

Distinct Neurocognitive Strategies for Comprehensions of Human and Artificial Intelligence

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Abstract

Although humans have inevitably interacted with both human and artificial intelligence in real life situations, it is unknown whether the human brain engages homologous neurocognitive strategies to cope with both forms of intelligence. To investigate this, we scanned subjects, using functional MRI, while they inferred the reasoning processes conducted by human agents or by computers. We found that the inference of reasoning processes conducted by human agents but not

reasoning processes in HI and AI. This was examined by contrasting the MI task with a deductive reasoning (DR) task based on the first-person perspective, in which subjects made inference of the color of Agent B's hat in Figure 1a or the color of

substrates differentiating the inference of reasoning processes conducted by human agents and computers.

Previous research showed that taking a third-person perspective engages the precuneus [10,11] whereas taking first-person perspective [11] and conducting self-referential processing [9,18–20] recruits the ventral medial prefrontal cortex (vMPFC). Thus we were particularly interested in variations of activity in the precuneus and vMPFC in association with the inference of the

participants were asked to identify whether the computer could compute the color of the hat hung on Rod B based on the information it receives through the camera and the context information provided in a stimulus display. The instructions in the PC and DR tasks were identical with HI and AI stimuli.

A box-car design was used. Each task session repeated ten times and were evenly distributed in five scans. Each task session was preceded by an instruction of 4 s that identified the task, which was followed by 4 trials. On each trial, a stimulus display was presented for 3500 ms under the question and was followed by a 500 ms interval. Two task sessions were separated by a fixation cross ($0.36 \times 0.36^\circ$) of 6 s at the center of the screen. Participants pressed one of the two buttons with the right index or middle finger to answer the questions. The order of the tasks and the assignment of response buttons were counterbalanced across scans and participants.

Behavioural Data Analysis. Response accuracy and reaction time (RT) were recorded to each task and subjected to a one-way analysis of variance (ANOVA) with Task (MI, DR, PT, PC) as the main effect (Figure S2). Separate t-tests were also conducted to compare the difference in behavioural performances between each two tasks.

fMRI Data Acquisition. 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 ($64 \times 64 \times 32$ matrix with $3.4 \times 3.4 \times 4.4$ -mm spatial resolution, TR = 2000 ms, TE = 30 ms, FOV = 220 mm, flip angle = 90°). After the functional scanning, anatomical images were obtained using a standard 3D T1-weighted sequence ($256 \times 256 \times 176$ matrix with $0.938 \times 0.938 \times 1.3$ -mm spatial resolution, TR = 1600 ms, TE = 3.93 ms).

fMRI Data Analysis. SPM2 (the Wellcome Department of Cognitive Neurology, UK) was used for data processing and analysis. The blood oxygen level dependence (BOLD) 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 $2 \times 2 \times 2$ mm³ Montreal Neurological Institute (MNI) template in Talairach space using bilinear interpolation. Functional images were spatially smoothed using a Gaussian filter with a full-width at half maximum (FWHM) parameter for 8 mm. The image data were modeled using a box-car function. Parameter estimates for each condition were calculated from General Linear Model (GLM) based on hemodynamic response function. Contrasts were calculated between each two conditions. Statistical effects were first assessed in individual subjects using a fixed effect analysis. Random effect analyses were then conducted based on statistical parameter maps from each individual subject to allow population inference. A one-sample t-test was applied to determine group activation for each effect. Significant activation was identified at the cluster level for values exceeding a P value of 0.05 (corrected for multiple comparisons). The SPM coordinates for a standard brain from MNI template were converted to Talairach coordinates using a nonlinear transform method (<http://www.mrc-cbu.cam.ac.uk/Imaging/mnispac.html>). To compare the neural activities with HI and AI, parameter estimates of signal intensity were extracted from region of interests (ROIs) and compared using two-sample t-tests. The ROI in the precuneus was defined as a sphere with 6 mm diameter centered at the peak voxel observed in the contrast of PT vs. PC tasks and the ROI in vMPFC was defined as a sphere with 6 mm diameter centered at the peak voxel of vMPFC activation (BA10, 0/49/7) associated

with self-referential processing observed in our previous research [19,20]. The ROI in the intraparietal sulcus was defined as a sphere with 6 mm diameter centered at the peak voxel observed in the contrast of DR vs. PC tasks.

