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Cultural differences in neurocognitive mechanisms underlying believing

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ABSTRACT

Believing as a fundamental mental process influences other cognitive/affective processes and behavior. However, it is unclear whether believing engages distinct neurocognitive mechanisms in people with different cultural experiences. We addressed this issue by scanning Chinese and Danish adults using functional MRI during believing judgments on personality traits of oneself and a celebrity. Drift diffusion model analyses of behavioral performances revealed that speed/quality of information acquisition varied between believing judgments on positive and negative personality traits in Chinese but not in Danes. Chinese adopted a more conservative strategy of decision-making during celebrity- than self-believing judgments whereas an opposite pattern was observed in Danes. Non-decisional processes were longer for celebrity- than for self-believing in Danes but not in Chinese. Believing judgments activated the medial prefrontal cortex (mPFC) in both cultural groups but elicited stronger left anterior insular and ventral frontal activations in Chinese. Greater mPFC activity in Chinese was associated with longer duration of non-decision processes during believing-judgments, which predicted slower retrieval of self-related information in a memory test. Greater mPFC activity in Danes, however, was associated with a less degree of adopting a conservative strategy during believing judgments, which predicted faster retrieval of self-related information. Our findings highlight different neurocognitive processes engaged in believing between individuals from East Asian and Western cultures.

1. Introduction

Culture provides a system of values, beliefs, and practices that are shared by a group of people or a society (Han et al., 2013; Kitayama and Savador, 2017). Culture not only affects people's behavior but also influences their mind (Gelfand et al., 2011; Markus and Kitayama, 1991; Nisbett et al., 2001) and brain (Han and Northoff, 2008; Han et al., 2013; Han and Ma, 2014; Han, 2017; Kitayama and Uskul 2011). Up to date, researchers have shown increasing evidence for East-Western cultural differences in cognition/emotion and underlying neural underpinnings. For instance, behavioral studies have shown that East Asians are prone to contextual information during perception, favor interdependent self-construals, and possess a holistic cognitive thinking style. Westerners, however, tend to concentrate primarily on salient objects during perception, evaluate autonomous and independent self-construals, and have an analytic cognitive thinking style (Markus and Kitayama, 1991; Hedden et al., 2008; Kitayama et al., 2003; Nisbett et al., 2001; Han et al., 2011). Brain imaging studies have revealed that individuals in East Asians tend to show greater neural activities in brain regions including the temporoparietal junction (TPJ) and dorsal lateral prefrontal cortex (dlPFC), related to inference of others' mind and emotion regulation. By contrast, individuals in Europe and North America tend to exhibit greater neural activities in the ventral medial prefrontal cortex (vmPFC), inferior frontal cortex (IFC), and anterior insula (AI), which are involved in self-relevance encoding and emotional responses (see Han and Ma, 2014, for a meta-analysis). Despite these findings, to our knowledge, cultural differences in a fundamental cognitive function — believing— and its underlying brain activity have not been fully understood.

Beliefs refer to mental representations of various events that are not necessary to be presented here and now (Fuentes, 2019) and have substantial impact on people's behavior. Beliefs may serve a purpose by being linked to personal intuitive judgments about subjective certainty of sensory perceptions and mental constructs (Harris et al., 2008). Beliefs may also serve as a foundation of concepts about oneself and others (Blaine et al., 1998; Han et al., 2008) and influence reliant commitment to others and large-scale cooperation (Atkinson and Bourrat, 2011; Rotter,1980; Weingast,1995). Brain imaging studies have investigated the neural correlates of religious or secular beliefs and revealed that the mPFC is engaged in religious experiences (Azari et al., 2001) and in

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maintaining own political beliefs (Kaplan, Gimbel, and Harris, 2016). Believe, as a fundamental human brain function that happens frequently in everyday lives and results in beliefs (Seitz et al., 2018), is conceptually supposed to consist of multiple mental operations including perception, valuation, information storage, and prediction (Angel and Seitz, 2016). The processes engaged in believing are supposed to be connected with personal relevance, to deal with a set of knowledge with a hierarchically organized structure, and to have social and personal adaptive functions (Sugiura et al., 2015). As a consequence of and through the process of believing, people may intuitively attribute confidence to a given sensory perception or mental construct (Seitz et al., 2018).

Despite the important functional role of believing in formation of beliefs, there have been few empirical studies of neural processes specifically engaged in believing. It is a challenge to develop a behavioral paradigm to quantify neural correlates of believing by controlling other related but unessential neural processes. For example, an fMRI study compared brain activity during believing judgments of testable and non-testable beliefs (Howlett and Paulus, 2015). The results showed greater activations in the bilateral middle frontal gyrus and posterior cingulate cortex when making believing judgments on testable than non-testable statements. Believing judgments on non-testable than testable propositions, however, elicited stronger activations in the bilateral inferior/superior frontal gyrus and left superior temporal gyrus. These results, however, were obtained by comparing two different believing judgments (i.e., on testable and non-testable statements) rather than by contrasting a believing task versus a control task that does not engage believing, and thus did not uncover neural processes that are specific to believing.

To disentangle neural processes of believing from neural representations of mental contents for believe, Han et al. (2017) asked one Chinese sample to judge whether they *believe* that a trait adjective describes the self or a celebrity and another Chinese sample to judge whether they *think* that a trait adjective describes the self or a celebrity. Believing and thinking are regarded as the most similar mental processes in lay opinions (Allen et al., 1990). However, ‘thinking’ encompasses numerous processes of ideas and associations that may lead to logical conclusions whereas ‘believing’ does not necessarily give conclusions that stand logically. Indeed, behavioral research showed evidence that people from diverse cultures are more likely to use the word “believe” to describe religious beliefs, but to use “think” to describe matter-of-fact beliefs (Heiphetz et al., 2021; Van Leeuwen et al., 2021). The behavioral findings suggest that different cognitive processes may be engaged by believing and thinking. Han et al. (2017) compared brain activities recorded from the two samples to identify neural underpinnings of believing while controlling perceptual, cognitive, affective and motor processes that are similarly involved during believing and thinking. The results showed that, relative to the thinking task, the believing task was characterized with better memory of self-related adjectives. fMRI results revealed that believing compared to thinking tasks performed on one’s own personality traits was associated with stronger activations in the left anterior insula/inferior frontal cortex and stronger functional connectivity between the mPFC and left occipital cortex.

