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Research Paper

Theory of mind difficulties in people with social anhedonia: Evidence from behavioural and task-based functional magnetic resonance imaging findings

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ABSTRACT

Background: Social Anhedonia (SA) is recognised as a negative symptom of the schizophrenia spectrum. Despite the emerging evidence of general impairment in Theory of Mind (ToM), the behavioural manifestation and underlying neural mechanisms of ToM deficits in SA remain unclear. The current study therefore adopted a multidimensional assessment approach to examine the effect of SA on ToM ability behaviourally and using fMRI.
Methods: A total of 47 participants with high SA (*Mage* = 21.43 years, *SD* = 4.23) and 46 with low SA (*Mage* = 22.70, *SD* = 2.91) were recruited to complete an adapted version of the Virtual Assessment of Mentalising Ability to evaluate ToM. Group differences were analysed using 2 (Type: Cognitive vs Affective ToM) × 2 (Order: First- vs Second-Order ToM) × 2 (Group: high vs low SA) repeated measures ANOVA. fMRI data were examined with general linear models and group comparisons, including ROI analyses to assess correlations between brain activation and behavioural measures.
Results: The participants with low SA showed better performance for first-order ToM than for second-order ToM. However, those with high SA did not show such a differential effect. Based on the fMRI results, the low SA group showed more activation than the high SA group in the medial frontal cortex and posterior cingulate cortex in second-order ToM than in first-order ToM.
Conclusion: The results demonstrate the impairment of ToM performance among those with high SA and highlight that it is crucial to examine the pattern of results rather than solely focusing on general ToM.

1. Introduction

Schizotypy refers to a multi-dimensional personality organisation that puts one at-risk of developing schizophrenia-spectrum disorders (Meehl, 1962). A key characteristic of the negative dimension of schizotypy is social anhedonia (SA), defined as a reduced ability to perceive pleasure in situations that others normally find enjoyable (Chapman et al., 1976; Kwapil, 1998; Pieslinger et al., 2022). Studying social anhedonia in non-clinical samples could provide further insight into the underlying mechanisms of social impairments, without the confounding issues of a clinical sample, such as medication (Bora, 2020; Hu et al., 2025).

Similar to patients with schizophrenia, people with high SA display deficits in social cognition (Bedwell et al., 2014; Braak et al., 2022; Dodell-Feder et al., 2014) and social functioning (Cohen et al., 2006; Li et al., 2016). However, the mechanisms of the association between the negative symptoms of schizophrenia and theory-of-mind (ToM) are still poorly understood (Thibaudeau et al., 2022).

ToM is defined as the ability to attribute mental states to other individuals (Quesque and Rossetti, 2020). There is emerging evidence that overall, people with SA exhibit impairments in ToM with mild to moderate effect sizes (Bora, 2020; Thibaudeau et al., 2022). Previous studies

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have described a bi-directional relationship between SA and ToM deficits (Thibaudeau et al., 2022), although Pelletier-Baldelli and Holt (2020) proposed a unitary model that situates negative symptoms of schizophrenia as a behavioural manifestation of social-cognitive abnormalities. Notably, ToM is considered to comprise cognitive and affective components (Tager-Flusberg and Sullivan, 2000) as well as two levels of complexity, first-order ToM (understanding another person's direct mental states, e.g., "What does John think?") and second-order ToM (understanding someone's mental state about another person's mental state, e.g., "What does John think that about what Mary thinks") (Perner and Wimmer, 1985). However, studies on SA have not examined ToM using such a multidimensional approach.

Previous studies that have specifically examined the impact of SA on ToM predominantly used the hinting task (Bora, 2020; Pflum et al., 2013). Two studies found that the high SA group had lower accuracy (Monestes et al., 2008; Villatte et al., 2008), whereas two other studies reported that the high SA group did not differ from the low SA group (Gooding and Pflum, 2011; Pflum et al., 2013). As the authors of the latter studies suggested, their null result was probably because the hinting task is not sensitive enough to detect group differences (Gooding et al., 2010). Therefore, it is important to further study ToM in relation to SA through the use of nuanced and ecological methods.

Moreover, few studies have examined the neural correlates of ToM in people with high SA. Krohne et al. found that activations in the left TPJ and inferior lateral prefrontal cortex were important for distinguishing between high and low SA groups while they were responding to a comic strip task (Krohne et al., 2019). Wang et al. (2015) demonstrated that SA among university students was positively associated with brain activation in several regions while they undertook the comic strip ToM task. These included the bilateral middle temporal gyrus, medial frontal gyrus, and right TPJ (Wang et al., 2015). Taken together, previous studies have only examined ToM as a unidimensional general construct and have therefore been unable to pinpoint the exact nature of the various types of ToM deficit in SA. Considering the important role of SA in the diagnosis and prognosis of schizophrenia spectrum disorders, a better understanding of the relationship between SA and ToM in non-clinical populations could inform earlier detection and treatment of social dysfunctions. The present study adopted the four-subconstruct model of ToM, by using a task with good ecological validity, to compare ToM performance in non-clinical sample with high and low SA at both behavioural and neural levels. This approach would allow us to investigate social cognitive mechanisms without the confounding effects of clinical status or medication. We hypothesised that people with high SA would perform worse in on ToM tasks than those with low SA and that this difference was likely to be reflected in the activation of various prefrontal regions of the brain.