Psychophysiological Interaction Analysis. After we identified the involvement of several brain areas in the MI task, we conducted a psychophysiological interaction (PPI) analysis [21] to examine the covariation between the neural activities in tovaluation o2 w3(funon)-2-273.47conditnevitiesy0723(with)-451.3(6)-peaveastas

right index finger. The assignment of the left or right index finger to ‘Yes’ and ‘No’ responses was counterbalanced across subjects.

Results

The mean response accuracy across all tasks was 95.2% and 91.3% related to HI and AI stimuli, respectively. A one-way analysis of variance (ANOVA) of reaction times (RTs) showed a significant main effect of Task (HI: $F(3,39) = 151.8$, $p < 0.0001$; AI: $F(3,39) = 152.5$, $p < 0.0001$, **Figure S2**). Paired t-tests confirmed that RTs to the PC task were shorter than those to the PT, DR, and MI tasks (all $p < 0.002$). Furthermore, RTs to the PT task were shorter than those to the DR and MI tasks (all $p < 0.0001$). However, there was no significant difference in RTs between the DR and MI tasks ($p > 0.05$).

fMRI data analysis first identified neural correlates of perspective taking by contrasting PT vs. PC tasks in association with HI, which uncovered increased blood-oxygen-level dependent (BOLD) activity in the precuneus (Brodmann area (BA) 7, Talairach coordinates: $8/-65/51$, $Z = 4.60$, voxel number = 354, and $-10/-60/50$, $Z = 4.10$, voxel number = 129, both $p < 0.05$, corrected for multiple comparisons, Figure 1c, d). However, the precuneus activation was not observed with the PT task when assessing AI. The difference in precuneus activation linked to PT task between HI and AI was verified by two-sample t-tests comparing contrast values of signal intensity in the region of interest (ROI), a sphere with a 6 mm diameter centered at the peak voxel of the precuneus activation ($t = 2.285$, $p = 0.03$). However, the PT task with AI resulted in increased activity in the visual cortex (BA18, $-6/-70/2$, $Z = 4.34$, voxel number = 432, $p < 0.001$, corrected), suggesting enhanced visual analysis of the stimuli when dealing with AI. The contrast of DR vs. PC tasks applied to both HI and AI revealed neural correlates of deductive reasoning in bilateral intraparietal sulci (BA 7, HI: $-28/-52/39$, $Z = 5.40$, voxel number = 1020, and $33/-62/40$, $Z = 4.71$, voxel number = 1574; AI: $-34/-50/43$, $Z = 5.28$, voxel number = 899, and $28/-56/44$, $Z = 4.88$, voxel number = 785; all $p < 0.001$, corrected, Figure 1e, f), and the magnitudes of DR-related parietal activities did not differ between HI and AI ($t = 0.007$; $p = 0.994$). These results are consistent with previous observations that the precuneus is involved in taking third-person perspective in space [11] and that the posterior parietal cortex subserves mental calculation and reasoning [22–25].