While these findings provide insight into neurocognitive processes that characterize believing as a unique mental process, it remains unclear whether people from different sociocultural environments employ distinct neurocognitive processes during believeing. We addressed this issue by recording behavioral and brain responses in the believing task used in our previous work (Han et al., 2017) from a Western sample (i.e., Danes). We compared behavioral and neural imaging data in the believing task obtained from the Danish sample with those from the Chinese sample of the previous work (Han et al., 2017). Our previous cross-cultural neuroimaging study investigated cultural difference in neural correlates of reflective thinking of attributes of oneself and a celebrity between Chinese and Danes (Ma et al., 2014). It was found that Danes showed stronger mPFC activations during thinking of one’s own physical/mental/social attributes whereas Chinese showed greater TPJ activations during thinking of one’s own social attributes. These findings uncovered cultural differences in neural underpinnings of thinking. The current work further examined potential cultural group differences in cognitive processes underlying believing.

We applied a drift diffusion model (DDM, Ratcliff, 1978) to analyze behavioral data (reaction time and response type) of both Chinese and Danes to estimate cognitive mechanisms underlying individuals’ performances. The DDM decomposes behavioral performances during yes/no judgments into cognitive processes that can be captured by four parameters (Ratcliff and McKoon, 2008; Voss et al., 2015). The *drift rate* (v) assesses speed and quality of information acquisition (a larger v implicates quicker information update) and has been interpreted as an estimation of stimulus processing during decision making (White and Poldrack, 2014). *Threshold separation* (a) estimates the distance between the two decision thresholds (e.g., yes vs. no) (a larger a suggests a more conservative strategy of decision making). The *starting point* (z) defines the position where evidence accumulation begins and indicates the relative amount of evidence needed for each response (a z larger than $a/2$ indicates less evidence is required to reach the upper boundary (e.g., 'no' response in our study). The *non-decision time* (t_0) captures the duration of all non-decisional processes (e.g., stimulus encoding, response execution). We compared these parameters obtained by analyses of behavioral performances of Chinese and Danes during believing judgments to assess cultural differences in cognitive processes underlying believing judgments on personality traits of oneself and a celebrity. We also applied the DDM to the behavioral data of the thinking task in our previous research (Ma et al., 2014) to examine cultural differences in cognitive processes involved in thinking.

Brain activities underlying believing were identified by contrasting believing judgments on personality traits and valence (positive vs. negative) judgments of trait adjectives. We assessed potential cultural differences in neural correlates of believing by comparing increased brain activities during believing vs. valence judgments in Chinese and Danes to control possible influences of unrelated factors such as language/social economic status on neurocognitive processes involved in believing. Given the previous findings regarding East Asian/Western cultural differences in contextual sensitivity of perception, self-construals, and thinking styles (Markus and Kitayama, 1991; Hedden et al., 2008; Kitayama et al., 2003; Nisbett et al., 2001; Zhu et al., 2007), we predicted that cognitive processes involved in believing may be more sensitive to contextual information such as valence of trait adjectives in Chinese than in Danes. Moreover, processes engaged in believing may distinguish oneself and others to a greater degree in Danes than in Chinese who may even show a reverse pattern. We examined brain activities underlying believing that either distinguished between or were common for the two cultural groups. We conducted DDM analyses of behavioral data to test these predictions. In addition, given our previous findings of neural correlates of believing in the left anterior insula/inferior frontal cortex in Chinese (Han et al., 2017) and greater mPFC activity underlying think judgments in Danes than in Chinese (Ma et al., 2014), we expect cultural group differences in neural activities involved in believing in the left anterior insula/inferior frontal cortex but not in the mPFC. We tested this prediction by comparing brain activities involved in believing judgments between Chinese and Danes. Differences in cultural traits (i.e., self-construals) and cognition (i.e., memory retrieval) between the two cultural samples were estimated by asking participants to complete the self-construal scale (Singelis, 1994) and to perform a memory test after fMRI scanning.

2. Methods

2.1. Participants

Thirty-six Chinese (18 males, 19-27 years, mean age ± SD = 22.19 ± 2.32 years) and 36 Danes (18 males, 22–29 years, mean age ± SD = 24.61 ± 1.67) undergraduate and graduate students were recruited as paid volunteers in this study. Danish participants were students who studies in a master program in Beijing and had stayed in China for less than a year when being tested. None of Danes had bicultural bringing-up. The sample size of the Danes group was determined to match the sample size of the Chinese sample in the previous work (Han et al., 2017). Religious beliefs were identified by self-report. The Danes sample consisted of 28 non-religious, 3 Christians, 1 Muslim, 1 Catholic, 1 Hindu, 1 agnostic, and 1 non-identified. All Chinese participants reported to be non-religious. All participants had normal or corrected-to-normal vision and reported no neurological or psychiatric diagnoses. Informed consent was obtained from all participants before scanning. The study was approved by the local ethics committee at the School of Psychological and Cognitive Sciences, Peking University.

2.2. Stimuli and procedure

Two hundred and eighty-eight trait adjectives were selected from a personality trait adjective pool (Liu, 1990). A bidirectional translation between Chinese and Danes was performed independently by two Chinese-Danes bilingual speakers to verify that Chinese and Danes items were identical in content. Half of these trait adjectives (144) were applied to the believing judgment tasks during fMRI scanning, and the remaining were used as novel words in the surprising memory test after scanning. Both old and new words consisted of 72 positive and 72 negative trait adjectives.

During scanning, participants were required to judge whether they believed that a given trait adjective can describe himself/herself or a well-known national/gender matched athlete (Lin Dan – a Chinese male athlete, Li Na— a Chinese female athlete, Nicklas Bendtner – a Danes male athlete, and Caroline Wozniacki – a Danes female athlete). Participants were asked to perform three different tasks by making judgments of whether they believe that a trait adjective describes the self or a celebrity or of whether a trait adjective is positive or negative. We adopted a block design with two functional scans of 264 s. Each scan consisted of 6 blocks (2 for Self believing judgments, 2 for Celebrity believing judgments, and 2 for Valence judgments) of 12 traits adjectives (6 positive and 6 negative words) presented in a pseudorandom order. There was an 8-s interval between two successive blocks. The valence judgment task was also included as a control condition. Different judgment tasks were indicated by a cue (the word 'Self', a name of celebrity, or "Positive or Negative") presented on the screen. On each trial a trait adjective, which subtended a visual angle of 2.72° (width in Chinese), 2.36°~13.41°(width in Danes) × 1.28°(height) at a viewing distance of 80 cm, was presented at the center of the screen below a cue (2.0° × 1.0°) for 2250 ms followed by a fixation of 750 ms. Participants were asked to make a 'yes' response or a 'no' response after the onset of a trait adjective by pressing one of two buttons using the right index and middle finger. Response times were recorded and used in the DDM analyses.

