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ORIGINAL ARTICLE

Frontal Pole, Cingulate Gyrus, and Precuneus Cortex Represent the Confidence Level in the Prediction of Others' Risky Decision-Making

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Abstract

Purpose: Reporting confidence after a decision-making task is widely used in the studies of metacognition. A cognitive factor is usually defined as “thinking about thinking.” When people predict others’ behavior in risky situations, they consider various factors affecting others’ choices; at that point, they can determine how confident they are about their predictions about the others' decision.

Materials and Methods: This study investigates human neural activities in different confidence levels when participants predict others’ financial choices in a risky decision-making task. For this aim, functional Magnetic Resonance Imaging (fMRI) combined with behavioral tasks is used to demonstrate the neural representation of human confidence level about others’ possible choices. We scanned 21 healthy and normal participants in two separate sessions each containing three runs.

Results: The results indicate that the Frontal Pole Cortex (FPC), cingulate gyrus, and precuneus cortex activities are correlated with the confidence of people in their predictions ($P < 0.0005$; cluster size, $k > 75$). Using behavioral data, we found that when participants answer correctly, their confidence level as a metacognition factor increases simultaneously and vice versa.

Conclusion: These key findings suggest that the brain's activities can represent subjects’ confidence level in predicting risky behaviors and show how metacognition in the theory of mind for prediction of others’ choices is represented in the brain’s activity.

Keywords: Confidence Level; Prediction; Metacognition; Decision-Making.

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1. Introduction

Theory of mind is an important topic in social psychology and social neuroscience. In the theory of mind, we try to understand others' behavior and predict their thoughts which are necessary for our interactions in daily life. When we predict others' behavior, our metacognition about the accuracy of our prediction and how confident we are helps us to have better control of our social relations. This affects many fields such as game theory, reinforcement learning, and social learning.

Decision-making is a two-step cognitive process [1]. First, we evaluate each option by its value and reward; then, we choose based on our assessment. Previous studies have shown that neural activity in the ventromedial prefrontal cortex (vmPFC) is correlated with value [2, 3]. It is also shown that vmPFC involves encoding value in decision-making [2].

Metacognition has been discussed a lot in recent years. Confidence in decision-making and value-based decision-making tasks have been represented in the activity of vmPFC [4-6]. It is shown that vmPFC reflects both value comparison and confidence in the value comparison in a cognitive process [4]. Moreover, our confidence in the prediction of others' choices is less investigated, though there are studies in the domain of predicting others' decisions [7].

In this study, we try to answer how our confidence in the prediction of others' behavior represents in the brain as an aspect of metacognition. To answer our main question, we designed a monetary risky decision-making task. This experimental design uses functional Magnetic Resonance Imaging (fMRI) combined with a risky decision-making task to investigate the active brain regions correlated with participants' confidence in the prediction of others' risky decision-making.

2. Materials and Methods

2.1. Participants

We scanned 21 healthy and normal participants with an age range between 22 and 29 (average of 24.6 ± 1.9); 10 females (average of 24.3 ± 2) and 11 males (average of 24.8 ± 1.9). Age, gender, and education were set balanced among participants (P = 0.55 for age). Before the beginning of each experiment, participants were asked to sign a written consent to make sure that they had no psychological disorders/illnesses or used any psychiatric drugs. We also announced to participants that all their personal information will be anonymized for later analyses. After the second session, each participant filled out a post questionnaire. The key question in the questionnaire was "Do you strongly doubt that another person was real?". Three male participants responded "yes" to the aforementioned question, thus, later participants were removed and 18 remained for behavioral and fMRI analyses. Participants were also rewarded 10.4 ± 0.2$ after completing the second session.

2.2. Experimental Task

The experimental task consisted of three runs in two sessions. Experiment sessions were run on two different days. In the first runs (self-trials), participants repeatedly choose between two risky and sure monetary reward options for themselves in 39 trials (Figure 1A). The probability of winning for the risky option was set to 40%, 50%, or 60%. Options were assigned randomly to the left and the right side to avoid motor response biases. We gave no feedback to participants about how much money they have won. In each trial, participants chose each option in the decision phase (4 seconds) and observed their choice with a yellow rectangle in the confirmation phase (one second). To avoid hemodynamic response overlapping, a jittered inter-trial interval sampled from uniform distribution was considered (6-8 seconds). After completing the first run, participants predicted a stranger's (observee) choices in the second run (prediction trials) and simultaneously report their confidence within the scale of two in 39 trials (Figure 1B). Before the experiment, participants were told the choices they observed in prediction trials were made by two real people (one person in each session) who had previously participated. But in fact, the observee choices are generated by computer algorithms (one risk-seeker and the other risk-averse) which is very common in social