To assess whether the inference of reasoning processes of human agents is characterized with enhanced processing of perspective taking and inhibition of self-referential processing, we compared signal intensity in the precuneus and vMPFC associated with the MI and DR tasks. The ROI in the precuneus was centered at the peak voxel observed in the contrast of PT vs. PC tasks (BA7, $8/-65/51$) and the ROI in vMPFC was centered at the peak voxel of the vMPFC activation (BA10, $0/49/7$) associated with self-referential processing observed in the previous research [19,20]. Relative to the DR task, the inference of reasoning processes of human agents gave rise to increased BOLD signal intensity in the precuneus but decreased BOLD signal intensity in vMPFC (precuneus: $t = 6.957$, $p = 0.000$; mPFC: $t = -3.654$, $p = 0.002$, Figure 2a, b). Nevertheless, the inference of reasoning processes of computers failed to modulate precuneus ($t = 1.606$, $p > 0.1$) or vMPFC ($t = -0.719$, $p > 0.4$) activity relative to the DR task. Two-sample t-tests confirmed the different patterns of precuneus and vMPFC activations linked to the MI task between HI and AI (precuneus: $t = 2.486$, $p = 0.02$; vMPFC: $t = -2.897$, $p = 0.008$). Relative to the DR task, the MI task also induced increased activity in the right intraparietal sulcus when perceiving both HI ($t = 2.881$, $p = 0.013$) and AI ($t = 7.083$,

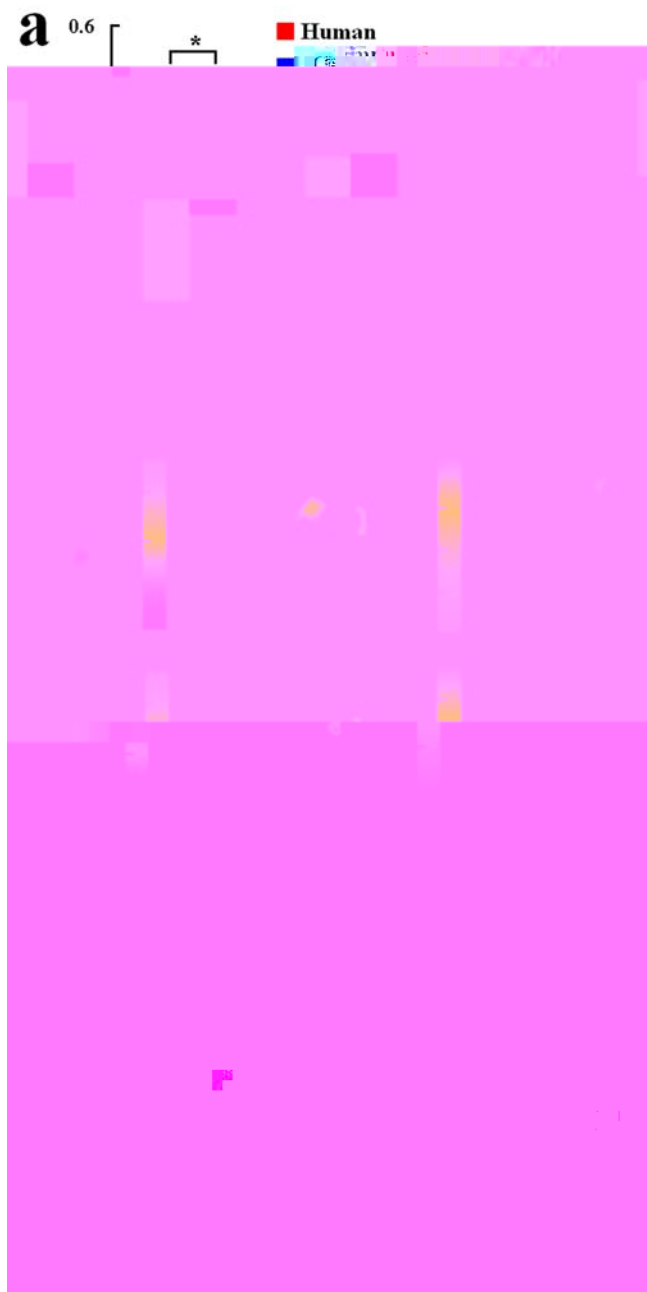


Figure 2. Neural activity specific for the MI task. (a) Parameter estimates of signal intensity for suprathreshold voxels from the contrast of MI vs. DR tasks with human agents and computers; (b) T-Map projected on a single subject anatomical structure for the contrast of MI vs. DR tasks with HI. Activations in the precuneus and intraparietal sulcus and deactivation in vMPFC were observed. Activation was observed only in the intraparietal sulcus in the contrast of MI vs. DR tasks with AI. Color bars show scales of t-values; (c) Correlation between RT changes and the precuneus/vMPFC activity associated with the MI task with HI.