Before scanning, participants were asked to complete the Self-Construal Scale (Singelis, 1994) to assess their cultural orientations of independence/interdependence. After fMRI scanning the participants were asked to complete a 'surprising' memory test. The trait adjectives used during fMRI scanning were intermixed with the new trait adjectives for the memory test. The memory test required identification of old vs. new items presented in a random order by pressing one of two buttons. Corrected recognition scores were calculated by subtracting the false alarm rate from the hit rate.

2.3. DDM analysis

We employed the DDM analyses (Ratcliff, 1978) of reaction times and response type (yes or no responses) to decompose behavioral performances during believing judgments into separate cognitive processes. We compared the following parameters of the DDM across the two cultural groups: (1) the *drift rate* (v), which reflects speed of evidence acquisition during believing judgments (i.e., a larger drift rate reflects faster information update); (2) the distance between the two boundaries (a), which represents decision strategies (i.e., a larger thresholds distance indicates a more conservative strategy of decision making); (3) the *starting point* (z), which determines the position where evidence accumulation begins and reflects the relative amount of evidence needed for a response. A z larger than a/2 indicates that less (or more) evidence is required to reach upper (or lower) boundary; (4) the *non-decision time* (t_0), which captures the duration of preparatory process (i.e., stimulus encoding) and post decisional phase (i.e., movement initiation and execution). We fitted our behavioral data into the DDM using the hierarchical Bayesian implementation of the HDDM toolbox (Wiecki et al., 2013) that assumes the model parameters for individuals are randomly sampling from group distributions. Thus both group- and individual-level parameters were estimated by Bayesian statistical methods (Vandekerckhove et al., 2011). The behavioral data from all participants were fitted to the DDM with 'No' response toward upper threshold and 'Yes' response corresponded to lower threshold (termed 'stimulus coding' in Wiecki et al. 2013). 5% of trials with the longest response are treated as outliers by estimating a mixture model that enables stable parameter estimation even with outliers present in the data. We adopted this criterion because percentages from 0.01% to 10% are sufficient to capture outliers for the DDM analysis (http://ski.clps.brown.edu/hddm_docs/howto.html#outliers, Ratcliff and Tuerlinckx, 2002). To capture the variation induced by stimulus valence (e.g., positive vs. negative word), believing tasks (e.g., self vs. celebrity vs. valence judgement), and cultural groups (e.g., Chinese vs. Danes), we estimated the DDM parameters in each condition. A Bayesian posterior distribution of these parameters was modeled using Markov Chain Monte Carlo (MCMC) algorithm. To improve the probability of convergence for samples in MCMC, 10,000 posterior samples were repeated and the first 1000 samples were discarded.

2.4. fMRI data acquisition and analysis

Both cultural groups were scanned using the same 3.0 T Siemens scanner with a standard head coil in Beijing. Functional images were acquired by using T2-weighted, gradient-echo, echo-planar imaging (EPI) sequences sensitive to BOLD contrast (64 × 64 × 32 matrix with 3.75 × 3.75 × 5 mm^3 spatial resolution, repetition time = 2000 ms, echo time = 30 ms, flip angle = 90°, field of view = 24 × 24 cm). A high-resolution T1-weighted structural image (256 × 256 × 144 matrix with a spatial resolution of 1 × 1 × 1.33 mm, TR = 2530 ms, TE = 3.37 ms, inversion time (TI) = 1100 ms, FA = 7°) was subsequently acquired.

Functional images were preprocessed using SPM12 (the Wellcome Trust Centre for Neuroimaging, London, UK). Head movements were corrected within each scan and six movement parameters (translation; x, y, z and rotation; pitch, roll, yaw) were extracted for further analysis in the statistical model. The functional images were resampled to 3 × 3 × 3 mm^3 voxels, normalized to the MNI space and then spatially smoothed using an isotropic of 8 mm full-width half-maximum (FWHM) Gaussian kernel. Fixed effect analyses were first conducted by applying a general linear model (GLM) to fMRI data. All four conditions (i.e., Self, Celebrity, Valence, and rest (i.e., the 8-s interval between two blocks of trials)) were included in the model. The design matrix also included the realignment parameters to account for any residual movement-related effect. A box-car function was used to convolve with the canonical hemodynamic response in each condition. The whole-brain random effect analyses were conducted to reveal brain regions that were involved in self-believing vs. valence-judgments, self-believing vs. celebrity-believing and celebrity-believing vs. valence-judgments in Chinese and Danes samples, respectively. To further examine cultural differences in neural activities involved in believing, we conducted a whole-brain two-sample t-test of the contrast images (self-believing vs. valence-judgment, self-believing vs. celebrity-believing, and celebrity-believing vs. valence-judgment) between Chinese and Danes. Significant activations were defined using a threshold of single voxel-level ($p < 0.001$, uncorrected) and cluster-level ($p < 0.05$, FWE corrected). A conjunction null analysis (Nichols et al., 2005) was conducted to examine brain activities that were common for the two cultural groups using a threshold of single voxel-level ($p < 0.001$, uncorrected) and cluster-level ($p < 0.05$, FWE corrected).

2.5. Mediation analysis

We performed mediation analyses to examine cognitive processes (indexed by different DDM parameters) that mediate the relationship between the mPFC activity in response to self-believing judgment and response speeds of memory retrieval of self-related traits after scanning. We first adopted the mPFC peak coordinates from the results of the conjunction analysis of the contrast of self-believing vs. valence-judgment shared by Chinese and Danes. We then defined the region of interest (ROI) as a sphere with 8-mm-radius centered at the peak voxel. The contrast values were extracted from the ROI using MarsBaR (http://marsbar.sourceforge.net). In the mediation model the mPFC activity was an independent variable and the performance (reaction time) of the memory test was a dependent variable. Non decision time or threshold separation was the potential mediator. The mediation analyses were conducted in Chinese and Danes, respectively. A bootstrapping method was used to estimate mediation effects. 10,000 resamples were taken to estimate the bias-corrected confidence intervals (CIs) of mediation effects. The analyses were performed using Hayes's PROCESS macro (Model 4, Hayes, 2013).

3. Result

3.1. Behavioral results

3.1.1. Cultural differences in self-construals

Given the well-known theoretical hypothesis of differences in self-construals between East Asians and Westerners (Markus and Kitayama, 1991), we tested whether the Chinese and Danish samples tested in our work showed differences in self-construals by calculating and comparing rating scores of the self-construal scale (Singelis, 1994) . The results showed that Chinese participants reported higher interdependence but lower independence compared to Danes participants (interdependence: 5.10 ± 0.56 vs. 4.45 ± 0.70, t(70) = 4.37, $p < 0.0001$, Cohen's d = 0.92, 95%CI = [0.53, 1.51]; independence: 4.69 ± 0.49 vs. 5.00 ± 0.66, t(70) = -2.27, $p = 0 .026$, Cohen's d = -0.52, 95%CI = [-0.06, -1.00], Fig. 1A, Table 1). These results replicate our previous findings (Ma et al., 2014) and indicate reliable cultural group differences in self-construals between the two cultural samples tested in the current study.