2. Methods

2.1. Participants

We screened potential participants from a large pool of college students in Beijing, China ($N = 1016$) using the Chinese version of the Chapman Social Anhedonia Scale (CSAS) (Chan et al., 2012). Participants in the current study were categorised into high (CSAS score ≥ 17) and low (CSAS score ≤ 10) SA groups (Chan et al., 2012; Chapman et al., 1976). Regarding the CSAS cutoff scores, they determined based on the distribution reported by Zhang et al. (2020). For the cutoff for low SA group, we followed previous studies using CSAS as the basis of group classification, which adopted the similar cutoff below the sample mean to define individuals with low levels of social anhedonia (Wang et al., 2025; Xie et al., 2018; Zhang et al., 2020). In addition, from a conceptual standpoint, by using the large-sample mean score as the cutoff, our low SA group represents individuals whose social anhedonia levels fall below the average, rather than those with extremely low scores. We consider this approach theoretically more meaningful for addressing our research questions, as it delineates a group representative of a broader segment of the population (approximately the lower 50 %), rather than a narrowly defined, extreme subgroup (e.g., the bottom ~16 % defined by mean − 1 SD).

Seven participants were excluded during data cleaning: four due to missing fMRI data and two due to excessive head motion, with mean framewise displacement (FD) Power > 0.2 (Power et al., 2012, 2013). One participant was identified as an outlier in the behavioural data, defined as having a score more than 2.5 SD below the sample mean of the ToM task (Tabachnick and Fidell, 2018).

This study was approved by the Human Subjects Ethics Committee of the Institute of Psychology, Chinese Academy of Sciences (reference number: H20045). Written informed consent was obtained from each participant before data collection, and they were compensated RMB110 (~USD14) after completing the study.

2.2. Measures

2.2.1. The adapted version of Virtual Assessment of Mentalising Ability-fMRI (VAMA-fMRI)

The adapted version of the Virtual Assessment of Mentalising Ability (VAMA; Cao et al., 2025) was used to assess the four aspects of ToM. The original English VAMA is an ecologically valid and reliable video-based ToM assessment tool that has been used in studies of patients with schizophrenia (Canty et al., 2017b). The adapted version contained story scripts that capture China's collectivistic culture. It showed similar psychometric properties to the English version and had been used in schizophrenia patients and extreme groups of SA (Cao et al., 2025).

The fMRI version used inside the MRI scanner contained six emotional scenarios (#1, #2, #3, #8, #9, #10) and two control scenarios (#Control 3, #Control 4), each presented as a video clip. Each emotional scenario was followed by four ToM questions (24 ToM trials in total), with four multiple-choice answers covering different levels of mentalising abilities: correct guess (correct), incorrect perception (no ToM), difficulties applying mental state information (reduced ToM) and excessive mental state attribution (hypermentalising). The version inside the MRI scanner was similar to that of Cao et al. (2025) in reliability (see Supplementary Tables 1 and 2). Accurate ToM responses were scored as 1, and others as 0. Control scenarios were followed by plot-based recall questions (8 trials in total).

The participants completed the VAMA task in two functional runs (Run 1: 510 s; Run 2: 576 s). At the beginning of each run, a 23-s fixation was set for noise reduction (excluded from analysis). There were four trials in each run (three ToM trials and one control trial). Each trial started with a 2-s fixation followed by a video clip that lasted 20–110 s. Then, four multiple-choice questions appeared on the screen successively: ToM questions (i.e., first-order, second-order, and cognitive and affective ToM) in the ToM trials and control questions (e.g., recall questions such as 'What did Character A say to Character B?') in the control trials. The participants answered each question by pressing the buttons on the response box with their right (index finger = A; middle finger = B) or left hand (index finger = C; middle finger = D). Each question was presented for a jittered duration of 12–26 s, and if the participant answered the question within this time, a fixation point replaced the question on the screen. The VAMA was presented using E-prime 3.0, and a pair of high-fidelity MRI-compatible earphones (OptoACTIVE) was used to reduce the scanner noise and ensure optimal audibility of the video content (see Fig. 1).

2.2.2. The Yoni task

The Chinese version of the Yoni task (Ho et al., 2015; Shamay-Tsoory et al., 2007b) was also used to assess the participants' ToM. This task examines participants' ability to judge the mental states of others based on eye gaze and verbal cues. It consists of 64 trials (24 affective trials, 24 cognitive trials and 16 physical condition trials), each with a cartoon face, 'Yoni', in the centre of the screen surrounded by four coloured

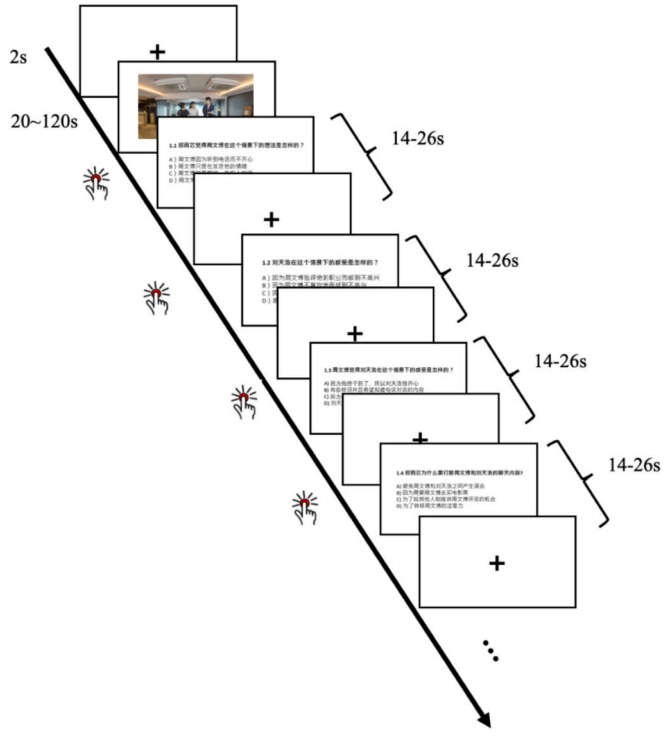

Fig. 1. Experimental procedure.
Note. The experimental procedure of the current study. Participants completed the VAMA task during fMRI scanning.

items (e.g., fruits, chairs) or cartoon faces. The participants were asked to determine which of the items Yoni preferred.