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$p = 0.000$, Figure 2a, b). However, the parietal activity associated with the MI task did not differ between HI and AI (two-sample t-tests: $t = -0.213$; $p = 0.834$), suggesting that inference of reasoning processes of human agents and computers engaged similarly enhanced processes of mental calculation and reasoning.

To examine how the cognitive strategies specific to the inference of reasoning processes of human agents influences individual behavioral performances, we calculated the correlation between signal intensities in the precuneus and the vMPFC and the percentage of RT change in the MI relative to DR tasks. We found that RT variations correlated positively with precuneus signal intensity ($r = 0.528$, $p = 0.05$) but correlated negatively with signal intensity in the vMPFC ($r = -0.576$, $p = 0.03$, Figure 2c), suggesting that recruitment of others' perspective and self-inhibition results in delayed behavioral performance in the MI task.

As taking others' perspective requires resisting interference from processing of stimuli from the self-perspective [12], these two processes should coordinate inversely with each other during the inference of reasoning processes of human agents. Indeed, we found a significant negative correlation between the neural activities in the precuneus and the vMPFC linked to the MI task with HI ($r = -0.794$, $p = 0.001$, Figure 3a), indicating that subjects who recruited more perspective-taking were also more likely to inhibit self-referential processing. Because the correlation implies the existence of functional connectivity between the two areas, we conducted a psychophysiological interaction (PPI) analysis [25] to assess covariations between the neural activity in the two brain areas. The PPI analysis confirmed enhanced functional connectivity between the precuneus and vMPFC during the MI relative to the DR task (Figure 3b). However, such enhanced functional connectivity was evident with HI ($p < 0.05$, corrected) but not with AI. The difference in functional connectivity strength between the precuneus and vMPFC was confirmed between HI and AI using two-sample t-test ($t = 3.322$, $p = 0.006$, Figure 3c).

The hypothesis that the inference of reasoning processes of human agents engages taking another's perspective while inhibiting self-referential processing predicts that, relative to situations when the information obtained from the first- and third-person perspective is consistent, inconsistencies between the information obtained from the first- and third-person perspective may recruit additional neural process to overcome the conflict during the MI task and thus slow down behavioural responses. To verify this, we conducted an independent experiment to measure RTs in the MI task with both HI and AI (see supplementary methods). We were particularly interested in RTs of 'No' responses that could be classified into two categories: (1) *Consistent*: the information obtained from the first- and third-person perspective was consistent and neither subjects nor Agent B could conclude the color of B's hat based on the contextual information; (2) *Inconsistent*: the information obtained from the first- and third-person perspective was inconsistent and subjects could conclude the color of B's hat but Agent B could not. If subjects took Agent B's perspective and inhibited their self-perspective during mental inference, responses should be slower in the inconsistent rather than consistent conditions. RTs in each condition for HI and AI groups were shown in Table S1. To normalize the individual differences of response speeds, the percentage congruency effect $((RT_{\text{inconsistent}} - RT_{\text{consistent}}) / RT_{\text{consistent}})$ was calculated to index the RT variation between *Consistent* and *Inconsistent* conditions. There was a significant congruency effect with HI ($9.36\% \pm 2.81\%$, $t = 3.33$, $p = 0.005$), suggesting that incongruent information from the first- and third-person perspective slowed 'No' responses. However, no reliable congruency effect was observed with AI ($1.58\% \pm 3.51\%$, $t = 0.216$, $p = 0.832$), indicating that incongruent information from the first- and third-person perspective did not affect 'No' response speed when subjects inferred reasoning processes conducted by computers (Figure 4). Two-sample t-test confirmed the difference in congruency effect between HI and AI groups ($t = 2.070$, $p = 0.047$).

