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Watching cartoons activates the medial prefrontal cortex in children

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The medial prefrontal cortex (MPFC) of human adults is involved in attributing mental states to real human agents but not to virtual artificial characters. This study examined whether such differential MPFC activity can be observed in children who are more fascinated by cartoons than adults. We measured brain activity using functional magnetic resonance imaging (fMRI) while 10-year-old children watched movie and cartoon clips, simulating real and virtual visual worlds, respectively. We showed neuroimaging evidence that, in contrast to adults, the MPFC of children was activated when perceiving both human agents and artificial characters in coherent visual events. Our findings suggest that, around the age of 10 years, the MPFC activity in children is different from that in adults in that it can be spontaneously activated by non-human agents in a virtual visual world.

fMRI, theory-of-mind, MPFC, children, cartoon

Children are commonly more fascinated by cartoons than adults. Are there any brain regions of children specifically engaged in viewing cartoons? A recent functional magnetic resonance imaging (fMRI) study found that, in adults, distinct neural substrates were involved in the perception of human beings in the real visual world (shown in movie clips), compared with when cartoon clips were seen with artificial characters in a virtual visual world[1]. In particular, relative to a baseline with static random images, movies clips of human agents in successive events induced stronger activation in the medial prefrontal cortex (MPFC) of adults, an area linked to our ability to explain and predict behaviour in terms of mental states, or to form a theory of mind[2−5]. However, no activation was observed in the MPFC when adults watched cartoon clips of artificial characters (robots or machine dinosaurs), suggesting that adults differentiate real and virtual visual worlds by automatically attributing mental states to human agents in the real visual world, a process that does not spontaneously take place when artificial characters are viewed in a virtual visual world. In the current work we tested if, for children, the MPFC is engaged when non-human agents are viewed in a virtual world, as well as when humans are viewed in the real world. One possibility is that children are interested in cartoons because particular brain areas are engaged in perception of cartoons.

We tested this hypothesis by measuring brain activation when 10-year-old children freely viewed silent movie and cartoon clips. There were brief sequences of actions involving either humans in real-life situations, such as people walking at a subway station or taking lectures in a class room (in the movie clips, Figure 1(a)), or non-human agents such as robots and machine dinosaurs walking and fighting in virtual worlds (in the cartoon clips, Figure 1(b)). Brain activity when watching the clips was compared with activity when participants viewed static images from the movie and cartoon clips

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shown in a random order, to control low-level visual feature processing. Of particular interests was whether MPFC shows activation when children watch both movie and cartoon clips.

1 Methods

1.1 Participants

Ten children (5 male, all 10 years of age) with no neurological or psychiatric history participated in this study. All participants were right-handed, had normal or corrected-to-normal vision, and were not color blind. Informed consent was obtained from the children's parents prior to scanning. This study was approved by a local ethic committee.

1.2 Stimuli and procedure

The stimuli were presented through an LCD projector onto a rear-projection screen located at the subject's head. The screen was viewed with an angled mirror positioned on the head-coil. The stimuli were movie and cartoon clips without accompanying sound and static images extracted from them. As illustrated in Figure 1, movie clips depicted human beings in real visual scenes (e.g., people meeting and walking at a subway station or students taking lectures in a classroom). Cartoon clips depicted artificial characters in virtual visual scenes (e.g., robots or machine dinosaurs walking and fighting with transformed shapes). Both the movies and cartoons were made by showing 29 frames of images per second. At a viewing distance of 70 cm, the movie and cartoon subtended visual angles of 28°×16° (width × height) and 27°×20°, respectively. The sizes of static images were the same as the corresponding movies and cartoons. Four scans of 280 s were obtained from each subject. Each scan consisted of four 1-min epochs, alternating pseudo-randomly between movies, cartoons, and static images across subjects. There was a 10-s black screen before each epoch to set up a baseline for each epoch of stimuli. Thirty images were extracted at every 2 s from the corresponding movies and cartoons and were presented (each with a duration of 2 s) in a random order during the epochs of static images. Movie and cartoon clips and the corresponding static images were upright in two scans whereas upside down in the other two scans. The sequence of the four scans was counterbalanced across subjects. Subjects were asked to view freely the movies, cartoons, or static images while keeping their heads still.

1.3 fMRI image acquisition and analysis

Scanning was performed on a 3T Siemens Trio system using a standard head coil at Beijing MRI Center for Brain Research. 32 transversal slices of functional images that covered the whole brain were acquired using a gradient-echo echo-planar pulse sequence (64×64×32 matrix with 3.4×3.4×4.4-mm^3 spatial resolution, TR = 2000 ms, TE = 30 ms, FOV = 220 mm, flip angle = 90º). Anatomical images were obtained using a standard 3-D T1-weighted sequence (256×256×176 matrix with 0.938 ×0.938×1.3-mm^3 spatial resolution, TR = 1600 ms, TE = 3.93 ms). Subjects' heads were immobilized during the scanning sessions using pieces of foam.