2.2.3. The Questionnaire of Cognitive and Affective Empathy (QCAE)

The Questionnaire of Cognitive and Affective Empathy (QCAE) (Liang et al., 2019) was used as the measure for self-reported empathy. The QCAE includes 33 items on a 4-point likert scale (Reniers et al., 2011). The Chinese version has been validated in a sample of 1224 Chinese college students (Cronbach's alpha = 0.86) (Liang et al., 2019).

2.2.4. The Chinese version of the Chapman Social Anhedonia Scale (CSAS)

The Chinese CSAS assesses participants' ability to experience pleasure from social and interpersonal sources, such as engaging with others, conversing, or sharing emotions. The CSAS consists of 40 true-false items, with a higher score reflecting a better ability to experience pleasure from social interactions. The Chinese CSAS was found to show good internal consistency (Cronbach's alpha = 0.86) (Chan et al., 2012).

2.3. fMRI scanning parameters and preprocessing

MRI data were collected using the 3T GE Discovery MR750 scanner with an 8-channel head-coil in Beijing, China. Functional MRI scans were conducted using a T2-weighted EPI gradient echo sequence with the following parameters: TR = 2000 ms, TE = 30 ms, FOV = 220 mm, flip angle = 90°, slice number = 37, slice thickness = 3.5 mm, matrix size = 64 × 64 and voxel size = 3.4375 mm × 3.4375 mm × 3.5 mm. Structural MRI scans were conducted using a T1-weighted spoiled gradient echo sequence with the following parameters: TR = 6.652 ms, TE = 2.928 ms, FOV = 256 mm, flip angle = 12°, slice number = 192, slice thickness = 1 mm, matrix size = 256 × 256 and voxel size = 1 mm × 1 mm × 1 mm.

Standard pre-processing procedures were performed using SPM12 (Wellcome Centre for Human Neuroimaging, University College London, UK, http://www.fil.ion.ucl.ac.uk/spm). The structural images were first segmented and skull-stripped and then normalised into Montreal Neurological Institute (MNI) space. Preprocessing of the functional images included slice-timing correction and realignment. The functional images were then co-registered to the T1 image of each participant, which was then normalised to MNI space and resampled to a voxel size of 3 mm × 3 mm × 3 mm and smoothed using a Gaussian kernel with 8 mm full-width at half-maximum (Hu et al., 2025).

2.4. Statistical analysis

2.4.1. Behavioural data analysis

Independent sample *t*-tests were performed to verify Group (High SA vs Low SA) differences on self-report measurements of CSAS and QCAE. Accuracy on the adapted version of VAMA task and the Yoni task was then examined using a repeated measures ANOVA, with a 2 (Type: Cognitive vs Affective ToM) × 2 (Order: First-Order vs Second-Order ToM) × 2 (Group: High SA vs Low SA) mixed design. Simple effect analyses were carried out when significant interaction effects were observed.

2.4.2. fMRI data analysis

For the first-level analyses, a general linear model was built as a block design to model the first-order cognitive, second-order cognitive, first-order affective, second-order affective and control conditions. The onset time was set at the appearance of the corresponding question, and the block duration was set to be the same as the reaction time of the participant in answering the question. Six head motion parameters were added as nuisance regressors. Nine contrasts were set: [cognitive ToM > control], [affective ToM > control], [cognitive ToM > affective ToM], [affective ToM > cognitive ToM], [first-order ToM > control], [second-order ToM > control], [first-order ToM > second-order ToM], [second-order ToM > first-order ToM] and [correctly answered ToM > control].

For the second-level analyses, we first performed the whole brain analysis, where one-sample *t*-tests were performed with the whole sample. The threshold was set at the peak-level family-wise error (FWE) with corrected $p < 0.05$ and cluster size >10 voxels. We then performed two-sample t-tests to compare brain activation between participants with high and low SA, with the threshold at the peak-level uncorrected $p < 0.001$ and cluster-level FWE corrected $p < 0.05$.

Region of interest (ROI) analyses were then performed by extracting the Blood Oxygenation Level Dependent (BOLD) signal from the correctly answered ToM > control contrast, and Pearson's correlation analysis was performed separately for the high and low SA groups to explore the association between brain activation in the ROIs and the behavioural measures (on the ToM tasks and self-report questionnaires).

3. Results

3.1. Behavioural results

The final sample comprised 47 participants with high SA (*M* age = 21.43, *SD* = 4.23, 18M and 29F) and 46 with low SA (*M* age = 22.70, *SD* = 2.91, 22M and 24F). The two groups did not differ in age, education level or gender ratio (see Supplementary Tables 3 & 4 and Fig. 2 for the mean differences in CSAS and QCAE). As expected, the high SA group reported significantly higher CSAS score ($M = 22.43$, $SD = 3.74$) than the low SA group ($M = 5.76$, $SD = 2.99$), $t(91) = 23.7$, $p < 0.001$, Cohen's $d = 4.92$, 95 % CI [15.27, 18.06]. On the other hand, participants with low SA reported significantly higher QCAE subscores than participants with high SA, including Affective Empathy ($t(91) = -2.13$, $p = 0.036$, Cohen's $d = -0.44$, 95 % CI [−4.21, −0.15]), Proximal Responsivity ($t(91) = -2.78$, $p = 0.007$, Cohen's $d = -0.57$, 95 % CI [−1.83, −0.31]) and Peripheral Responsivity ($t(91) = -3.04$, $p = 0.001$, Cohen's $d = -0.71$, 95 % CI [−2.26, −0.60]).