3.1.2. Cultural differences in positive views of the self and significant others

There has been evidence for a general sensitivity to positive self-relevant information in Westerners but a tendency of self-criticism in East Asians (e.g., Kitayama et al., 1997). We assessed cultural group differences in positive views of the self and celebrity by analyzing the percentages of 'yes' responses to positive adjectives and 'no' responses to negative adjectives when making believing judgments during scanning. We expected less 'yes' responses to positive adjectives or less 'no' responses to negative adjectives during self- compared to celebrity-believing judgments in Chinese but no in Danes. Percentages of 'yes' responses to positive adjectives or less 'no' responses to negative adjectives (transformed using a arcsine-square-root function) were subject to repeated measure analyses (ANOVAs), after arcsine-square-root transformation, with Target (Self vs. Celebrity) as a within-subjects variable and Group (Chinese vs. Danes) as a between-subjects variable.

The ANOVA of percentages of 'yes' responses to positive adjectives showed a significant interaction of Target × Group (F (1,70) = 44.18, $p < 0.0001$, $\eta_p^2 = 0.387$, 90%CI =[0.238, 0.502]), as Chinese made less 'yes' responses to positive adjectives during self-believing than

Table 1
Results of questionnaires and behavioral measurements (means(SD)).

	Chinese	Danes
Self-construal		
Interdependence	5.10 (0.56)	4.45 (0.70)
Independence	4.69 (0.49)	5.00 (0.66)
Memory test	0.59 (0.13)	0.44 (0.15)
Self	0.47(0.14)	0.37 (0.14)
Celebrity	0.47 (0.11)	0.42 (0.16)
Valence		
Reaction Time (ms)	1053(194)	1313(153)
Self	1020(180)	1400(204)
Celebrity	972(159)	1288(176)
Valence		
Ratio of 'Yes' response to positive adjective		
Self	0.80 (0.15)	0.76(0.15)
Celebrity	0.90(0.11)	0.56(0.22)
Valence	0.95(0.07)	0.88(0.09)
Ratio of 'No' response	0.84(0.15)	0.80(0.11)
to negative adjective	0.92(0.11)	0.65(0.16)
Self	0.95(0.08)	0.86(0.09)
Celebrity		
Valence		

celebrity-believing judgments (mean difference = -0.176, $p < 0.0001$, 95%CI = [-0.263, -0.090]) whereas a reverse pattern was observed in Danes (mean difference = 0.231, $p < 0.0001$, 95%CI = [0.145, 0.317], Fig. 1B and C). The ANOVA of 'no' responses to negative adjectives also showed a significant interaction of Target × Group (Fig. 1B, F (1,70) = 33.10, $p < 0.0001$, $\eta_p^2 = 0.321$, 90%CI =[0.175, 0.443]), as Chinese made less 'no' responses (or more 'yes' responses) to negative adjectives during self-believing than celebrity-believing judgments (mean difference = -0.150, $p < 0.0001$, 95%CI = [-0.230, -0.069]). By contrast, Danes showed a reverse pattern (mean difference = 0.180, $p < 0.0001$, 95%CI = [0.099, 0.260]). These results suggest enhanced positive views of significant others than oneself in Chinese but enhanced positive views of oneself than significant others in Danes.

We further tested cultural group differences in positive views of others or the self by controlling the age difference between Chinese and Danes (Chinese: mean age = 19-27 years; Danes: mean age = 22-29 years). We conduct ANOVA analyses of percentages of 'yes' responses to positive adjectives or 'no' response to negative adjectives during believing judgments. The results showed significant interactions of Target × Group on both 'yes' responses to positive adjectives (F(1,69) = 34.404, $p < 0.0001$, $\eta_p^2 = 0.333$) and 'no' response to negative adjectives (F(1,69) = 26.308, $p < 0.0001$, $\eta_p^2 = 0.276$). These results further indicate cultural group differences in positive views of the self or others even when potential influences of age differences have been controlled.

3.1.3. Cultural differences in memory retrieval after scanning

The self-reference effect, i.e., better recognition of self-descriptive traits compared to other-descriptive traits after the initial trait judgments tasks (Symons and Johnson, 1997), suggests better encoding of information about oneself than others. Similarly, we assessed cultural group differences in information encoding during believing judgments by conducting ANOVAs of reaction times (RTs) and recognition scores (hit minus false alarm) of the memory test after scanning. The results revealed significant interactions of Judgment (Self, Celebrity and Valence) and Group (Chinese vs. Danes) on both RTs (F (2,140) = 5.66, $p = 0.004$, $\eta_p^2 = 0.075$, 90%CI = [0.0144, 0.144]) and recognition scores (F (2,140) = 10.18, $p < 0.0001$, $\eta_p^2 = 0.127$, 90%CI = [0.047, 0.207]). Post hoc comparison with Bonferroni corrections revealed that Chinese showed better recognition of self-related traits compared to those related to a celebrity and valence judgments