SPM99 (the Wellcome Department of Cognitive Neurology, UK) was used for data processing and analysis. The functional images were realigned to the first scan to correct for the head movement between scans. The anatomical image was co-registered with the mean functional image produced during the process of realignment. All images were normalized to a 2×2×2 mm^3 Montreal Neurological Institute (MNI) template in Talairach space[6] using bilinear interpolation. Functional images were spatially smoothed using a Gaussian filter with a full-width at half maximum (FWHM) parameter set to 8 mm. The image data were modeled using a box-car function. Contrasts were defined to compare the difference between movies or cartoons and their corresponding static images presented in a random order. Random effect analyses were then conducted across the group of subjects based on statistical parameter maps from each individual subject to allow population inference. Because we had a prediction of activations in the MPFC and other brain areas based on the results of our prior study on adults, areas of significant activation were identified at the voxel level for values exceeding an uncorrected P value of 0.0005. The SPM coordinates for standard brain from MNI template were converted to Talairach coordinates using a non-linear transform method (http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html). Region-of-interest analyses were conducted to compare relative changes of fMRI signals in the MPFC clusters showing significant activation in the SPM analysis associated with watching movie clips of humans. The mean fMRI signal changes in association with viewing movie (or cartoon) clips relative to viewing blank screens in the MPFC cluster in each condition

Figure 1 Illustration of the images extract from the movie and cartoon clips used in the current study. (a) Images from movie clips; (b) images from cartoon clips.

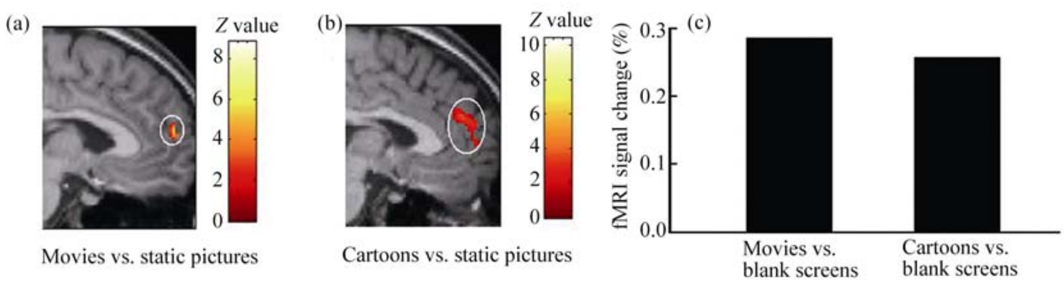

Figure 2 The MPFC activations associated with viewing upright movie and cartoons depicting human beings in real visual scenes. (a) The contrast between upright movie clips and static images; (b) the contrast between upright cartoon clips and static images; (c) mean fMRI signal changes for viewing movie and cartoon clips relative to viewing blank screens.

were compared using one-sample *t*-test.

2 Results

The contrast of movies-random static images showed activations in bilateral middle temporal cortex (MT) and the posterior superior temporal sulcus (STS) (centred at –50, –70, 4 and 50, –64, 10) and MPFC (centred at –4, 61, 10, corresponding to Brodmann's area 9, see Figure 2(a)). Relative to static images, cartoon clips also activated bilateral MT and posterior STS (centred at –44, –70, 4 and 51, –58, 3), bilateral superior parietal lobule (SPL, centred at –18, –34, 55 and 28, –46, 59), and MPFC (–12, 54, 23, Figure 2(b)). Because many cognitive functions show decreased MPFC activity relative to a resting condition[7], we further examined if viewing movie or cartoon clips also increased MPFC activity in comparison with watching blank screens. The region-of-interest analysis confirmed that, relative to blank screens, both movie and cartoon clips increased fMRI signals in the MPFC clusters (t = 2.318 and 2.193, respectively, both P<0.03, Figure 2(c)). The fMRI results obtained with children are similar to those obtained from adults[1] except that, uniquely, the MPFC in children was also activated by viewing cartoon clips. This provides brain imaging evidence that the perception of artificial characters in a virtual visual world differs between children and adults in that the MPFC is activated for children but not for adults.

The prior work showed that the MPFC activation associated with passive viewing of movie clips of humans was weakened when the movie clips were shown upside down[1], possibly because inverted faces are difficult to recognize or identify[8,9], leading to difficulties in reasoning about the characters' mental states. Consequently, we examined if the engagement of the MPFC, when children viewed movie and cartoon clips, was modulated by inversion. We had the same group of children watch the inverted version of the movie and cartoon clips, along with corresponding static images. Relative to when random static images were presented, inverted movie clips of humans activated bilateral MT and posterior STS (–48, –68, 3 and 50, –50, 7) and SPL (–32, –41, 53 and 40, –34, 49), but now no activation was found in the MPFC. This is similar to prior results with adults. The cartoons showed a different pattern. Like the movie clips inverted cartoon clips activated bilateral MT and posterior STS (–50, –60, 10 and 56, –61, 12) and SPL (–32, –33, 44 and 40, –33, 48), but they also generated significant activation of the MPFC (2, 59, 8).