For the VAMA, the 2 (Type: Cognitive vs Affective ToM) × 2 (Order: First-Order vs Second-Order ToM) × 2 (Group: High SA vs Low SA) repeated measures ANOVA revealed that there was a significant main

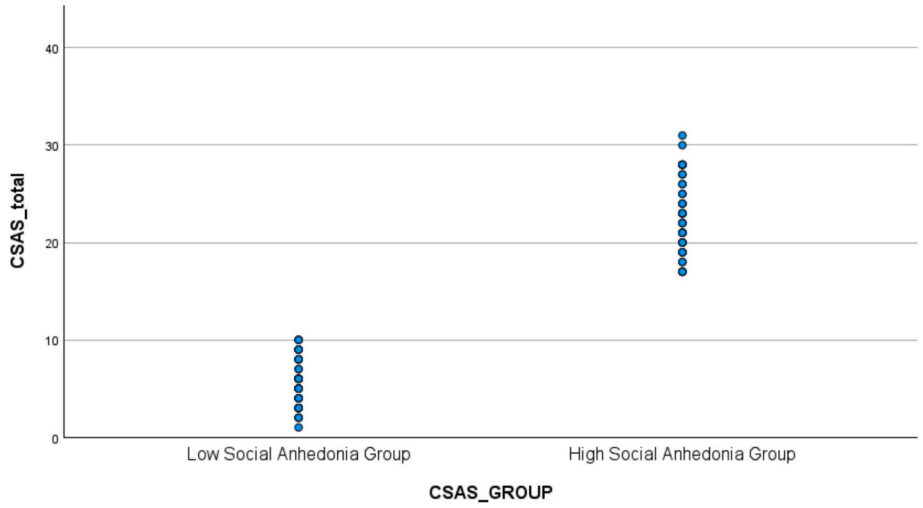

Fig. 2. Scatterplot of CSAS scores by group.

effect of Order, with higher accuracy on first-order ToM ($M = 2.99$, $SD = 0.99$) than on second-order ToM ($M = 2.63$, $SD = 0.99$), F (1, 91) = 10.55, $p = 0.002$, $\eta_p^2 = 0.104$. However, there was no significant main effect of Types ($p = 0.103$) and main effect of Group ($p = 0.777$). Regarding the interaction effect, there was a significant interaction between Order and Group, F (1, 91) = 3.96, $p = 0.049$, $\eta_p^2 = 0.042$. Post-hoc comparisons revealed that in the low SA group, the scores for first-order ToM were higher than those for second-order ToM, $p < 0.001$. However, for the high SA group, scores for the first-order and second-order ToM did not show a statistical difference, $p = 0.374$ (see Fig. 3A). There was also significant interaction effect between Order and Types, F (1, 91) = 27.56, $p < 0.001$, $\eta_p^2 = 0.23$. Post-hoc comparisons revealed that in the cognitive ToM, participants performed better in the first-order (M = 3.40, SD = 1.29) than the second-order ToM (M = 2.40, SD = 1.22; F (1, 91) = 33.78, $p < 0.001$, $\eta_p^2 = 0.27$); while in the affective ToM, participants performed similarly between first- and second-order ToM ($p = 0.070$); regarding the first-order ToM, they performed better in the cognitive ToM (M = 3.40, SD = 1.29) than affective ToM (M = 2.57, SD = 1.19; F (1, 91) = 28.90, $p < 0.001$, $\eta_p^2 = 0.24$); while in the second-order ToM, participants performed better in the affective ToM (M = 2.86, SD = 1.38) than cognitive ToM (M = 2.40, SD = 1.22; F (1, 91) = 7.02, $p < 0.01$, $\eta_p^2 = 0.07$). Non-significant interaction effects were found between Type and Group, F (1, 91) = 3.05, $p = 0.084$ (see Fig. 3B), and Order, Types and Group (F (1, 91) = 0.00, $p = 0.975$).