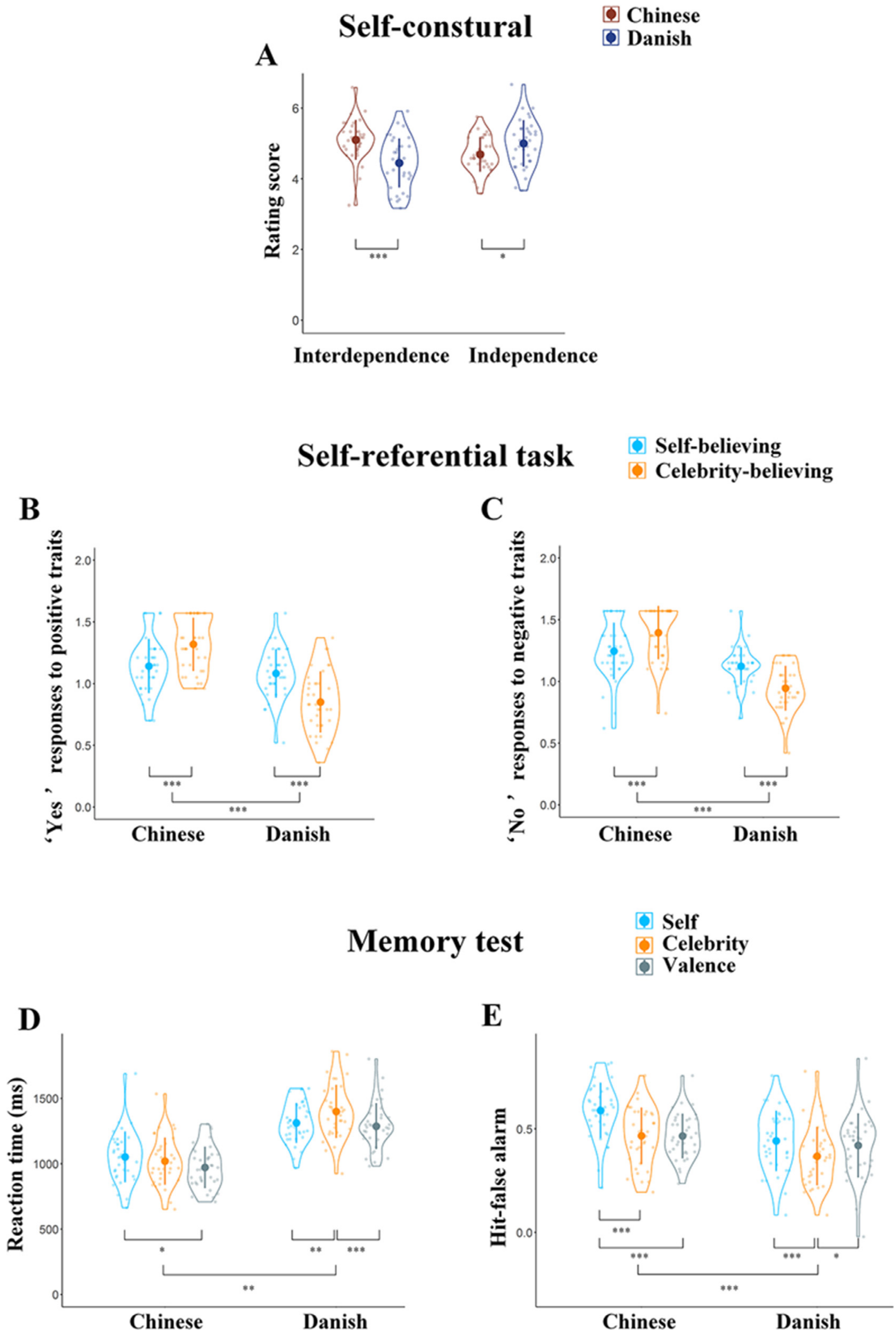

Fig. 1. Illustrations of behavioral results. (A) Results of questionnaire measures; (B) and (C) Behavioral performances during scanning; Note that percentages of 'yes' or 'no' responses were transformed using a arcsine-square-root function before ANOVAs. (D) and (E) Behavioral results of the memory test. Violin plots show means (big dots), individual participants (small dots), s.d. (bars), and distributions of parameter values. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, Bonferroni corrected.

(Recognition scores: Mean difference = 0.123/0.123, ps < 0.001, 95% CI = [0.087, 0.159]/[0.085, 0.162]) and slower responses to recognition of self-related adjectives compared to valance judgements (RT: Mean difference = 80.97, p = 0.009, 95%CI = [16.76, 145.17], Fig. 1D and E, Table 1). However, there was no significant difference in recognition scores (Mean difference = 0.001, p > 0.99, 95%CI = [-0.042, 0.043]) and RTs (Mean difference = 32.90, p = 0.50, 95%CI = [-24.85, 90.64]) between celebrity and valence judgments

Danes also showed better recognition of self-related adjectives compared to those related to celebrity judgments (Mean difference = 0.075, p < 0.001, 95%CI = [0.039, 0.110]) but responded faster to recognition of self-related compared to celebrity-related trait adjectives (Mean difference = -87.59, p = 0.001, 95%CI = [-145.34, -29.84]). In addition, Danes showed worse recognition of and responded slower to celebrity-related adjectives compared to those used for valance judgments (Recognition scores: Mean difference = -0.053, p = 0.010, 95%CI = [-0.095, -0.010]; RT: Mean difference = 112.29, p < 0.001, 95% CI = [47.76, 176.82], Table 1). These results replicated the self-reference effect in both cultural groups. However, RT results indicate a priority of memory retrieval of self-related over celebrity-related information in Danes but not in Chinese.

3.1.4. Cultural differences in DDM parameters during the believing task

We conducted DDM analyses of RTs and response types (i.e., 'yes' or 'no' responses) to further estimate latent cognitive mechanisms that underlie believing and are sensitive to cultural experiences. We fitted a full model that allowed all the four DDM parameters to vary as a function of the judgment tasks, word valence, and cultural samples. We calculated and compared posterior distributions of DDM parameters to examine cultural group differences in cognitive mechanisms involved in believing judgments. Because both behavioral and brain imaging findings suggest that individuals in Asian compared Western cultures are more capable of incorporating contextual information (Kitayama et al., 2003; Hedden et al., 2008; Han et al., 2011), we tested whether information acquisition process during believing judgments were more sensitive to the valence of trait adjectives in Chinese than Danes by comparing the drift rate (v) distributions between the two cultural groups. The results showed that, for Chinese, the posterior distributions of v for both self-believing and celebrity-believing judgments are centered lower than zero for positive trait adjectives but are centered higher than zero for negative trait adjectives ($P_{positive}[v_{self/celebrity} < 0]$ = 0.932/0.981; $P_{negative}[v_{self/celebrity} > 0]$ = 0.978/0.983, Fig. 2A). By contrast, for Danes, the posterior distributions of v are centered around zero for both self- and celebrity-believing judgments regardless of word valence ($P_{positive}[v_{self/celebrity} < 0]$ =0.507/0.601; $P_{negative}[v_{self/celebrity} > 0]$ = 0.576/0.724, Fig. 2B). These results indicate that processes underlying information acquisition during believing judgments were sensitive to emotion contexts produced by semantic meanings of trait adjectives for Chinese but not for Danes.