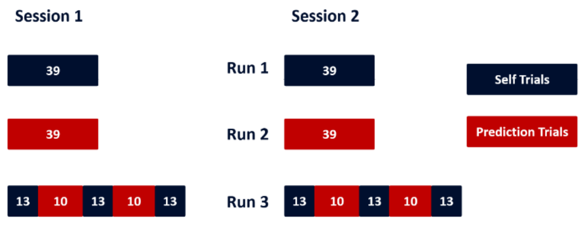

Figure 1. Experiment task structure. Each session was run on two separate days with the same structure

experiments [8, 9]. With counterbalancing, each observee was randomly assigned to the first or second session of the experiment. Participants observed two options in the observation phase (2 seconds). After two seconds, a scale bar appeared and participants predicted the other's choice with a two-scale confidence level for their prediction (4 seconds). In the feedback phase, others' choices were determined by a white rectangle while participants' prediction was in either a green (correct prediction) or red (wrong prediction) rectangle (2 seconds). The inter-trial interval was also considered similar to the first run. Lastly, the third runs contain a combination of the first and the second run in 5 blocks. The first, the third, and the fifth block contained 13 self-trials while the second and the fourth block contained 10 prediction trials. The observee in prediction blocks of the third run was the same as the second run. In fact, prediction blocks were used to remind the participants of the risk preferences of the observee. The experiment was performed in two separate sessions with the same structure (Figure 2).

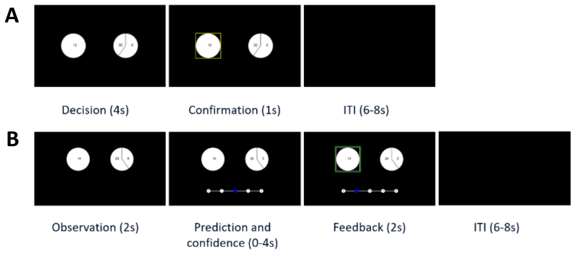

Figure 2. Experiment task paradigm in the first and the second run. (A) Self trial. In the decision phase, participants choose between a sure and risky option with a win probability of 40%, 50%, or 60%. After selection, the chosen option is determined with a yellow rectangle in the confirmation phase. (B) Prediction trial. In the observation phase, risky and sure choices are demonstrated to participants, and after prediction with a two-scale confidence level, true choice is given as feedback

2.3. fMRI Data Acquisition

Data were acquired over 8 months at the National Brain Mapping Laboratory (NBML), University of Tehran, Tehran, Iran, using Simens Prisma 3.0 Tesla with a 20-channel head coil. In each session, T1-weighted, T2*-weighted, and field map images were acquired from participants. Each session took about 40 minutes depending on the participants' response time. A response box with 4 keys (2 keys for each hand) was also used to get responses from patients.

For structural imaging, a standard Magnetization Prepared Rapid Gradient Echo (MPRAGE) pulse sequence with the isotropic voxel of $1mm^3$ was used at the beginning of each session. Repetition Time (TR), Time to Echo (TE), and Flip Angle were set to 1800 ms, 3.5 ms, and 7°, respectively. Each volume contained 160 sagittal slices with a slice thickness of 1mm and a matrix size of 255 × 255. Blood Oxygenation Level Dependent (BOLD) signal was acquired using Echo-planar Imaging (EPI) pulse sequence. As we analyzed data with an event-related technique, shorter TR was preferable [10], thus, TR was set to 2000 ms. TE and FA were also set to 30 ms and 90°. Each volume consisted of 36 oblique slices with a slice thickness of 3mm, Distance Factor (DF) of 20%, and matrix size of 72 × 64. After completing the second run and letting participants rest, fieldmap images were acquired which took around 100 seconds.

2.4. fMRI Data Analysis

In this study, we specifically focus on the prediction trials of each session to find active areas that represent the confidence in the prediction of the observee. For fMRI data preprocessing, FMRIB Software Library (FSL) [11] is used for slice timing correction, motion correction, spatial smoothing (8-mm full width at the half maximum), high-pass temporal filtering (filter width of the 100s), and field map correction. Moreover, Advanced Normalization Tools (ANTs) [12] were used to achieve accurate registration. After preprocessing, a Generalized Linear Model (GLM) [13] was applied to the fMRI data to calculate beta values and ultimately find the active brain regions based on different contrasts. For the design matrix, five main regressors were considered. To include the effect of the difference between the expected value of sure and risky options in the design matrix, chosen regressor was used (V_{sure} - $P_{gamble}V_{gamble}$) from trial onset to participant response. The expected value was calculated by multiplying the reward (V) with the reward probability (P). In the feedback phase, high and low confidence were modeled using 2 boxcar regressors. Correct and wrong prediction regressors similar to confidence regressors were also included in the design matrix. To regress out the effect of motion, 6 motion regressors obtained from the preprocessing step were also considered as nuisance regressors.