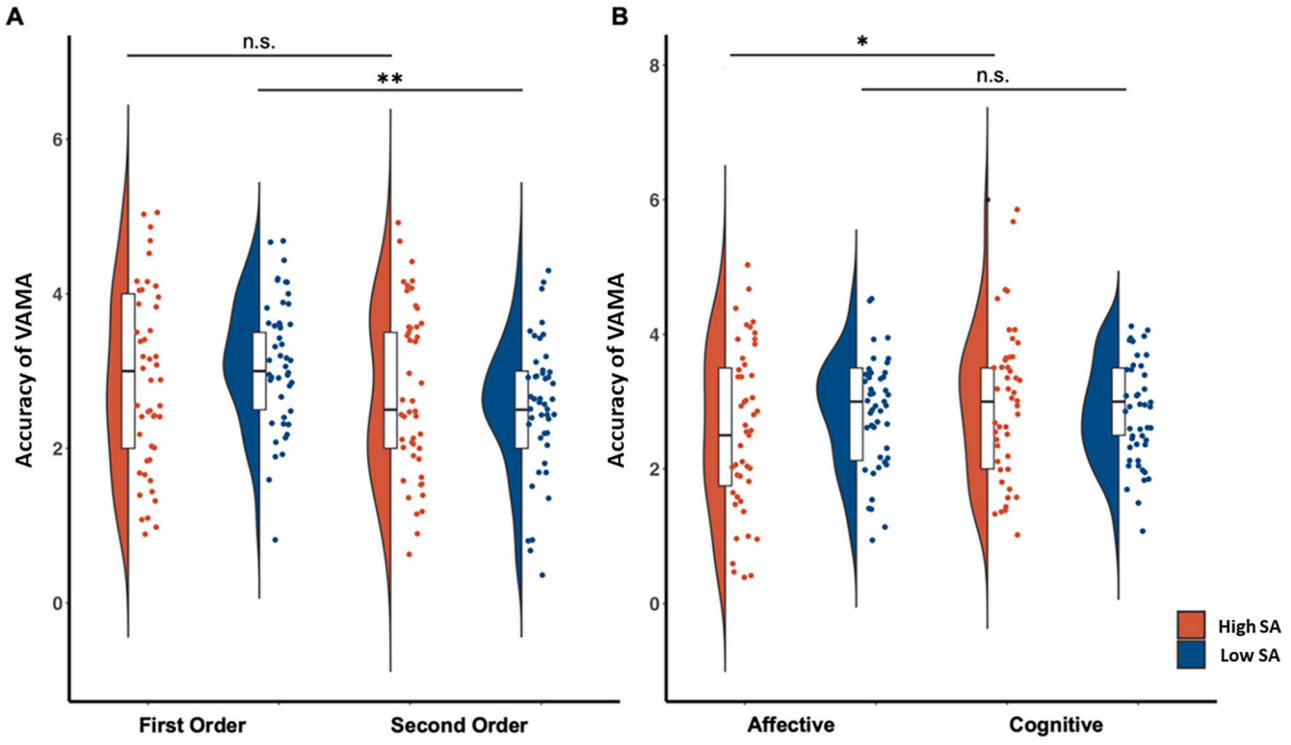

Fig. 3. VAMA performance between SA groups in (A) Order (First versus Second) and (B) Types (Cognitive versus Affective).
Note. The violin plots showed the behavioural result on the VAMA-fMRI task. In the low SA group, the scores for first-order ToM were higher than those for second-order ToM, $p < 0.001$. For the high SA group, scores for the first-order and second-order ToM did not show a statistical difference, $p = 0.374$ (see Fig. 3A). Non-significant interaction effect between Type and Group was also observed (see Fig. 3B).

For the Yoni, there was a significant main effect of Order, $F(1, 91) = 24.54$, $p < 0.001$. Accuracy in first-order ToM was higher than that in second-order ToM. There was no Group ($p = 0.980$) or Type main effect ($p = 0.102$). There was also no interaction effect between Order and Group ($p = 0.768$), Types and Group ($p = 0.488$), and Order and Types ($p = 0.313$). A significant three-way interaction was observed between Order, Type, and Group, $F(1, 91) = 5.16$, $p = 0.025$, $\eta_p^2 = 0.054$. Post-hoc analyses indicated that, within the low SA group, accuracy was significantly higher for first-order compared to second-order ToM in both cognitive (1st order ToM $M = 0.91$, $SD = 0.14$ vs. 2nd ToM $M = 0.83$, $SD = 0.14$; $p < 0.001$) and affective (1st order ToM $M = 0.92$, SD = 0.14 vs. 2nd ToM $M = 0.85$, $SD = 0.14$; $p = 0.004$) conditions. In the high SA group, this difference was significant only for affective ToM (1st order ToM $M = 0.92$, $SD = 0.14$ vs. 2nd ToM $M = 0.84$, $SD = 0.14$; $p < 0.001$), while the difference for cognitive ToM was not significant ($p = 0.062$). Additionally, among high SA participants, accuracy for first-

Table 1
Results of the one-sample *t*-tests of all participants across ToM conditions.

Brain region	L/R	BA	Cluster size k	MNI coordinates			*t*	$p_{FWE\text{-}corr}$
				x	y	z		
Cognitive ToM > control								
Medial frontal cortex	R	10	503	12	36	51	8.64	<0.001
Inferior temporal gyrus	R	21	19	48	9	−39	8.12	<0.001
Superior occipital gyrus	R	19	20	18	−84	30	6.88	<0.001
Angular gyrus	L	39	20	−54	−60	30	6.59	<0.001
Affective ToM > control								
Medial frontal cortex	R	6	16	12	39	51	6.84	<0.001
Temporal pole	R	21	13	48	12	−39	6.67	<0.001
Medial frontal cortex	R	10	77	6	54	15	6.52	<0.001
1st ToM > control								
Superior occipital gyrus	R	19	25	18	−84	30	7.01	<0.001
2nd ToM > control								
Medial frontal cortex	R	9	501	12	39	51	8.95	<0.001
Temporal pole	R	21	33	48	12	−39	8.28	<0.001
Angular gyrus	L	39	25	−54	−60	30	6.59	<0.001
Superior temporal gyrus	R	21	111	51	−9	−6	5.96	0.001
Cognitive ToM > affective ToM								
Insula	L	13	14,147	−33	24	−3	11.25	<0.001
Inferior parietal lobule	R	40	648	45	−54	42	8.69	<0.001
Middle temporal gyrus	L	20	52	−60	−45	−9	8.02	<0.001
Affective ToM > cognitive ToM								
Superior temporal gyrus	R	22	734	54	−12	−3	14.00	<0.001
Superior temporal gyrus	L	22	667	−48	−18	3	11.90	<0.001
Middle temporal gyrus	R	37	105	45	−63	0	8.44	<0.001
Middle occipital gyrus	L	17	78	−12	−96	0	8.28	<0.001
Inferior temporal gyrus	L	37	78	−48	−72	0	7.77	<0.001
Precentral gyrus	R	6	11	54	0	42	6.46	<0.001
1st order ToM > 2nd order ToM								
Calcarine cortex	L	18	1183	−6	−84	12	9.99	<0.001
Insula	R	13	33	33	18	0	5.87	0.001
Middle frontal gyrus	R	10	39	36	42	9	5.50	0.004
2nd order ToM > 1st order ToM								
Superior temporal gyrus	R	21	2537	60	−18	−3	19.07	<0.001
Middle temporal gyrus	L	22	2257	−60	−21	−3	18.14	<0.001
Precuneus	L	7	429	−6	−51	39	10.90	<0.001
Middle frontal gyrus	R	6	294	48	9	45	9.21	<0.001
Medial frontal gyrus	R	9	706	6	51	24	8.40	<0.001
Precentral gyrus	L	6	146	−48	0	45	7.23	<0.001
Brainstem	R		16	15	−27	−6	6.37	<0.001
Inferior frontal gyrus	L	45	14	−57	24	6	5.88	0.001
Correctly-answered ToM > control								
Superior occipital gyrus	R	19	36	18	−84	30	7.98	<0.001
Medial frontal cortex	R	6	255	12	39	51	7.85	<0.001
Lingual gyrus	L	18	38	−15	−75	−9	7.35	<0.001
Inferior temporal gyrus	R	21	16	48	9	−39	7.11	<0.001
Fusiform gyrus	R	19	37	27	−60	−12	6.24	<0.001

