Transcultural differences in neural representations of the Theory of Mind between Chinese and Japanese

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Abstract

Theory of mind (ToM) is a human-specific ability of explaining one's own and others' actions. Yet little is known about whether ToM abilities are universal or can be culturally influenced, especially in similar cultures. Here, we recorded the brain activities of Chinese (N=12) and Japanese (N=12) participants during a ToM video task using functional magnetic resonance imaging (fMRI). General linear model (GLM) and Representational similarity analysis (RSA) approaches were used to analyze the data. Although no significant difference was found in the GLM analysis and behavior results, the RSA analysis revealed a double dissociation in the neural representation of ToM. The Japanese displayed better encoding in the premotor area, while the Chinese displayed enhanced neural representation in the anterior temporal cortex. Our study indicates that there are both culture-independent and -dependent brain functions associated with ToM processing, and the diversity within East Asian Collectivism cultures can affect the neural representation of ToM, possibly due to differences in language and social norms.

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Keywords: Theory of mind; fMRI; Transcultural; Representational similarity analysis

Introduction

Importance of ToM

Theory of mind (ToM) is a human specific ability which allows people to explain and predict one's own and other people's behaviors in light of an independent mental state (Gallagher, Frith et al. 2003). Studies have shown individual differences in ToM understanding are a key predictor of social competency, mental health, and quality of life. For example, poor ToM ability was related to increased number of errors in a social communication task in healthy adults (Krych-Appelbaum, Law et al. 2007) and old age (Bailey, Henry & Von Hippel, 2008). Moreover, it was also revealed that ToM is a single-edged sword to decrease general aggression (Wang, Shang et al. 2022), and lower ToM is associated with more alcohol problems (Kumar, Skrzynski et al. 2022) and suicidality (Nestor and Sutherland 2022). Given the critical role that ToM played in social life, one intriguing question is whether ToM abilities are universal or whether they can be culturally influenced (Bradford, Jentzsch et al. 2018), as cultural differences in ToM, if exist, could be one of the reasons that leads to cross-cultural conflict.

ToM and culture

Investigating the architecture of the human mind also requires understanding how the human mind and brain shape and are shaped by culture-gene coevolutionary processes (Chiao and Immordino-Yang 2013). Yet ToM is traditionally thought to be a universal capacity across cultures. Only recent studies have looked at this issue, and demonstrated cultural differences in ToM (for a review, see (Aival-Naveh, Rothschild-Yakar et al. 2019)). These literatures mainly focused on between Eastern and Western cultures and on cultural differences in the timing of ToM acquisition. Behaviorally, for example, culture shapes young children's social motivation for dyadic peer collaboration that is related with ToM (Stengelin, Hepach et al. 2020). Wang et al reported Chinese middle-aged children performed comparably to Australian children on cognitive ToM stories, but more poorly than Australian children on affective ToM stories (Wang, Andrews et al. 2022). Similarly, in Eastern and Western relative to the Hong Kong sample, U.K. children showed superior performance and U.K. parents showed greater levels of mind-mindedness (Hughes, Devine et al. 2018). These studies indicate that during development, Westerners might have better ToM ability than East Asians. However, this East-West difference appears to disappear in adulthood. For example, despite differences in collectivism scores, Bradford et al reported that culture does not influence ToM task performance, with similar results found for both Western and Chinese adult participants, suggesting core and potentially universal similarities in the ToM mechanism across these two cultures (Bradford, Jentzsch et al. 2018). However, despite the equal level of ToM performance between adult East Asians and Westerners, previous studies revealed that neural representations underlying ToM may differ, indicating differential neuronal processing for ToM. To our knowledge, two groups have directly compared the neural correlates of group differences of ToM ability between the Eastern and

Western cultures in adults (Kobayashi, Glover et al. 2006, Kobayashi, Glover et al. 2007, Koelkebeck, Hirao et al. 2011). These results suggest that different cultural backgrounds can cause differences in ToM neural activities, albeit equivalent ToM performances, between Eastern and Western cultures (Kobayashi Frank and Temple 2009), with a possible brain region susceptible to culture being the medial prefrontal cortex (MPFC). Koelkebeck et al reported that there was stronger activation in the MPFC in 15 Caucasian samples (v.s 15 Japanese) during the presentation of ToM videos (Koelkebeck, Hirao et al. 2011). Also, Kobayashi et al reported that the inferior frontal gyrus (Kobayashi, Glover et al. 2006) and temporo-parietal junction (TPJ) (Kobayashi, Glover et al. 2007) were employed in a culture/language-specific manner during the ToM tasks. Han & Ma argued that East Asian cultures are associated with increased neural activity in the brain regions related to inference of others' mind and emotion regulation whereas Western cultures are associated with enhanced neural activity in the brain areas related to self-relevance encoding and emotional responses during social cognitive/affective processes (Han and Ma 2014). One intriguing question remains, i.e., whether two similar cultures could have different neural representations of ToM.