Next, we tested cultural group differences in the duration of non-decisional processes (e.g., stimulus encoding, response execution) during believing judgments. We calculated the *non-decision time* (t_0) in the DDM and examined whether nonoverlap of two posterior distributions is larger than 95% between self- and celebrity-believing judgments (Wiecki et al., 2013) in Chinese and Danes. The results showed that, for Chinese, the posterior distribution of t_0 is overlapped between self- and celebrity-believing judgments ($P(t_{self} < t_{celebrity})$ = 0.420/0.184, Fig. 2C), suggesting similar duration of non-decisional processes during self- and celebrity-believing judgments. For Danes, however, the majority posterior distribution of t_0 is not overlapped between self- and celebrity-believing judgments ($P(t_{self} < t_{celebrity})$ = 0.934/0.968, Fig. 2D), as the non-decision processes took longer for the celebrity than for the self. These results are consistent with previous findings that indicate shared cognitive/neural representations of oneself and significant others in East Asians but not in Westerners (Markus and Kitayama, 1991; Zhu et al., 2007; Zhu and Han, 2008; Han et al., 2013).

We also tested cultural group difference in decision-making strategies during believing judgments by calculating boundary separation (a) (i.e., the distance between believing vs. not-believing decision thresholds). The results revealed reverse patterns of posterior distributions of the thresholds related to self- and celebrity-believing judgments in the two cultural groups. The distribution of $a_{celebrity}$ is higher than a_{self} for Chinese ($P(a_{celebrity} > a_{self})$ = 0.996/0.949, Fig. 2E), suggesting that Chinese were more cautious during celebrity- than self-believing judgments. Danes, however, seemed to be more cautious during self- than celebrity-believing judgments ($P(a_{self} > a_{celebrity})$ = 0.895/0.882, Fig. 2F). These results suggest that Chinese were more cautious during celebrity-believing judgments whereas Danes were more cautious during self-believing judgments.

3.1.5. Cultural differences in DDM parameters during the think task

Next, we tested whether the cultural group differences in the results of DDM analyses mentioned above are specific to the believing task. To this end, we analyzed potential cultural group differences in behavioral performances of Chinese and Danes during the thinking task in our previous work (Ma et al., 2014). In this study, both Chinses (N = 32) and Danes (N = 32) were asked to make judgments regarding the question of whether they think that a trait adjective describes the self (or a well-known gender-/nation-matched athlete (see Ma et al., 2014 for details). The stimuli and procedures in Ma et al. (2014) were similar to those in the current study except not being able to distinguish between positive and negative trait words due to lack of separate coding. This did not allow analyses of drift rates. Thus we focused on non-decisional time and boundary separation to test whether the thinking task also generated similar cultural group differences as those in the believing task.

The results showed that, for both Chinese and Danes in Ma et al. (2014), the posterior distribution of non-decisional time (t_0) of judgments on the self and the celebrity did not show a significant cultural group difference ($P(t_{0\,self} < t_{0\,celebrity})$ = 0.876/0.895, Fig. 3A and B). There was no significant cultural group difference in boundary separation (a) during trait judgments on the self and the celebrity either ($P(a_{self} < a_{celebrity})$ = 0.520/0.709, Fig. 3C and D). These results suggest that the cultural group differences in latent cognitive processes are evident in the believing task but not in the thinking task and that the cognitive operations involve in believing may be at least partially different from those mediating thinking.

3.2. fMRI results

3.2.1. Brain activities underlying believing judgments in each cultural group

Our fMRI data analyses first examined brain activities involved in believing judgments in Chinese and Danes, respectively. Whole-brain analyses revealed that self-believing judgments compared to valence judgments significantly activated the dorsal medial prefrontal cortex (dmPFC), pre-supplementary motor area (pre-SMA), bilateral anterior insula/inferior frontal gyrus (AI/IFG), left middle frontal cortex, and right cerebellum in Chinese participants (voxel-level: p < 0.001, uncorrected, cluster-level: p < 0.05, FWE corrected, Fig. 4A, Table 1, 2 and 3). Celebrity-believing vs. valence-judgments was associated with increased activations in the bilateral temporal pole (TP)/left middle temporal cortex (MTC), ddmPFC, bilateral AI/IFG, left middle frontal cortex, left temporoparietal junction (TPJ), precuneus/PCC, and right cerebellum (Fig. 4B). Self-believing compared to celebrity-believing judgments increased activities in the ventral medial prefrontal cortex (vmPFC) and pre-SMA (Fig. 4C).

For Danes participants self-believing judgments compared to valence-judgments significantly activated the vmPFC, anterior cingulate cortex (ACC) and precuneus/PCC whereas celebrity- believing vs. valence-judgments only activated the precuneus/PCC (Fig. 4D and E). In addition, self- vs. celebrity-believing judgments were associated with activations in the vmPFC, bilateral caudate, left hippocampus and cerebellum (Fig. 4F).