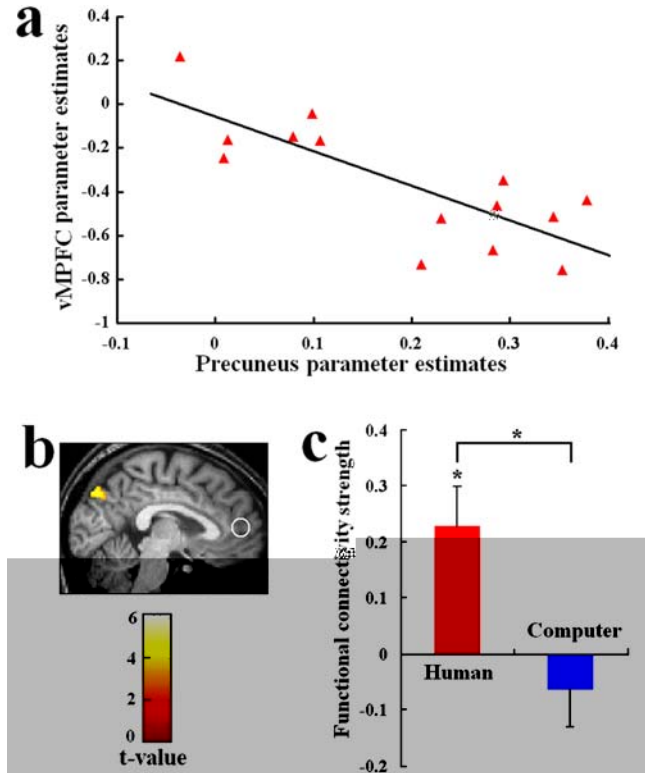


Figure 3. Functional connectivity associated with the MI task.

(a) Correlation between the neural activities in the precuneus and vMPFC during the MI task with HI; (b) The PPI analysis showed increased functional connectivity between the precuneus and vMPFC in the MI compared with DR tasks with HI. An ROI was defined in vMPFC and brain areas showed correlation the vMPFC activity was searched in the whole brain. The color bar shows scales of t-values; (c) Parameter estimates of the functional connectivity strength. The functional connectivity strength between the precuneus and vMPFC was stronger with HI than AI.

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Discussion

From a programmer's perspective, the same algorithm can be used to describe the reasoning processes conducted by both human agents and computers. However, our fMRI results demonstrate that the inference of reasoning processes engages distinct neurocognitive strategies in the human brain depending upon the agents affording the reasoning processes. Relative to deductive reasoning based on the first-person perspective, the inference of reasoning processes conducted by human agents was associated with increased activity in the precuneus but decreased activity in vMPFC. Interestingly, this pattern was not observed during the inference of the reasoning processes conducted by computers. Given the functional role of the precuneus in taking others' perspective [10,11] and of the vMPFC in self-referential processing [9,18–20], our findings indicate that the inference of HI is characterized by enhanced processes of taking others' perspective and inhibiting one's own perspective and self-referential processing compared with the inference of AI. Additionally, the results of the correlation analysis demonstrated that the amount of precuneus and vMPFC activity contributed to the response speeds of the inference of reasoning processes of human agents, suggesting a pivotal role of perspective taking and self inhibition in modulation of behavioral performance when interpreting HI.

the differential neural activity be elucidated by task difficulty, which was well controlled as RTs to the MI and DR tasks were comparable. The changes in the precuneus and vMPFC activity associated with the inference of reasoning processes of human agents showed a reverse pattern of variation and thus could not have been induced simply by changes of baseline activity in the default mode network since both medial frontal and parietal regions tend to decrease their activity during cognitively demanding tasks [27]. The precuneus activity cannot be attributed to enhanced deductive reasoning [28] in the MI compared with