Chinese and Japanese

The Chinese and Japanese belong to the same cultural cluster (Gupta, Hanges et al. 2002). Both Chinese and Japanese are typical collectivism of the East Asia, and cultural exchanges between them have lasted for thousands of years. However, cultural differences in language expression of emotion are recorded. For example, Zhang J reported that Japanese is more general and abstract than Chinese in expression of happiness (Zhang 2010). Differences in visual information processing are also reported. For example, Tajima & Duffield found that in picture description, Japanese participants reported more Ground information before mentioning figure information, mentioned more background details overall, and remembered background elements in a subsequent recall task significantly more accurately than Chinese participants (Tajima and Duffield 2012). Consistently, in judgment of appearance and attractiveness and material resources, more Japanese students noted various physical features than Chinese students, and more Chinese students noted specific behaviors than Japanese students (Crystal, Watanabe et al. 1998). Thus, despite similarities in cultures and a common emphasis on the role of family, differences exist in interpersonal relationship in Collectivism countries (Park, Phua et al. 2018), which may lead to changes of ToM between them. Tajima explained that these results are better interpreted as a consequence of the sentence structure of Japanese (Tajima and Duffield 2012). Recent studies suggest that linguistic differences may be also related with the observed cultural differences in False Belief understanding, a ToM task (Aival-Naveh, Rothschild-Yakar et al. 2019). Kobayashi et al also argued that there are possible strategic differences influenced by linguistic variations (Kobayashi Frank and Temple 2009), and reported that bilinguals recruit different resources to understand ToM depending on the language used in the task, with the L1 ToM condition eliciting more brain activity in the bilateral MPFC than the L2 task (Kobayashi, Glover et al. 2008). Hence, besides collectivistic and individualistic cultures, other linguistic factors may affect the neural correlates of ToM. The present study was carried out to investigate whether neural representation of ToM was affected by two collectivism cultures with linguistic differences, i.e., Chinese and Japanese.

RSA and GLM

Functional magnetic resonance imaging was applied to measure the blood oxygen level dependent (BOLD) brain activities while participants were asked to perform a ToM task. Note that cultural-related stimuli may lead to neural differences in higher level cognition. For example, same-race faces are processed more holistically (Michel, Rossion, Han, Chung, & Caldara, 2006) than other-race faces. Adam et al have shown that there is an intracultural advantage in the ability to infer mental states from the eyes with a sample of native Japanese and white American participants (Adams, Rule et al. 2010). In a previous study, we also found that the neural correlates of empathy for pain were modulated by racial bias (Shen, Hu et al. 2017). In the present study, we therefore used the Happé–Frith animated triangles task, a culturally neutral ToM task which has been widely used for investigating theory of mind both in behavior and imaging studies (Koelkebeck, Hirao et al. 2011, Bliksted, Frith et al. 2018, Livingston, Colvert et al. 2019). In this task, two triangles moved in a specific interaction (ToM condition), such as fighting or tricking, or moved randomly (NonTom condition) (Abell, Happé et al. 2000), and participants were asked to judge the content of the video. This paradigm has been validated for the assessment of ToM abilities in autism spectrum disorders (Castelli, Frith et al. 2002, Salter, Seigal et al. 2008, Ilzarbe, Lukito et al. 2020), Western-Asian cross cultural difference (Koelkebeck, Hirao et al. 2011, Beck, Simonsen et al. 2020), development along the age (Moriguchi, Ohnishi et al. 2010, Otti, Wohlschlaeger et al. 2015, Warrier and Baron-Cohen 2018), and genders diversity with depression (Koelkebeck, Liedtke et al. 2017). Results from Positron emission tomography (PET) (Castelli, Happé et al. 2000) and fMRI studies have found that the MPFC, superior temporal sulci, and premotor cortices are involved in ToM (vs NonToM) (Moriguchi, Ohnishi et al. 2006, Moriguchi, Ohnishi et al. 2010, Tholen, Trautwein et al. 2020), with few exception (Otti, Wohlschlaeger et al. 2015).

A general linear model (GLM) approach was typically used in these studies, in which ToM-related brain activation was identified through the contrast of ToM vs. NonToM. However, when complex stimuli like videos or movies are used, the GLM is implemented by a lack of accurate parametric models of the BOLD responses, which would decrease the sensitivities of detecting the target brain activities (Mandelkow, de Zwart et al. 2016). Recently, Representational Similarity Analysis (RSA) has been widely used in cognitive neuroscience field (Gui, Dong et al. 2013, Samuel and Davis 2015, Chen, Shimotake et al. 2016, Henriksson, Mur et al. 2019). In RSA, the representational dissimilarity matrices (RDMs) can be constructed from different neural modalities or research hypotheses, and be used in detecting the representation of specific items or mental state (Popal, Wang et al. 2020). It is a useful approach to examine which brain region represents a specific function precisely (Kriegeskorte, Mur et al. 2008, Chen, Shimotake et al. 2016, Popal, Wang et al. 2020) even though the sample size can be limited to 8 participants (Goddard and Mullen 2020). Moreover, this method is suited in experiments using complex stimuli such as videos (Gui, Dong et al. 2013, Samuel and Davis 2015, Chen, Shimotake et al. 2016, Urgen, Pehlivan et al. 2016, Dimsdale-Zucker and Ranganath 2018, Salmela, Salo et al. 2018, Henriksson, Mur et al. 2019, Dima, Tomita et al. 2020, Muukkonen and Salmela 2022), and has been used in the social cognitive neuroscience (Popal, Wang et al. 2020), as in the present study. Thus, in our ToM study, we applied RSA approach to explore the ToM encoding brain regions in Chinese and Japanese together with the GLM approach. We assumed that the RSA method will provide similar but not identical information to GLM approach on how brain regions are organized in functional networks (Pillet, de Beeck et al. 2020).

