQ, Iacoboni M. The self across the senses: an fMRI study of self-face and self-voice recognition. Soc Cognit Affect Neurosci 2008;3(3):218–23.
[6] Uddin LQ, Kaplan JT, Molnar-Szakacs I, Zaidel E, Iacoboni M. Self-face recognition activates a frontoparietal "mirror" network in the right hemisphere: an event-related fMRI study. Neuroimage 2005;25(3):926–35.
[7] Uddin LQ, Iacoboni M, Lange C, Keenan JP. The self and social cognition: the role of cortical midline structures and mirror neurons. Trend Cognit Sci 2007;11(4):153–7.
[8] Devue C, Collette F, Balteau E, Degueldre C, Luxen A, Maquet P, et al. Here I am: the cortical correlates of visual self-recognition. Brain Res 2007;1143:169–82.
[9] Kircher TTJ, Senior C, Phillips ML, Benson PJ, Bullmore ET, Brammer M, et al. Towards a functional neuroanatomy of self processing: effects of faces and words. Cognit Brain Res 2000;10(1–2):133–44.
[10] Morita T, Itakura S, Saito DN, Nakashita S, Harada T, Kochiyama T, et al. The role of the right prefrontal cortex in self-evaluation of the face: a functional magnetic resonance imaging study. J Cognit Neurosci 2008;20(2):342–55.
[11] Sugiura M, Kawashima R, Nakamura K, Okada K, Kato T, Nakamura A, et al. Passive and active recognition of one's own face. NeuroImage 2000;11(1):36–48.
[12] Hodzic A, Kaas A, Muckli L, Stirn A, Singer W. Distinct cortical networks for the detection and identification of human body. Neuroimage 2009;45(4):1264–71.
[13] Gallese V. The roots of empathy: the shared manifold hypothesis and the neural basis of intersubjectivity. Psychopathology 2003;36(4):171–80.
[14] Rizzolatti G, Craighero L. The mirror-neuron system. Annu Rev Neurosci 2004;27:169–92.
[15] Feinberg TE, Roane DM. Delusional misidentification. Psychiatr Clin North Am 2005;28(3). 665–83, 678–9.
[16] Uddin LQ, Molnar-Szakacs I, Zaidel E, Iacoboni M. rTMS to the right inferior parietal lobule disrupts self–other discrimination. Soc Cognit Affect Neurosci 2006;1(1):65–71.
[17] Jackson PL, Decety J. Motor cognition: a new paradigm to study self–other interactions. Curr Opin Neurobiol 2004;14(2):259–63.
[18] Berlucchi G, Aglioti S. The body in the brain: neural bases of corporeal awareness. Trends Neurosci 1997;20(12):560–4.
[19] Lowe MJ, Mock BJ, Sorenson JA. Functional connectivity in single and multislice echoplanar imaging using resting-state fluctuations. Neuroimage 1998;7(2):119–32.
[20] Hampson M, Peterson BS, Skudlarski P, Gatenby JC, Gore JC. Detection of functional connectivity using temporal correlations in MR images. Hum Brain Mapp 2002;15(4):247–62.
[21] Cordes D, Haughton VM, Arfanakis K, Carew JD, Turski PA, Moritz CH, et al. Frequencies contributing to functional connectivity in the cerebral cortex in "resting-state" data. Am J Neuroradiol 2001;22(7):1326–33.

[22] Fox MD, Corbetta M, Snyder AZ, Vincent JL, Raichle ME. Spontaneous neuronal activity distinguishes human dorsal and ventral attention systems. Proc Natl Acad Sci 2006;103(26):10046–51.

[23] Zhu Q, Zhang J, Luo YLL, Dilks DD, Liu J. Resting-state neural activity across face-selective cortical regions is behaviorally relevant. J Neurosci 2011;31 (28):10323–30.

[24] Case R. Intellectual development. Birth to adulthood. New York: Academic Press; 1985.

[25] Fischer KW. A theory of cognitive development: The control and construction of hierarchies of skills. Psychol Rev 1980;87(6):477–531.

[26] Harter S. The development of self-representations. In: Damon W, Eisenberg N, editors. Handbook of child psychology: Vol. 3, Social, emotional, and personality development. New York: Wiley; 1998. p. 553–617.