The contrast of PT vs. PC tasks in our study also provided evidence for the involvement of the precuneus in perspective taking, consistent with previous observations [10,11]. However, this was evident when subjects dealt with HI but not with AI. Judging what information a computer could process through a camera may be conducted by inspecting visual details of the stimuli, consistent with the enhanced visual activity in the PT task during assessment of AI. The precuneus and vMPFC activity correlated negatively and demonstrated significant coordination as revealed by enhanced functional connectivity between the two substructures. This supports the idea that taking another's perspective and inhibiting self-perspective related to the MI task are two processes that function in coordination [26]. Taking others' perspective may weaken self-referential processes and induce decreased vMPFC activity. Interestingly, the negative correlation and enhanced functional connectivity between the precuneus and the vMPFC were observed during the inference of the reasoning process associated with human agents but not with computers, providing further evidence for the unique neurocognitive strategies involved during coping with HI.

The dissimilar patterns of precuneus and vMPFC activity associated with HI and AI could not arise from general changes of brain activity related to arousal because other brain areas such as the right posterior parietal cortex, which reflects the recruitment of additional mental calculation and reasoning processes in the MI task, showed comparable magnitudes with HI and AI. Nor could

For instance, relative to the prediction of a computer's action, forecasting a person's finger movements activated a neural circuit consisting of the MPFC, superior temporal sulcus, and Broca's area [38]. In an ultimatum game in which one player decided how to split a sum of money with another player, human subjects rejected unfair offers from human partners at a higher rate than those made by a computer. The behavioral difference was associated with increased activation in bilateral anterior insula, dorsolateral prefrontal cortex, and anterior cingulate cortex [39]. It is not surprising that human brains utilize specific neurocognitive mechanisms to assign finger movements and to produce emotional responses to a person relative to a computer given that prediction of movements of body parts and moral judgment can only be applied to human agents. The current study extends the previous research by showing that, although HI and AI may use the same algorithms to conduct reasoning processes, human brains employ distinct neurocognitive strategies to deal with the two forms of intelligence possibly because, in the human mind, the relationship between humans (i.e., conspecifics) and the relationship between humans and AI (i.e., creator vs. creature) are essentially different.

In summary, we have shown that the inference of reasoning processes of human agents is underpinned by a unique pattern of neural activation including increased precuneus activity, decreased vMPFC activity, and enhanced functional connectivity between the two brain areas. These fMRI results lend support to the hypothesis that comprehension of HI engages two key processes, i.e., taking others' perspective and inhibiting self-referential process. These neurocognitive processes are not involved in the inference of reasoning processes conducted by a computer, highlighting the essential difference in neurocognitive strategies used to cope with HI versus AI, which shed new light on future research of human-robot interactions.

Supporting Information

Figure S1 Illustration of stimuli and procedure of the fMRI study. (a) and (b) Illustration of the stimulus displays showing

human agents or computers. Instructions for each task are shown below each stimulus display. (c) Illustration of the block design of the current study. Each block of 20s consisted of 4 trials preceded by a 4s instruction. Two neighboring blocks were separated by a 6s interval during which only a fixation cross was displayed.

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Figure S2 Behavioral performance in the fMRI study. Reaction times to the MI, DR, PT, and PC tasks with the human agent. (b) Reaction times to the MI, DR, PT, and PC tasks with the computer.

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Figure S3 Dorsal MPFC activation in association with the MI task linked to human and artificial intelligence. (a) The dorsal MPFC activation shown in the contrast of MI vs. PC tasks in association with the human agent (BA8/32, $-6/14/50$, $Z = 3.96$, voxel number = 352). (b) The dorsal MPFC activation shown in the contrast of MI vs. PC tasks in association with the computer (BA8, $-4/36/45$, $Z = 4.60$, voxel number = 335).

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Table S1 Mean RTs and response accuracy (\pm SD) of the behavioral study

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Author Contributions

Conceived and designed the experiments: JG SH. Performed the experiments: JG SH. Analyzed the data: JG SH. Wrote the paper: JG SH.

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