3 Discussion

Our results indicate that, as for adults, the MPFC of children is involved when human agents in the real visual world are perceived, but not when an inverted scene is presented. This is consistent with that inverted images of humans are difficult to encode[8,9]. Similarly to that observed in adults[1], movie and cartoon clips induced increased activation in bilateral MT and posterior STS in children relative to static images. These areas have been reported to be engaged in the processing of motion direction[10] and biological motion[11]. Our results indicate that the neural mechanisms underlying the processing of motion characters of movie and cartoon clips are similar in children and adults. However, unlike adults, children of 10 years showed increased activation in the MPFC when watching virtual non-human agents such as robots and machine dinosaurs shown in cartoons.

Previous studies have shown consistent evidence that the MPFC is engaged when humans engage in a theory of mind of other people[2–5]. Thus activation of the same region when other humans are viewed in the real world suggests that adults spontaneously engage in mentalising about other minds in these circumstances[1]. However, the same processes are not automatically involved when cartoons are observed. In contrast, the MPFC activity in children at the age of 10 years did not automatically differentiate human in the real visual world and non-human agents in the virtual visual world. While our fMRI results indicate that, compared with adults, children of 10 years old employed distinct neural substrates in perceiving a virtual visual world shown in cartoon clips, the functional role of MPFC activation is still unclear. One possible account is that children at the age of 10 years empathise with and attribute mental states to both human and non-human characters in movie and cartoon clips using the MPFC. However, this interpretation cannot be demonstrated in the current study. Future research is required to examine the functional role of the MPFC activation in watching cartoon clips in children.

Interestingly, the data when inverted cartoons are perceived suggests that children continue to engage the MPFC with the agents even in an upside-down virtual visual world. The result emphasizes the robust nature of MPFC involvement when children view cartoons, which remains when actions are inverted. If, as speculated above, the MPFC activation is involved in attributing mental states to non-human characters in cartoon clips, one may further hypothesize that, children are more interested in cartoons and thus pay more attention to characters' mental states even when they look upside-down.

Our neuroimaging findings raise an interesting issue about the development of cognitive capacities, such as the ability to form a theory of mind. Previous research mainly focuses on when children start to show the ability to attribute mental states[12–15], but ignores when children are able to automatically differentiate agents with or without human mental states. Our findings suggest that, although children acquire the ability to form a theory of mind by the age of 4—6 years[13–15], children at the age of 10 years still do not automatically differentiate real-world human agents and non-human agents operating in virtual worlds in terms of the activity in MPFC. Future research is required to further examine if both human and non-human agents are attributed mental states through the activation of the MPFC in children at the age of 10 years.

1 Han S, Jiang Y, Humphreys G W, et al. Distinct neural substrates for the perception of real and virtual visual worlds. NeuroImage, 2005, 24: 928—935[DOI]

2 Fletcher P C, Happe F, Frith U, et al. Other minds in the brain: A functional imaging study of "theory of mind" in story comprehension. Cognition, 1995, 57: 109—128[DOI]

3 Brunet E, Sarfati Y, Hardy-Baylé M, et al. A PET investigation of the attribution of intentions with a nonverbal task. NeuroImage, 2000, 11: 157—166[DOI]

4 Gallagher H L, Happe F, Brunswick N, et al. Reading the mind in

cartoons and stories: An fMRI study of 'theory of mind' in verbal and nonverbal tasks. Neuropsychologia, 2000, 38: 11—21[DOI]

5 Gallagher H L, Frith C D. Functional imaging of 'theory of mind'. Trends Cogni Sci, 2003, 7: 77—83[DOI]

6 Talairach J, Tournoux P. Co-Planar Stereotaxic Atlas of the Human Brain. New York: Thieme, 1998

7 Gusnard D A, Raichle M E. Searching for a baseline: Functional imaging and the resting human brain. Nat Rev Neurosci, 2001, 2: 685—694[DOI]

8 Farah M J, Tanaka J W, Drain H M. What causes the face inversion effect? J Exp Psychol Hum Percep Perform, 1995, 21: 628—634[DOI]

9 Eimer E. Effects of face inversion on the structural encoding and recognition of faces: Evidence from event-related brain potentials. Cogni Brain Res, 2000, 10: 145—158[DOI]

10 Tootell R B, Reppas J B, Kwong K K, et al. Functional analysis of human MT and related visual cortical areas using magnetic resonance imaging. J Neurosci, 1995, 15: 3215—3230

11 Puce A, Allison T, Bentin S, et al. Temporal cortex activation in humans viewing eye and mouth movements. J Neurosci, 1998, 18: 2188—2199

12 Frith C D, Frith U. Interacting minds — A biological basis. Science, 1999, 286: 1692—1695[DOI]

13 Frith U, Frith C D. Development and neurophysiology of mentalizing. Phil Trans R Soc Lond B, 2003, 358: 459—473[DOI]

14 Wellman H M. The Child's Theory of Mind. Cambridge, MA: MIT Press, 1990

15 Wellman H M, Cross D, Watson J. Meta-analysis of theory-of-mind development: The truth about false belief. Child Dev, 2001, 72: 655—684[DOI]