Notes: The table exhibits the results of the one-sample *t*-tests of brain activations during all ToM conditions compared with Control condition, as well as differences between ToM conditions in the whole sample ($n = 93$). Significant threshold was set at peak-level family-wise error (FWE) corrected $p < 0.05$, and cluster size >10 voxels. ToM = theory of mind; L = left; R = right; BA = Brodmann areas; MNI = Montreal Neurological Institute.

order affective ToM was higher than for first-order cognitive ToM ($M = 0.92$, $SD = 0.14$ vs. $M = 0.89$, $SD = 0.14$; $p = 0.021$). No significant group differences were found within any specific ToM condition (all $p > 0.05$), and no significant differences between cognitive and affective ToM were observed in other comparisons (all $p > 0.05$).

3.2. Whole brain analysis: brain activation for different conditions of VAMA

For the whole sample, activation was found in the expected mentalising regions (see Table 1 and Fig. 4). Comparing the cognitive and affective components of ToM, we found a broad activation that peaked at the left insula in the cognitive ToM condition (see Fig. 5). We also found higher activation at the right inferior parietal lobule in the cognitive ToM. For the affective component of ToM, we found higher activation at the temporal gyrus, left middle occipital gyrus and right precentral gyrus. Notably, the right anteromedial PFC was activated when participants were answering both cognitive and affective ToM questions compared to control questions. In first-order vs. second-order comparisons, we found higher activation in the left calcarine cortex, right insula and middle frontal gyrus during the first-order ToM questions, whereas during the second-order ToM, the bilateral temporal gyrus, left precuneus, precentral gyrus, inferior frontal gyrus, right middle frontal gyrus and anteromedial PFC were more activated (See Fig. 5).

3.3. Whole brain analysis: group comparisons of brain activities

Regarding the second-order > first-order ToM contrast, we found that the low SA group showed stronger activation in the anteromedial PFC (MNI coordinates: [0, 60, 21], $t = 4.16$, $k = 103$, $p = 0.024$) and left posterior cingulate cortex (PCC; MNI coordinates: [−3, −51, 27], $t = 3.94$, $k = 87$, $p = 0.041$) than the high SA group (see Fig. 6). No other significant Group or Group × Order conditions differences were observed.

3.4. ROI analysis: associations between brain activation and ToM behavioural performance

The correlations between brain activation of the [correctly answered ToM > control] contrast and ToM behavioural measurements are presented in Supplementary Table 5. Non-significant result was found (after Bonferroni correction).

3.5. ROI analysis: associations between brain activation and other self-report measurements

There were no significant correlations between the ROI beta estimates and questionnaire data after Bonferroni correction (see Supplementary Table 6).

4. Discussion

SA has been recognised as an important risk factor for schizophrenia spectrum disorders. However, to the best of our knowledge, no study has examined the specific effect of SA on the subconstructs of ToM based on complexity and emotional subcomponents. Furthermore, there has been limited research on the effects of the underlying neural mechanisms of high and low SA differences on these dimensions. This is the first study to examine the effects of SA on the different dimensions of ToM using a ToM task with high ecological validity.

The key results were that the low SA group showed more activation than the high SA group in the medial frontal cortex and posterior cingulate cortex in second-order (compared with first-order) ToM. Behaviourally, there was a statistical difference between the high SA and low SA groups on the order of the ToM. More specifically, the low SA group showed better performance on first-order ToM than on second-order ToM. In contrast, the high SA group had similar scores for the two orders of ToM. Group differences were only noted on the VAMA and not on the Yoni task.

Across the whole sample, the right medial frontal cortex was activated when the participants answered the cognitive, affective and second-order ToM questions. Under the cognitive and second-order ToM conditions, the left angular gyrus and TPJ were significantly activated, whereas during the affective and second-order ToM questions, the right temporal pole was activated compared with the control condition. These brain areas have been commonly reported in previous ToM studies (Molenberghs et al., 2016; Tholen et al., 2020), including a study that used a video-based tool (Wolf et al., 2010). The results, therefore, supported the validity of the adapted version of VAMA.

There was greater activation in the left insula and right inferior parietal lobule for cognitive ToM than for affective ToM. Similarly, Campanella et al. (2021) reported that the right parietal regions contributed significantly to understanding others' intentions. However, the role of

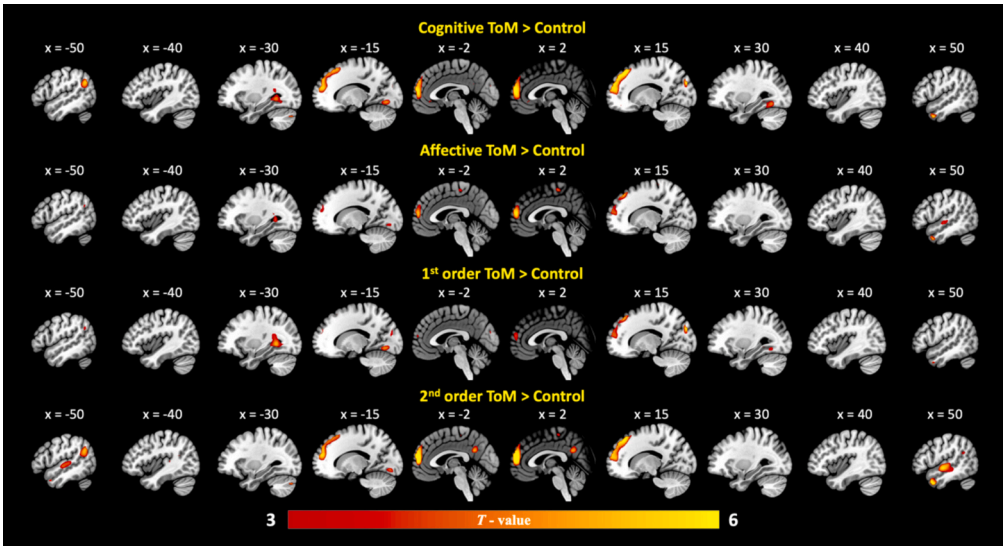

Fig. 4. Brain activations for different experimental conditions in contrast to control condition in the whole sample.
Note. One-sample *t*-tests were conducted with significant threshold set at the peak-level FWE corrected $p < 0.05$ and cluster size >10 voxels.