In the present study, we sought to investigate the neural representations for ToM between native Chinese and native Japanese. We compared the brain activation patterns of encoding ToM between the two cultural groups with fMRI, using both GLM and RSA methods. We considered cultural factors involved in the ToM representation and expected a different brain activity pattern in these two similar cultural groups. The present study was one of the first that compared the brain representations of ToM between two similar cultures. Also, this was the first study which applied RSA to understand the neural mechanism of ToM.

Methods

Participants

Twelve native Chinese (mean age=28.8, SD=2.9; 6 males) and 12 native Japanese (mean age=32.5, SD=7.9; 6 males) participated in the present study. Participants were native speakers of Mandarin/ Japanese respectively. The Japanese participants were born and grew up in Japan, and have been working in China for a maximum of two years. No neurological or psychiatrical disorder was reported. All participants had normal vision or corrected-to-normal vision. This study was approved by the University Committee on Human Research Protection of the East China Normal University, and written informed consents were obtained from all participants.

Stimuli

The Happé–Frith animated triangles task was used as stimuli (Abell, Happé et al. 2000). This task included four ToM videos and four random movement videos (NonToM). The ToM videos depicted two triangles coaxing, mocking, seducing, and surprising each other. The control NonToM depicted two triangles moving or rotating around the background without any intentional interaction. It is obvious that the sample size of the Happé–Frith task is relatively small (4 ToM and 4 NonToM videos only). To increase the power of the study, we created eight more videos based on the same rationale. The new animations consisted of four ToM videos and four NonToM videos. The new ToM videos depicted four behaviors: I) A square and a triangle are playing ball; II) Two circles are fighting with a square; III) A square is trying to escape from a circle; IV) A big triangle blames a small triangle snatching the other's ball, and then the small triangle returns the ball back. An RSA analysis was used to validate these new videos, see supplementary materials, Table S3. Differences was found only in the visual cortices but not in any brain region that responsible for higher cognitive functions. The control NonToM depicted two triangles moving or rotating around the background without any intentional interaction, as the Happé–Frith task's NonToM tasks. All materials are available on the OSF: (https://osf.io/rfs9t/).

Questionnaires

Three questionnaires were used in the experiment to measure participant' self-identity, scores of collectivism/individualism, and social and emotional functions. To be specific, the Suinn-Lew Asian self-identity Acculturation Scale (SL-Asia) (Suinn, Richard et al. 1992), the Individualism/Collectivism Scale (IND/COL) (Triandis 1994), and the Autism Spectrum Questionnaire (AQ) (Wakabayashi, Tojo et al. 2004, Lau, Gau et al. 2013) were used. The SL-Asian measures the participant's identification with his/her own culture and with Western culture. The score of 1 indicated high acculturation with Japanese/Chinese culture, whereas the score of 5 indicated high acculturation to Western culture. The IND/COL assessed the horizontal collectivism, horizontal individualism, vertical collectivism, and vertical individualism. The AQ scale was used to assess the participants' social and emotional functions. All questionnaires were administered in Chinese and Japanese for Chinese and Japanese participants respectively.

MRI procedure

An event-related design was applied. There were two runs, and each run included eight videos (4 ToM and 4 NonToM). The videos were pseudo-randomly selected. Each video appeared only once during the entire fMRI session. Each video was followed by two questions (Figure 1, Left). Question 1 asked the participant whether she/he considered the video clip a specific interaction behavior, i.e., the eight behaviors depicted in the Stimuli session or random movement. Question 2 asked the participants how much he agreed with the depiction in the Question 1, from a range of 1 to 5, and participant can press a hand-shape keyboard to respond. Each question lasted for 5 seconds. After a 24s fixation, the next video was displayed. There was a 1-minute break after the first run. E-Prime Ver 2 software was used for stimuli presentation. All stimuli were projected onto a screen, and participants could view the screen through a mirror mounted on the head coil. Participants lay in the fMRI scanner and were asked to keep head still throughout the scan.

The scanning was conducted on a 3-Tesla Siemens Trio MR scanner, including two functional runs and one anatomical run. For functional images, 35 axial slices (FOV = 240 mm × 240 mm, matrix = 64 × 64, in-plane resolution = 3.75 mm × 3.75 mm, thickness = 4 mm, without gap) covering the whole brain were obtained using a T2*-weighted echo planar imaging (EPI) sequence (TR = 2000 ms, TE = 30 ms, flip angle = 90°). A high-resolution structural image was also acquired using 3D MRI sequences for anatomical co-registration and normalization (TR = 1900 ms, TE = 3.43 ms, flip angle = 7°, matrix = 256 × 256, FOV = 240 mm × 240 mm, slice thickness = 1 mm).

fMRI Preprocessing

SPM12 was adopted for data preprocessing (Wellcome Department of Cognitive Neurology, London, United Kingdom) and the first three volumes for each EPI run were discarded. For each subject, EPI images were first realigned to the first volume to correct for head motion. Then, the anatomical image was co-registered with the mean EPI image, and was further segmented and then generated normalized parameters to MNI spaces. Next, all EPI data were projected to MNI template with a re-sampled voxel size of 2 mm × 2 mm × 2 mm. Finally, the functional images were spatially smoothed with a Gaussian kernel with a full width at half maximum (FWHM) of 8 mm. To remove low-frequency drifts, high-pass temporal filtering with a cutoff of 128 s was carried out.