3. Results

Using fMRI, we find that the activities in the Frontal Pole Cortex (FPC), cingulate gyrus, and precuneus cortex (Table 1) (P < 0.0005; cluster size, k > 75) reflect more variation in participants' confidence level (high confidence–less confidence contrast) while predicting others' decisions (Figure 3A). Frontal pole plays important roles in behavior and cognitive abilities such as choosing an option [14]. Another study using a recognition memory task, found activity in the frontal pole when participants had a higher confidence level in recalling the name of a person in each trial [15]. It's shown that high confidence compared to low confidence is associated with activation in the Posterior Cingulate Cortex (PCC) using a Deese–Roediger McDermott (DRM) paradigm [16]. In a monetary Wheel Of Fortune (WOF) task, activity was found in the cingulate gyrus when participants chose the reward with a higher magnitude (rather than a lower magnitude) or selected the risky option (rather than a safe option) [17]. In two-word recognition memory studies [18, 19], activity in the precuneus cortex was correlated with the confidence level. Our results are consistent with previous studies and indicate the human brain's capability to represent the confidence level in predicting others' risky behaviors.

Table 1. Active regions in high confidence – less confidence contrast

Region	Hemi	MNI coordinate			Z-state	Voxels
		x	y	z		
Cingulate Gyrus	R/L	-6	-18	44	4.42	417
Frontal pole	L	-6	66	6	4.12	195
Precuneus Cortex	L	-8	-48	40	3.92	292

In the behavioral data, a higher confidence level correlated with more accuracy in predictions (Figure 3B). Participants' predictions with higher confidence were 15% more accurate in comparison to the low confidence level. When participants answer correctly, their confidence level as a metacognition factor increases simultaneously and vice versa. Similarly, it's shown that participants with a higher confidence level in each trial achieved greater accuracy in visual and auditory memory in comparison to lower confidence [20]. This correlational relation can represent the metacognitive processes during the task.

4. Conclusion

Confidence levels in decision-making conditions remain a trending topic in metacognition studies. Our finding indicates a positive correlation between confidence level as a metacognitive factor and choice accuracy in predicting others' choices. The importance of this confidence representation is its social context and it can be considered metacognition in the theory of mind; because during the task, subjects try to read the mind of other people and predict their decisions. This type of metacognition plays a crucial role in social interactions and can show distinct activity relative to metacognition studies on perceptual or mnemonic decision-making. We also found that a high confidence level in the prediction of other's risky behavior could be localized by neural mechanisms in the brain. Cingulate gyrus, FPC, and precuneus cortex were highly correlated with a high confidence level in comparison to a low confidence level (high – low contrast). Future studies are needed to compare these different types of decision-making with social decision-making.

The theory of mind and metacognition can be affected by mental disorders, so our findings can open

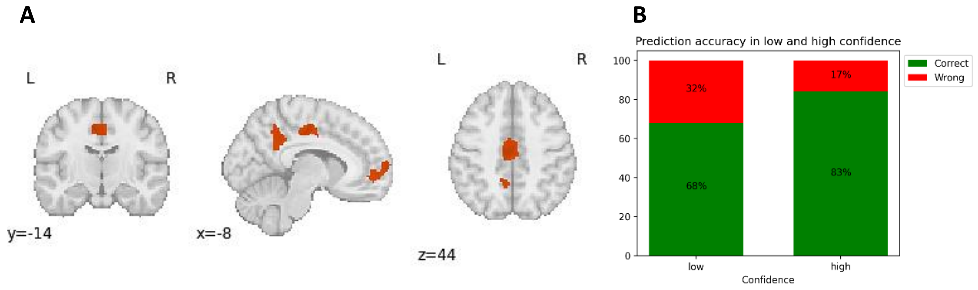

Figure 3. FMRI and behavioral results for confidence level. (A) Neural representation of higher confidence level when predicting others' behavior. (B) Prediction accuracy in low and high confidence trials

a new path to design novel tasks for predicting and distinguishing different mental illnesses. Considering computational psychiatry as an intensively discussed topic, we can create a new diagnostic tool in the future with the help of behavioral data acquired from people. Furthermore, the neural mechanism of confidence level can be used as a biomarker in the psychiatric disorders diagnosis in computation psychiatry.

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