[27] Harter S. Construction of the self: developmental and sociocultural foundations. New York: Guilford; 1999.

[28] Liu WC, Flax JF, Guise KG, Sukul V, Benasich AA. Functional connectivity of the sensorimotor area in naturally sleeping infants. Brain Res 2008;1223:42–9.

[29] Wilke M, Holland SK, Ball WS Jr. Language processing during natural sleep in a 6-year-old boy, as assessed with functional MR imaging. Am J Neuroradiol 2003;24(1):42–4.

[30] Cox RW. AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. Comput Biomed Res 1996;29(3):162–73.

[31] Talairach J, Tournoux P. Co-planar stereotaxic atlas of the human brain. New York: Thiem; 1988.

[32] Sanchez CE, Richards JE, Almli CR. Neurodevelopmental MRI brain templates for children from 2 weeks to 4 years of age. Dev Psychobiol 2012;54(1):77–91.

[33] Schlaggar BL, Brown TT, Lugar HM, Visscher KM, Miezin FM, Petersen SE. Functional neuroanatomical differences between adults and school-age children in the processing of single words. Science 2002;296(5572):1476–9.

[34] Biswal B, Yetkin FZ, Haughton VM, Hyde JS. Functional connectivity in the motor cortex of resting human brain using echo-planar MRI. Magn Reson Med 1995;34(4):537–41.

[35] Greicius MD, Krasnow B, Reiss AL, Menon V. Functional connectivity in the resting brain: a network analysis of the default mode hypothesis. Proc Natl Acad Sci 2003;100(1):253–8.

[36] Wang L, Zang Y, He Y, Liang M, Zhang X, Tian L, et al. Changes in hippocampal connectivity in the early stages of Alzheimer's disease: evidence from resting state fMRI. Neuroimage 2006;31(2):496–504.

[37] Birn RM, Smith MA, Jones TB, Bandettini PA. The respiration response function: the temporal dynamics of fMRI signal fluctuations related to changes in respiration. Neuroimage 2008;40(2):644–54.

[38] Hamilton JP, Glover GH, Hsu JJ, Johnson RF, Gotlib IH. Modulation of subgenual anterior cingulate cortex activity with real-time neurofeedback. Hum Brain Mapp 2011;32(1):22–31.

[39] Vernooij MW, Smits M, Wielopolski PA, Houston GC, Krestin GP, van der Lugt A. Fiber density asymmetry of the arcuate fasciculus in relation to functional hemispheric language lateralization in both right-and left-handed healthy subjects: a combined fMRI and DTI study. Neuroimage 2007;35(3):1064–76.

[40] Vikingstad EM, George KP, Johnson AF, Cao Y. Cortical language lateralization in right handed normal subjects using functional magnetic resonance imaging. J Neurol Sci 2000;175(1):17–27.

[41] Breen N, Caine D, Coltheart M. Mirrored-self misidentification: two cases of focal onset dementia. Neurocase 2001;7(3):239–54.

[42] Hodzic A, Muckli L, Singer W, Stirn A. Cortical responses to self and others. Hum Brain Mapp 2009;30(3):951–62.

[43] Platek SM, Keenan JP, Gallup GG, Mohamed FB. Where am I? The neurological correlates of self and other. Cognitive Brain Research 2004;19(2):114–22.

[44] Platek SM, Loughead JW, Gur RC, Busch S, Ruparel K, Phend N, et al. Neural substrates for functionally discriminating self-face from personally familiar faces. Hum Brain Mapp 2006;27(2):91–8.

[45] Turk DJ, Heatherton TF, Kelley WM, Funnell MG, Gazzaniga MS, Macrae CN. Mike or me? Self-recognition in a split-brain patient. Nat Neurosci 2002;5 (9):841–2.

[46] Salinas E, Sejnowski TJ. Correlated neuronal activity and the flow of neural information. Nat Rev Neurosci 2001;2(8):539–50.

[47] Kenet T, Bibitchkov D, Tsodyks M, Grinvald A, Arieli A. Spontaneously emerging cortical representations of visual attributes. Nature 2003;425 (6961):954–6.