General linear model (GLM) analysis

For the first-level analysis, a box-car model was used. The ToM and NonToM conditions convolving with the canonical hemodynamic response function (HRF) were taken as regressors, each included eight videos. The six estimated head movement parameters were included in the design matrix to minimize residual effects of head motion. Parameter estimates were then subject to a mixed second-level 2×2 ANOVA analysis, with conditions (ToM vs. NonToM) as within-subject factor and cultural backgrounds (Chinese vs. Japanese) as between-group factor. The threshold was set at $p = 0.05$, FDR corrected.

To investigate whether cultural differences lead to differences in the MPFC, a further ROI analysis with MNI coordinates based on previous studies that have been reported shown a higher activation in Caucasian participants than in the Japanese participants during the similar ToM task were selected as the ROIs, which centered at MNI coordinate 12, 48, 34 and 4, 40, 54 (Koelkebeck, Hirao et al. 2011). Two 3 mm cubes were created based on these coordinates, and parameter estimates were extracted and independent t-test was used to examine the group difference between Chinese and Japanese participants.

Representational Similarity Analysis (RSA)

A Searchlight RSA analysis was performed. We first constructed whole-brain 16 × 16 neural representational dissimilarity matrices (RDMs), using the normalized neural responses elicited by the 16 videos. Thus, we calculated the neural dissimilarities across 16 videos for every pair of videos (1-Pearson rho). Next, we constructed a 16 × 16 hypothesis-based ToM coding model RDMs (Figure 1, Right). In this design, when two videos were under the same experimental conditions, the representational dissimilarities were 0. When two videos were under two different experimental conditions (ToM vs. NonToM), the representational dissimilarities were 1. In the Searchlight RSA, we calculated the similarities (Spearman rho) between searchlight fMRI RDMs and the coding RDMs. We then conducted Fisher's Z transformation for searchlight similarities and then used searchlight one-sample t-test vs zero. The final significant RSA brain maps were assessed using a threshold $p < 0.05$, cluster-wise FDR-corrected. A further group-wise comparisons were applied in the brain regions that were found to be related with the ToM task. All RSA results were implemented through the NeuroRA toolkit (Lu and Ku 2020).

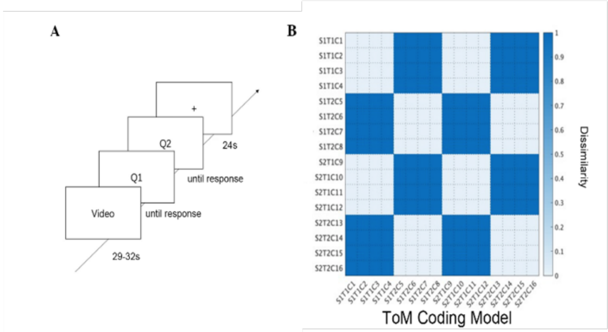

Figure. 1: Left: an illustration of a sample trial. A cultural neutral video was first presented, followed by two questions. In Question 1 the participants were asked whether the video clip depicted a specific behavior, i.e., the eight behaviors depicted in the Stimuli session, or random movements. In Question 2 participants were asked how much the participant agreed with the depiction in the Question 1, from a range of 1 to 5. Each question lasted for 5 seconds. Participant pressed a hand-shape keyboard to respond. All language-related stimuli were presented in Chinese and Japanese respectively.

Right: The ToM coding model of the representational dissimilarity matrices (RDM). The “S” represents video Style. “S1” and “S2” correspond to Happé–Frith version and the new videos we created based on the same rationale to increase power. “T1” and “T2” correspond to ToM condition and NonToM condition. “C1” to “C16” represents 16 video clips.

Results

Demographic data and questionnaire results

Independent t-test was used to analyze the data. The demographic data were listed in Table 1. There were no significant differences in the age and AQ scores between Chinese and Japanese participants and none of the participants met the pathological criteria for autism or alexithymia. The SL-Asian scores showed that Chinese participants identified their cultural background as Chinese and Japanese participants identified their cultural background as Japanese respectively. There were no significant differences in any dimensions of the IND/COL scale, i.e., horizontal collectivism, horizontal individualism, vertical collectivism, and vertical individualism.

Table 1

Characteristics and results of the study groups' questionnaires

	Japanese (N=12)	Chinese (N=12)	Statistics
Age	32.5(7.9)	28.8(2.9)	$t(22)=-1.51$, $p=0.14$
Gender	♀6, ♂6	♀6, ♂6	$\chi^2(2)= 0$, $p=1$
AQ	19.67(6.91)	18.83(5.95)	$t(22)=-0.32$, $p=0.75$
IND/COL			
Horizontal Collectivism	26.75(2.30)	26.33(2.31)	$t(22)=0.44$, $p=0.66$
Horizontal Individualism	28.67(3.65)	29.08(2.60)	$t(22)=0.28$, $p=0.78$
Vertical Collectivism	24.33(6.27)	25.50(6.08)	$t(22)=0.46$, $p=0.65$
Vertical Individualism	23.08(3.99)	22.83(3.95)	$t(22)=-0.15$, $p=0.89$
SL-ASIA	1.73(0.20)	1.77(0.24)	$t(22)=0.44$, $p=0.$ 67

Notes: AQ: Autism Spectrum Quotient; IND/COL: individualism/Collectivism Scale; SL-ASIA: Suinn-Lew Asian Self-identity Acculturation Scale. Data format: Mean(SD).