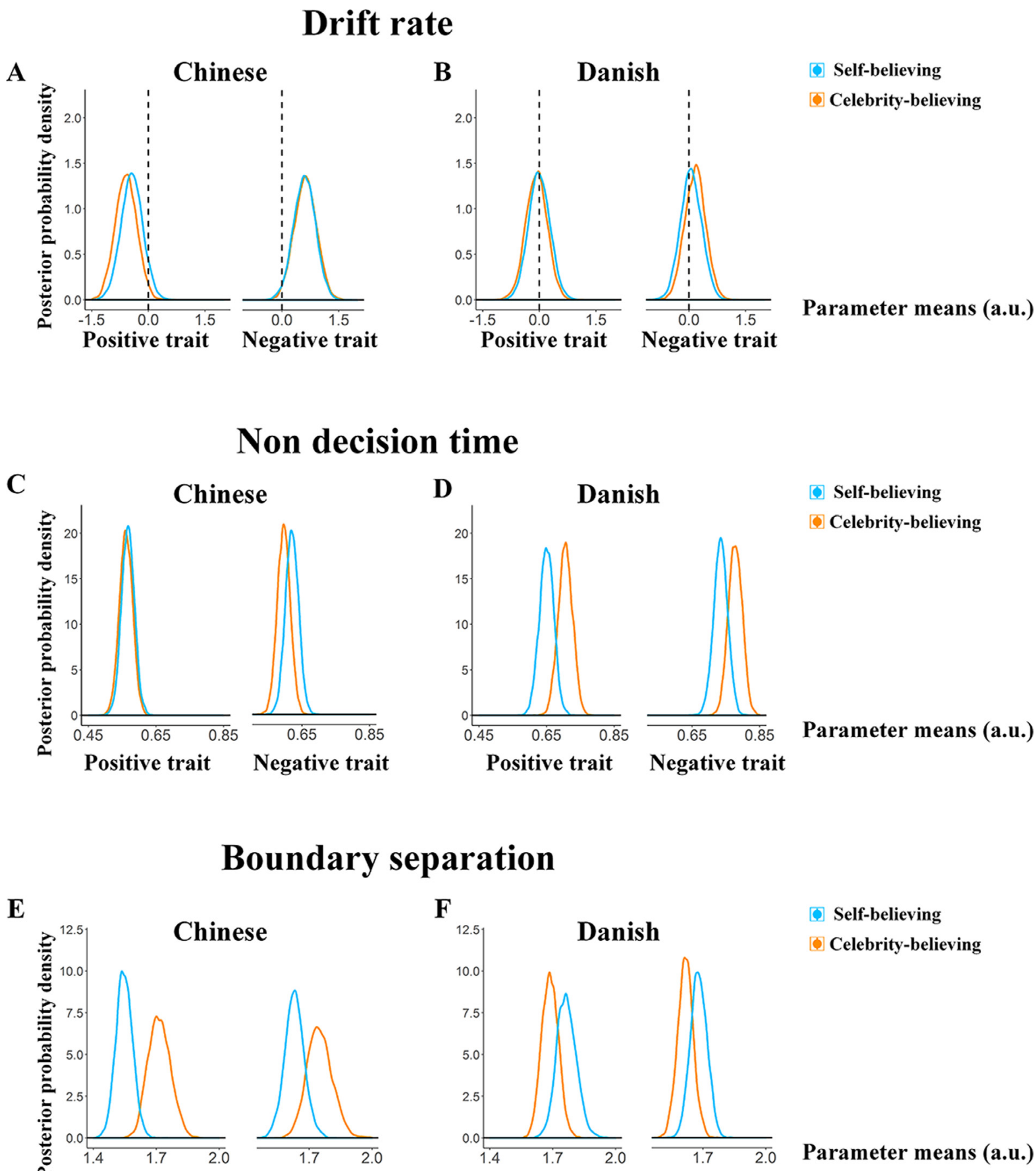

Fig. 2. Results of DDM analyses of behavioral performance during believing judgments. (A) and (B) Group-level posterior probability densities for means of drift rate in Chinese and Danes; (C) and (D) Group-level non-decision time in Chinese and Danes; (E) and (F) Group-level threshold separation in Chinese and Danes. The abscissa represents the normalized parameter means estimated by Markov chain Monte Carlo, which can be arbitrary and have no unit. The ordinate represents the "counts" (probability densities) of a given value. The area under each curve represents probability that equals to 1.

3.3. Common brain activities underlying believing judgments in the two cultural groups

To examine brain activities that were commonly involved in self- or celebrity-believing judgments in Chinese and Danes, we performed conjunction analyses of the following contrasts from the two cultural groups: self-believing vs. valence judgments, celebrity-believing vs. valence judgments, and self- vs. celebrity-believing judgments. The results showed activations in the vmPFC (-3/35/1, voxel-level: $p < 0.001$, uncorrected, cluster-level: $p < 0.05$, FWE corrected, Fig. 5) during self- vs. celebrity-believing judgments. Significant activations were observed in the dmPFC (-6/56/22) and bilateral superior parietal lobe (SPL, left: -12/-67/58; right:18/-67/58) during self-believing (vs. valence) judgment. Increased activities were also observed in the PCC (0/-52/22) and bilateral SPL (left: -18/-70/46; right:24/-61/43) during celebrity-believing (vs. valence) judgments.

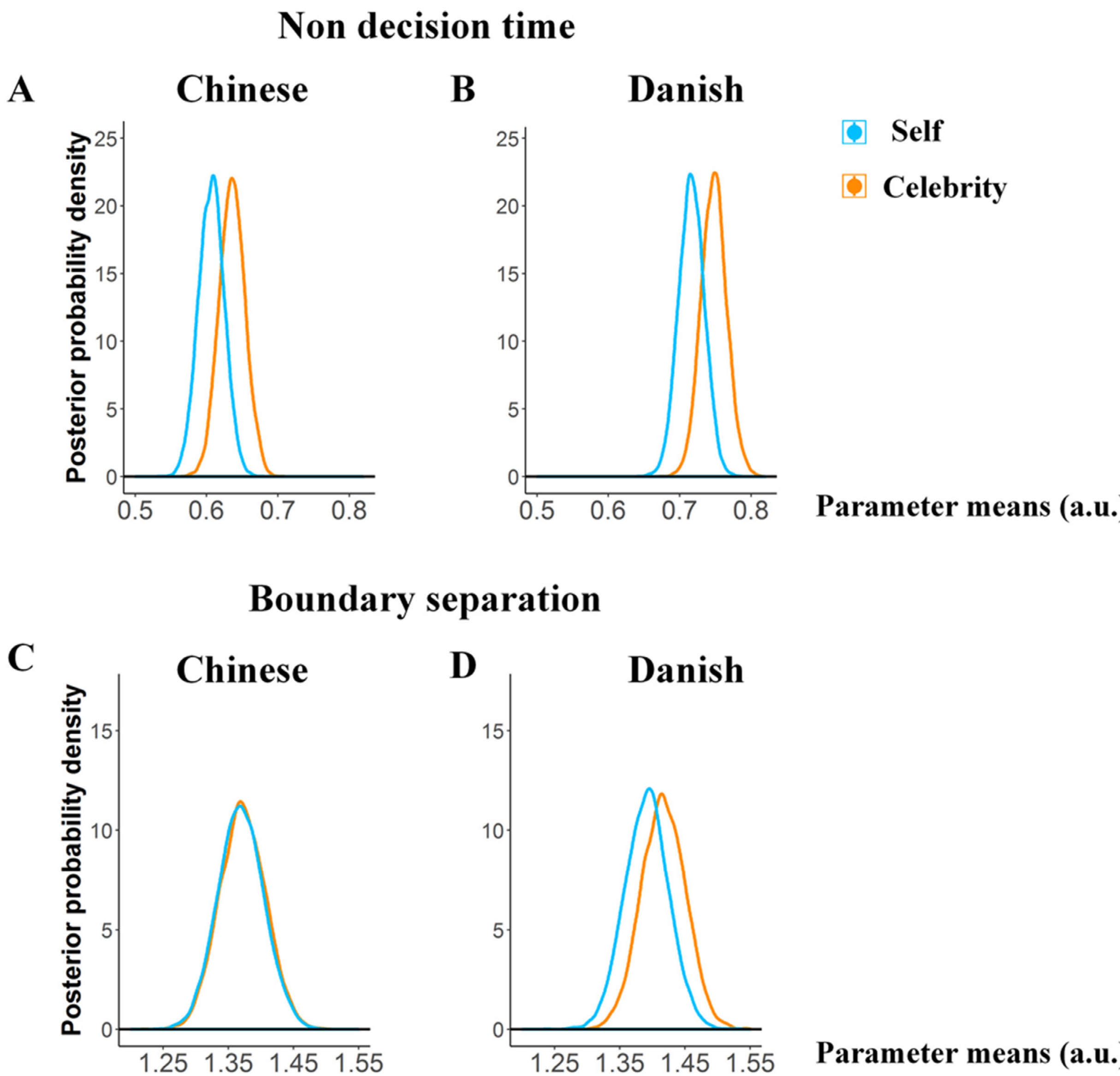

Fig. 3. Results of DDM analyses of behavioral performance during a thinking task (data from Ma et al., 2014). (A) and (B) Group-level posterior probability densities of the means of non-decision time of Chinese and Danes; (C) and (D) Group-level boundary separation of Chinese and Danes.