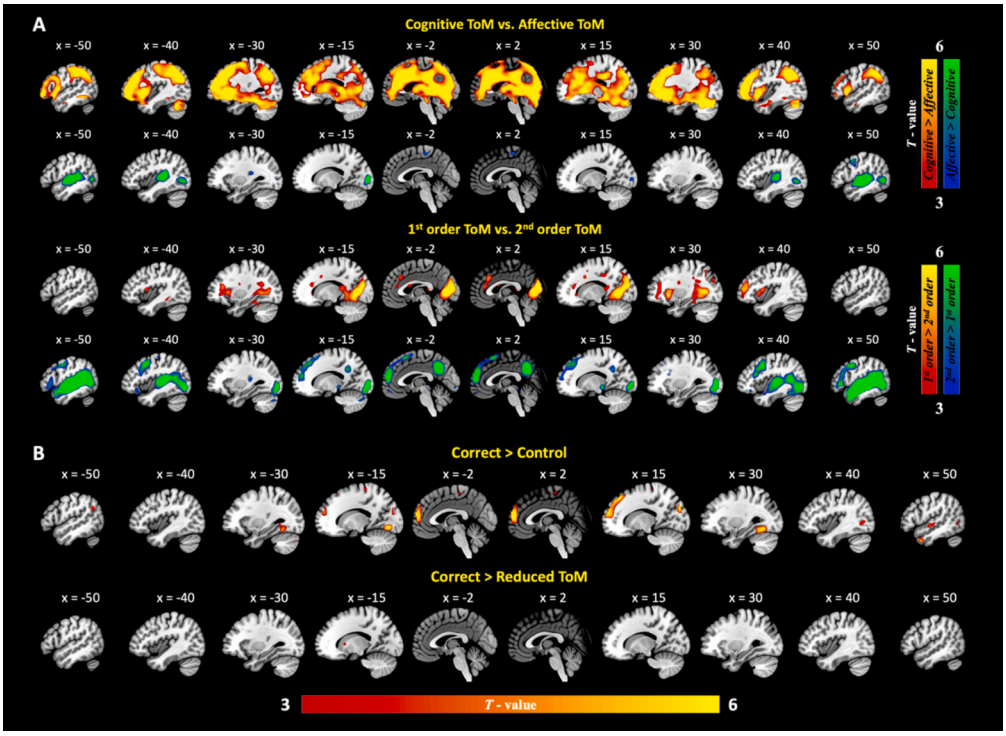

Fig. 5. Results of one-sample *t*-tests.
Note. Results of one-sample *t*-tests of cognitive ToM vs. affective ToM (red-yellow: Cognitive ToM > Affective ToM; blue-green: Affective ToM > Cognitive ToM), and 1st order ToM vs. 2nd order ToM (red-yellow: 1st order ToM > 2nd order ToM; blue-green: 2nd order ToM > 1st order ToM) (Panel A). Brain activations under correctly answered ToM trials in contrast to control trials and reduced ToM trials, respectively (Panel B). One-sample *t*-tests were conducted with significant threshold set at the peak-level FWE corrected $p < 0.05$ and cluster size >10 voxels. All analyses were conducted in the whole sample.

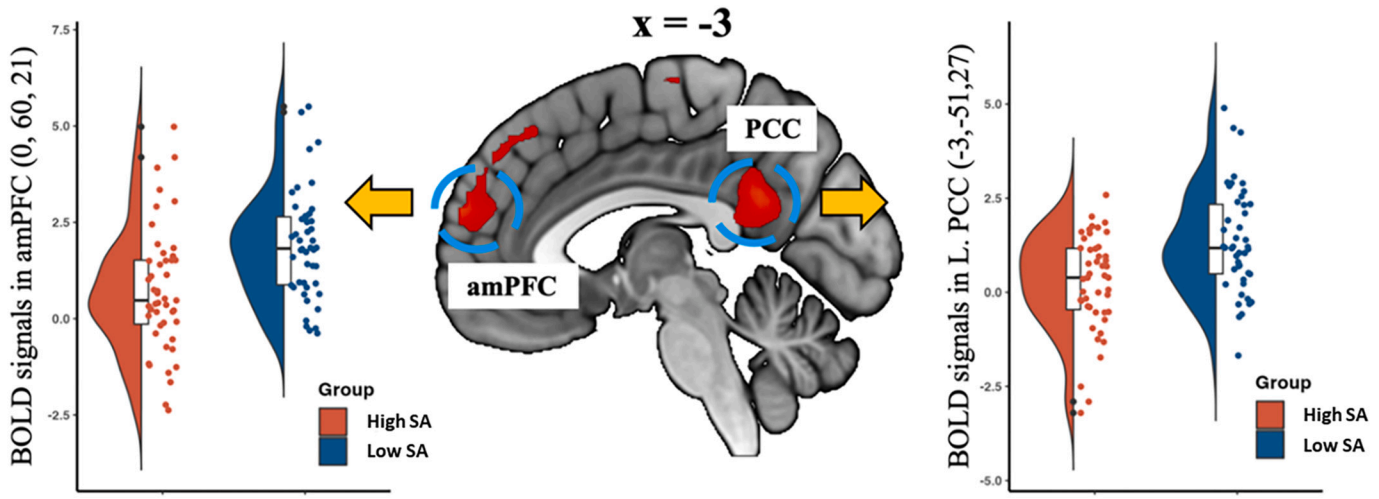

Fig. 6. Brain map.
Note. This brain map showed significantly higher activation in Low SA group than High SA group in the amPFC and L. PCC in the 2nd order ToM comparing with 1st order ToM condition. The violin plots depicted the distribution of the BOLD signals in amPFC and L.PCC in both groups. Significant threshold was set at peak-level uncorrected $p < 0.001$, and cluster-level FWE corrected $p < 0.05$. SA = social anhedonia; amPFC = anteromedial prefrontal cortex; PCC = posterior cingulate cortex; L = left.