Behavioral results

To analyze the behavioral results, we conducted a mixed 2×2 ANOVA with ToM condition (ToM vs. NonToM) as within group factor and cultural backgrounds (Chinese vs. Japanese) as between group factor analysis. In the first ANOVA, the performance of Question 1 during the fMRI session was the dependent variable. The results revealed that participants could distinct ToM videos from NonToM videos (main effect of ToM, $F(1, 22) = 29.59$, $p<0.001, \eta^2=0.328$). Post hoc comparison revealed that the mean scores in the ToM condition were significantly higher than those in NonToM condition ($t(22) = 5.439$, $p<0.001$). The main effect of cultural background ($F(1, 22)=1.46$, $p=0.24, \eta^2=0.041$) and the interaction between group and ToM/video type ($F(1, 22)=0.56$, $p=0.463, \eta^2=0.009$) were not significant.

For the performance of the Question 2 during the fMRI session, the main effect of ToM was significant ($F(1, 22) = 31.94$, $p<0.001$, $\eta^2=0.074$), and post hoc comparisons revealed a higher score in the ToM condition than in the NonToM condition($t(22) = 5.652$, $p<0.001$). Neither significant group difference ($F(1, 22) = 1.82$, $p=0.192, \eta^2=0.072$) nor ToM by group interaction ($F(1, 22)=0.06$, $p=0.801$, $\eta^2=0.001$) was found.

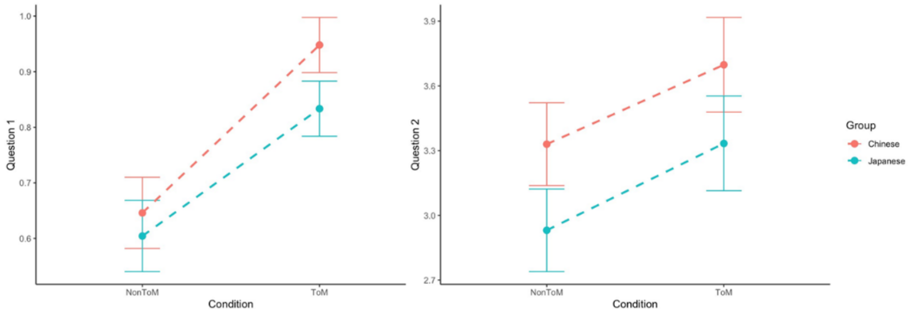

Figure. 2 Behavioral results during the fMRI sessions.

Question 1: whether the video clip depicted a specific behavior, 1 means yes.

Question 2: how much the participants agreed with the depiction in the Question 1 (from 1 to 5. 1 means disagree, 5 means totally agree). Data format: mean (SE).

fMRI results

GLM results

The results of the GLM analysis with ToM > NonToM for all participants (both Chinese and Japanese), as revealed by a paired t-test, were displayed in Figure 2. Differences were significant in the right MPFC, middle frontal gyrus, right temporal pole regions, as well as in the bilateral angular gyri, fusiform gyri, middle temporal gyri, superior frontal gyri, precentral gyri, supramarginal gyri, and middle occipital gyri. However, no significant between group difference survived the statistical threshold, which is set at $p<0.05$, FDR corrected. Detailed coordinates and volume were listed in Table S1.

A further ROI analysis was applied to analyze the data in the MPFC, as this brain region has been shown to be susceptible to cultural difference between Eastern and

Western. Two selected regions of right MPFC that have been reported in previous studies were included in the ROIs analysis, centered at 12, 48, 34, and 4, 40, 54. We did not find any significant group difference in both ROIs (for the first coordinates, the parameter estimate values are M: -0.046, SD: 0.064 for Japanese and M: -0.040, SD:0.05 for Chinese; t(22)=-0.236, p=0.816. For the second coordinates, the parameter estimate values are (M:0.03, SD:0.14) for Japanese and (M: -0.04, SD:0.046 for Chinese, t(22) =1.65, p=0.113).

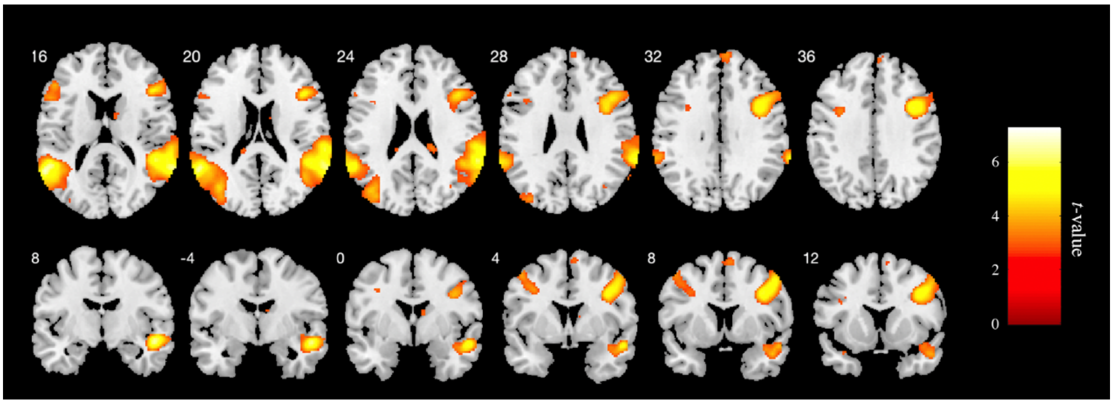

Figure 3 GLM results of ToM > NonToM of all participants (p<0.05, FDR corrected).

RSA results

For RSA results with the ToM coding RDM of all participants, searchlight neural RDMs showed significant similarities in the bilateral middle frontal gyri, and superior frontal gyri, precentral gyri, the right angular gyrus, as well as the left superior occipital gyrus, left middle occipital gyrus (Figure 4, top; Table S3).

For RSA results of Chinese participants between neural RDMs and the ToM coding model RDM, the similarity was significant in the right middle frontal gyrus, right angular gyrus, precentral gyrus, and the right superior temporal gyrus (Figure S2, A and Table S4). For RSA results of Japanese participants between neural RDMs and the ToM coding model RDM, the similarity was significant in bilateral middle frontal gyri, and superior frontal gyri, precentral gyri, and left middle occipital gyri (Figure S2, B and Table S5).

The group comparison revealed significant greater similarities in the Chinese participants than the Japanese participants in the right superior/middle temporal gyri and. On the other hand, significantly greater similarities in Japanese participants than Chinese participants were found in bilateral premotor cortices (Table 2).

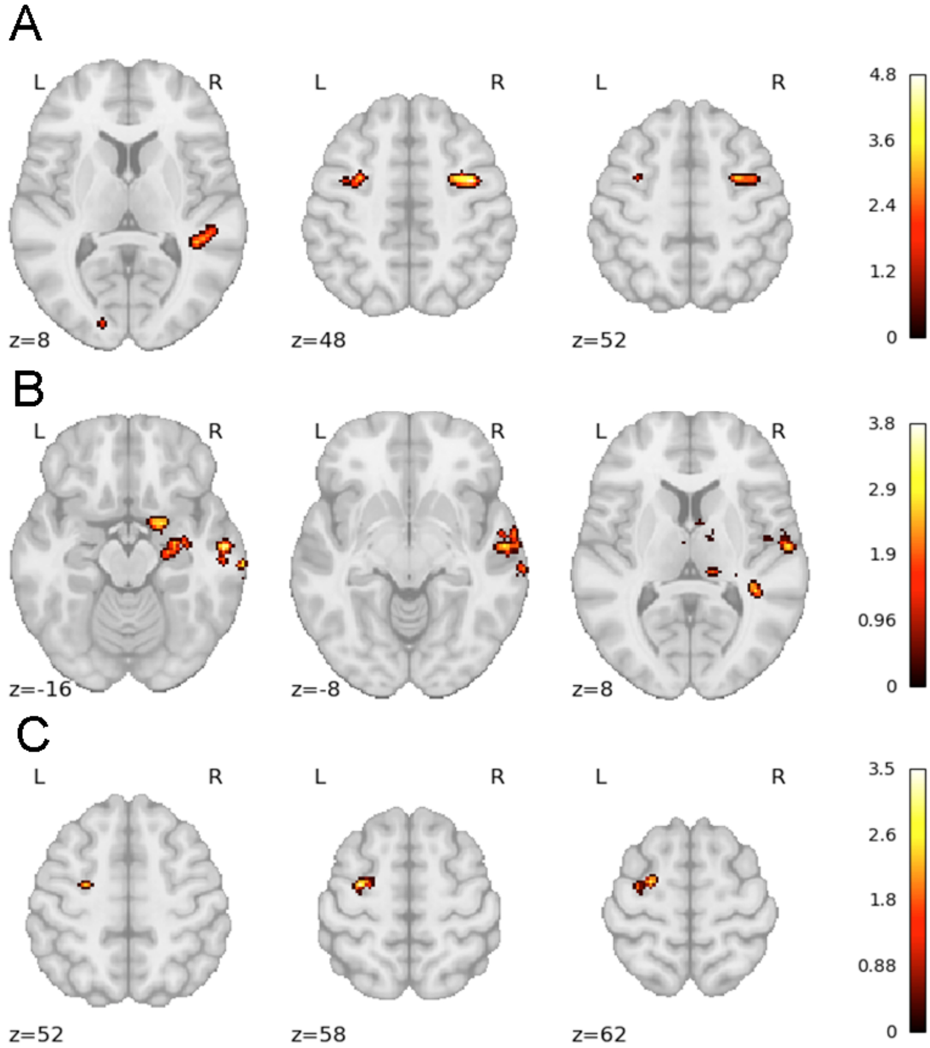

Figure 4. (A) RSA results with ToM coding model RDM; (B) RSA results with ToM coding model RDM of Chinese participants > Japanese participants in the superior/middle temporal gyri; (B) RSA results with ToM coding model RDM of Japanese participants > Chinese participants in the premotor cortices (*p*<0.05, cluster wise FDR corrected).

Table 2. Differences between RSA results of Chinese and Japanese participants with the ToM coding RDM in the temporal cortices and premotor cortices

Brain region	Hemisphere	X	Y	Z	Number of voxels	Peak intensity
Chinese > Japanese participants						
Superior/middle temporal gyri	Right	60	-12	6	490	3.4
Amygdala	Right	20	2	-16	35	3.2
Caudate	Right	12	0	16	166	3.8
Japanese > Chinese participants						
Premotor cortices	Left	-62	4	26	97	3.2
	Left	-26	-6	60	67	3.2

Note: p<0.01, cluster wise FDR-corrected at cluster level.