the insula in cognitive ToM may be different from the finding of a previous study that reported a central role of the insula in emotional processing (Corradi-Dell'Acqua et al., 2020). It is possible that the participants made reference to the emotional cues of the social situation (e.g., facial expression, body gesture) to infer the beliefs and intentions of the target character. The temporal gyrus, left middle occipital gyrus and right precentral gyrus showed higher activation for affective ToM than for cognitive ToM. A previous study suggested that the temporal gyrus and middle occipital gyrus are part of a shared network for understanding others' emotional states, as well as when making references to one's own emotional experience (Reniers et al., 2014).

Using the VAMA and Yoni Task, the participants with low SA showed better behavioural performance on first-order ToM than second-order ToM, which is consistent with the findings of previous studies (Bedwell et al., 2014; Braak et al., 2022; Dodell-Feder et al., 2014). In contrast, the participants with high SA did not show such differentiation

between first-order ToM and second-order ToM. In previous studies, healthy participants also demonstrated such a preferential effect (Canty et al., 2017a; Cao et al., 2025). It has been hypothesised that second-order ToM requires more mentalising than first-order ToM, as an individual needs to engage in deeper analysis and keep multiple perspectives in mind. Previous studies on patients with schizophrenia have also found a deficit in second-order ToM (Li et al., 2017). It is possible that the high SA group was less sensitive to the different orders of ToM.

The fMRI results indicated that, in the second-order ToM compared to the first-order ToM, the low SA group showed greater activation than the high SA group in the medial frontal cortex and posterior cingulate cortex. Previous research has shown that the posterior cingulate cortex is more activated when people are analysing the intention of another person rather than merely describing a situation (Spunt and Adolphs, 2014). Although our sample did not include individuals with schizophrenia, studies in schizophrenia patients have reported reduced activation in the medial prefrontal cortex during ToM task (Hegde et al., 2021), which may reflect a lack of engagement of top-down regions and result in poorer ToM task performance (Lokey et al., 2021). This is in line with the proposal by Thibaudeau et al. (2022) that the cognitive and negative symptoms of schizophrenia may interfere with abstraction in social context, thereby hindering ToM performance. These findings suggest that social anhedonia, even in non-clinical populations, may share some neural mechanisms with schizophrenia, particularly in relation to ToM processing. Further studies are needed to better understand the apparent insensitivity to the order of ToM among individuals with high SA.

This study contributes to a better understanding of the impact of SA on ToM. The results show that people with SA show some subtle impairments in ToM, as evident from the comparison of performances across multiple dimensions of ToM rather than an obvious impairment in a single dimension. Therefore, it is suggested for future research and clinical practice that comprehensive measurement tools of ToM be adopted in SA cases.

The present study has several limitations. First, because our sample consisted of university students with a high educational background (Gooding et al., 2010), it is possible that their general cognitive ability ameliorated their ToM abilities to a certain degree, and that, therefore they did not show issues with second-order ToM or affective ToM more explicitly. Future research could involve participants with varied educational backgrounds. Second, the lack of significant correlations between brain activation and the behavioural indicators might be due to the relatively small sample size. The strict activation thresholds (after Bonferroni correction) may be applied with larger sample sizes in future studies to further verify the brain-behaviour associations. In addition, future studies can adopt the original 10-item version of the adapted version of VAMA to further explore the group differences of its different subconstructs. Finally, although SA is an important risk factor that merits research attention, the participants were not clinical cases. More research on prodromal and clinical cases of schizophrenia and ToM is also needed.

5. Conclusion

To the best of our knowledge, this is the first study to examine the effects of SA on the different dimensions of ToM. Regarding the fMRI results, the participants with low SA showed more activation than those with high SA in the medial frontal cortex and posterior cingulate cortex in second-order ToM than in first-order ToM. Overall, the results suggest that the poorer ToM performance among individuals with SA is subtler than in clinical populations with schizophrenia. Acknowledging the preliminary nature of the study in a non-clinical sample, future studies are needed to better understand ToM among other at-risk populations and those diagnosed with schizophrenia.

CRediT authorship contribution statement

Yuan Cao: Writing – original draft, Project administration, Methodology, Conceptualization. **Ding-ding Hu:** Writing – original draft, Visualization, Software, Formal analysis, Data curation. **Winnie W.Y. So:** Writing – review & editing, Visualization, Project administration, Formal analysis. **Yi Wang:** Writing – review & editing, Project administration, Methodology, Conceptualization. **Xiao-dong Guo:** Writing – review & editing, Data curation. **Raymond C.K. Chan:** Writing – review & editing, Supervision, Funding acquisition. **David H.K. Shum:** Writing – review & editing, Supervision, Funding acquisition.

Role of the funding source

The funding sources of this project provided the financial resources necessary for the project. They had no involvement in the data analysis, interpretation, write up of the study, or the decision to publish the results.

Declaration of competing interest

The authors declare that there are no conflicts of interest concerning this study. We thank all of the participants for participating in this project.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scog.2025.100402.

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