Discussion

The aim of this study was to examine potential cross-cultural neural differences in ToM processing by utilizing the cultural neutral Happé–Frith animated triangles task in two similar East Asia cultures, i.e., Chinese and Japanese. We found that there is a double dissociation between Chinese and Japanese participants in the anterior temporal cortex and the premotor cortex through RSA analysis, despite the same neural network is recruited by both Collectivism cultures in the GLM analysis and behavioral similarity. Our findings suggest that there are both culture-independent and -dependent brain functions associated with ToM processing in Chinese and Japanese participants.

Common activations in the ToM network between Chinese and Japanese through a GLM approach

In line with previous studies, a distributed neural network was activated by the ToM tasks (v.s. NonToM tasks) (Dodell-Feder, Tully et al. 2014, Dodell-Feder, Tully et al. 2014, Kris, Ma et al. 2014, Koelkebeck, Liedtke et al. 2017, Tholen, Trautwein et al. 2020). One of the brain regions, i.e., the MPFC, was consistently activated in most of the ToM studies (Moriguchi et al, 2007; Koelkebeck et al, 2011), with few exception (Otti, Wohlschlaeger et al. 2015). This brain region is of particular interest, as this region was found probably susceptible to cultural differences. To be specific, Koelkebeck et al found stronger activation in this brain region in Caucasian samples during the presentation of ToM videos (versus Japanese samples) (Koelkebeck, Hirao et al. 2011). Kobayashi et al (2006) also found language dependent activation in the frontal parts of the brain among American monolinguals and Japanese bilinguals completing a second-order false belief task (Kobayashi, Glover et al. 2006).

In the present study, we compared the neural activity during ToM task between two similar East Asian cultures, i.e., Chinese and Japanese. Our questionnaires analyses suggested behavioral similarity between these two cultures. Under this condition, we found a higher activation in the right MPFC in ToM condition than NonToM condition but we did not find significant difference between Chinese and Japanese. This result was confirmed by further ROI analysis, and by the RSA analysis. These results are inconsistent with the result of Koelkebeck et al (2011) that showed no MPFC activation during the same ToM task in Japanese subjects. Moreover, similar MPFC activation was found in Chinese subjects in the present study. Taken together, these results suggest that the presence/absence of MPFC activation during ToM task is not due to a simple East-West (or collectivism-individualism) dichotomy. Supporting this, past studies have also shown MPFC activation in Japanese (young subjects: Kobayashi et al; Moriguchi et al) but no MPFC activation in Western adults (Otti, Wohlschlaeger et al. 2015). At this stage, we do not know what factors determine the presence/absence of MPFC activation during ToM task. But we note one clear difference between Koelkebeck et al (2011) and our study; that is, the Japanese subjects recruited in our study were those who lived outside Japan. We thus speculate that local adult Japanese, like those recruited in Koelkebeck et al's study, are under strong ongoing influence from Japanese society and show different MPFC activation patterns from others.

Both Chinese and Japanese are Collectivism cultures. Although there were no questionnaire tools directly to compare the culture similarity and dissimilarity between Chinese and Japanese cultures at present, we selected Suinn-Lew Asian self-identity Acculturation Scale and Individualism/Collectivism scale to measure the culture related factors in both Chinese and Japanese. The results indicated that Chinese and Japanese share similar cultural factors and that the only difference is that Chinese participants defined them as Chinese and were affected by Chinese culture while Japanese participants defined them as Japanese and were affected by Japanese culture though they lived in China for at least three months. The Autism Spectrum Quotient results showed that Chinese and Japanese participants were very similar in social and emotional functions, and these two groups showed a very similar theory of mind abilities during the task. They could easily distinct the ToM videos from NonToM videos. A previous study (Chiao, Harada et al. 2010) found that cultural values of individualism and collectivism can modulate the neural activity within MPFC. Therefore, our result that MPFC showed no group difference might be due to the similar collectivism and individualism in these two groups. Thus, it appears that although the ToM related brain activities can be shaped by Eastern and Western cultures, i.e., two distinct cultures, the neural network are less affected by the difference of Japanese and Chinese, i.e., two similar Collectivism cultures, suggesting a culture-independent brain functions associated with ToM processing.

A double dissociation between Chinese and Japanese participants through RSA analysis

Interestingly, a further RSA analysis revealed a double dissociation in the neural representations of the ToM between Japanese participants and Chinese participants in the ToM-related brain regions. While the Chinese participants displayed better encoding in the superior/middle temporal gyri, the Japanese participants displayed better encoding in the premotor cortices than the Chinese participants did during the ToM task.

The superior/middle temporal gyri and premotor cortices play important roles in social animation, yet their functions are believed different (for a review, see (Schurz, Radua et al. 2021), (Diveica, Koldewyn et al. 2021), and (Kobayashi, Glover et al. 2007)). In essence, researchers suggested that the superior temporal lobes are important for storage and retrieval of social semantic scripts (e.g., (Frith and Frith 2003) and (Gallagher and Frith 2003)) and social semantic concepts, and contribute to the understanding of implied meaning through access to both general conceptual knowledge and to specific social conceptual knowledge, such as social rules and social etiquette (Ross and Olson 2010). Moreover, the superior temporal gyri is one of the core regions of the affective and emotion related neural network (Neukel, Herpertz et al. 2019), and these brain regions are recognized to play important roles in cognitive empathy (Dziobek, Preißler et al. 2011, Kemp, Berthel et al. 2013, Stoica and Depue 2020, Jie, Fan et al. 2022). In our study, the RSA results showed that, compared with Japanese, the superior temporal gyri encoded the ToM process more in Chinese participants. Cheon et al also found that the right superior temporal gyri showed a higher activation in Chinese than Western participants during an empathy task (Cheon, Im et al. 2011). In a study of (de Greck, Shi et al. 2012), Chinese participants were informed to feel the expressions of Western faces, and it was found that temporal gyri showed a similar function in cross-cultural cognitive empathy process. These evidences suggest that Chinese are more likely than Japanese (and perhaps Westerners) to simulate the emotion or the scene, feeling the simulated emotion and thinking the simulated scene, or using social semantic scripts to understand the animated videos.

On the other hand, the Japanese participants encoded more premotor cortices for ToM tasks than the Chinese participants. In a recent critical review, Schurz argued that the premotor cortex is part of the affective cluster of social cognition, and is linked to the mirroring function (Schurz, Radua et al. 2021). ToM is a multifaceted construct consisting of several distinct components (Bora, Bartholomeusz et al. 2016), for example, the representation of movement as well as motor imagery of others are needed. The premotor cortex is known to be associated with the representation of movements and motor imagery (Porro, Francescato et al. 1996). Alcala argued that the premotor cortex is part of the mirror neuron system (Alcala-Lopez, Smallwood et al. 2018) and speculated about an intimate functional relation between brain regions related to action observation and execution and those related to vicarious appraisal of someone else’s emotional states. In a study, Geiger et al compared the brain activities with the identical stimuli under different task demands (Geiger, Bente et al. 2019), and they found that during the evaluation of the correct mood, the anterior temporal cortex was involved. However, brain regions including the dorsal premotor cortex were recruited during the detection of the correct movement (Geiger, Bente et al. 2019). As action simulation in an observer' s mirror neuron system was often proposed to enable inference of others’ mental states from their nonverbal behavior (Alcala-Lopez, Smallwood et al. 2018), it could be argued that that seeing ToM animation videos activates the corresponding motor- and somatosensory representations in the observers, which produces an embodied representation and facilitates the decoding/understanding of these videos (Schurz, Radua et al. 2021). Thus, we speculate that a complementary mechanism is used by the Japanese participants, the Japanese participants require more motor imagery and mirror neuron system than Chinese participants to aid them to infer the social meaning of social animation, as they displayed less encoding in the social norm related anterior temporal cortex.

These speculations agreed with the mediation role of language in social cognition. There is a uniqueness of Japanese, which asserts that emotional adjectives are very personal and is usually restricted by the personal pronoun (Ran 2013). When the third person (but not the first person) is used as subject, a speculative manner or past tense must be used for emotional adjectives (孙成志 2008, 石袭霞 2012), a phenomenon that was not found in Chinese or English. Nishio Toraya argued that emotional adjectives are subjective and thus can only represent oneself, while other's feeling cannot be confirmative which thus must be speculative in Japanese (西尾寅弥 1972). In line with this explanation, behaviorally, in the Question 2 of the fMRI session, Japanese tended to less agree with the depictions of Question 1 (Figure 2, right), although the statistics did not reach significant ($F(1,22) = 2.69$, $p = 0.115$, $\eta^2=0.109$), likely due to the small sample size. Hence, we speculate that Chinese are more likely to use social norms and simulate the emotion of the scene to understand the behavior or mental state of others, while Japanese used more mirror neuron system to help them to infer the social meaning of the animation social videos. We also note that Japanese have been taught from early childhood to "read the air", or to be attuned to unspoken social signals all around and to react in a socially accepted way (Koelkebeck, Hirao et al. 2011). On the other hand, Chinese students are taught to "see the big picture" or "put oneself in someone else's shoes" (in Chinese, 换位思考), which means understanding the feeling or thought of others through pretending to become the one who is thinking, and indeed the Chinese children develop understanding the other's cognitive mental states at earliest, compared with other Western children (Wellman, Fang et al. 2006). These differences in social norms and social demands may influence the underlying mechanisms of ToM.

Limitations

First, Japanese participants are recruited in China. Although the stay time is limited (⩽ 2 years) and none of them have learnt Chinese so well that they could communicate in Chinese, this may affect their neural representations of ToM. In other words, this may be one of the possible reasons that we had results different from Koelekebeck et al (2011). Second, the sample size is 12 for each group. Although it is enough for the RSA analysis (Levine and Schwarzbach 2021), studies with a larger sample size are desired to detect possible minor signal changes for the GLM analysis as well as behavioral differences. Last but not least, there is a discrepancy between the behavioral results and RSA results. Although we hypothesized that differences in language may play a crucial role for the double dissociation between the RSA pattern between Chinese and Japanese, we noted that the ToM is very hard to be quantified and there was a lack of credible questionnaire tools to directly measure and compare the cultural factors in Chinese and Japanese. And the behavioral task employed in our study only provides an abstract measurement of the ToM ability, and is unable to investigate the different subcomponents of Theory of Mind in details.

Conclusion

In summary, we found a double dissociation between the neural representations of ToM encoding patterns between two East Asian collectivism groups (Chinese and Japanese) using an RSA approach, despite similar ToM-associated MPFC activation through a GLM analysis and behavioral similarity. Our results indicated for the first time that the ToM-associated brain activation can be different even between two similar East Asian collectivism cultures with linguistic differences. Further studies are desired to investigate how culture and language shape the neural representations of ToM using a larger sample size.

Acknowledgments: The authors declare this is no interest of conflict.

Funding:

National Natural Science Foundation of China (32071060)

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