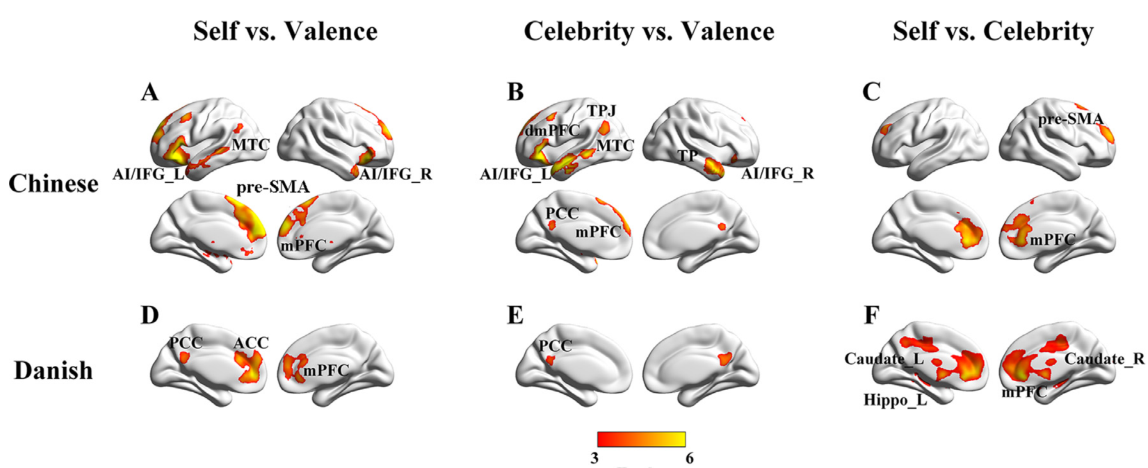

Fig. 4. *fMRI results of whole brain analyses*. Activations are shown for the contrast of self-believing vs. valence judgment (A) and (D), celebrity-believing vs. valence judgment (B and E) and self- vs. celebrity-believing judgments (C and F) in Chinese and Danes, respectively. ACC: anterior cingulate cortex; AI: anterior insula; Hippo: hippocampus; dmPFC: dorsal medial prefrontal cortex; IFG: inferior frontal gyrus; MTC: middle temporal cortex; mPFC: medial prefrontal cortex; PCC: posterior cingulate cortex; pre-SMA: pre-supplementary motor area; TPJ: temporoparietal junction.

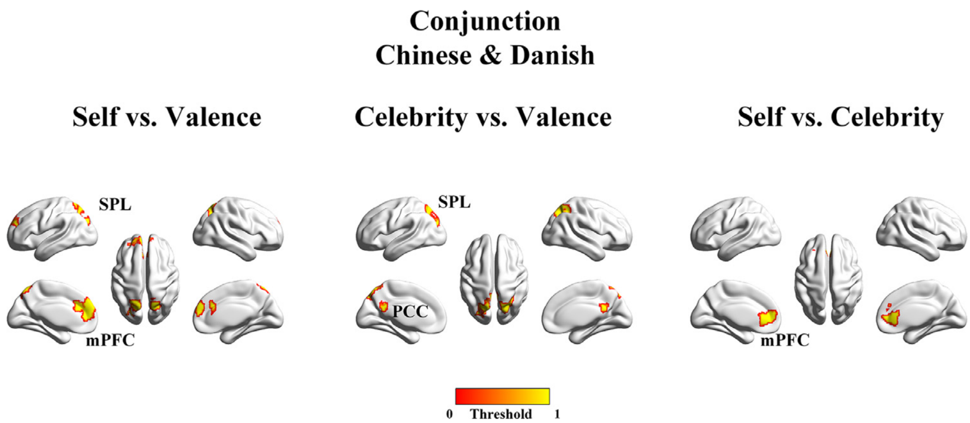

Fig. 5. Results of conjunction analyses. Common activations observed in Chinese and Danes include greater activities in the mPFC and bilateral SPL during self-believing (vs. valence) judgment, increased activities in the PCC and bilateral SPL during celebrity-believing (vs. valence) judgments, and stronger activation in mPFC during self- compared to celebrity-believing judgments. mPFC: medial prefrontal cortex; SPL: superior parietal lobe; PCC: posterior cingulate cortex.

Table 2
fMRI results of the whole-brain analyses.

Regions	Size	MNI Coordinate X	y	z	Z
Chinese Self- vs. Valence-judgment					
dmPFC	3743	-12	59	28	6.57
pre-SMA		-9	32	61	6.03
Right AI/IFG		39	26	-11	5.27
Left AI/IFG	1858	-42	26	-11	5.93
left middle frontal cortex	170	-39	17	49	4.61
Celebrity- vs. Valence-judgment					
Left TP/MTC	1223	-45	17	-29	6.63
Left AI/IFG		-42	32	-11	5.81
dmPFC	777	-15	53	46	5.75
right TP	427	39	17	-35	5.31
left middle frontal cortex	107	-42	17	49	4.67
left TPJ	200	-48	-58	28	4.49
Precuneus/PCC	150	0	-49	22	4.42
Self- vs. Celebrity-judgment					
vmPFC	1903	-6	32	4	5.15
pre-SMA	150	15	14	67	4.33
Danes					
Self- vs. Valence-judgment					
vmPFC	1865	-15	47	1	5.31
ACC		12	20	22	4.68
Precuneus/PCC	133	-6	-52	28	3.87
Celebrity- vs. Valence-judgment					
Precuneus/PCC	217	3	-55	19	4.10
Self- vs. Celebrity-judgment					
vmPFC	939	0	35	-2	5.24
Left Hippocampus	161	-30	-40	7	4.67
Right Caudate	103	21	-19	28	4.36
Left Caudate	134	-24	-10	37	4.17

dmPFC: dorsal medial prefrontal cortex; vmPFC: ventral medial prefrontal cortex; pre-SMA: pre-supplementary motor area; AI/IFG: anterior insula/inferior frontal gyrus; TP/MTC: temporal pole/middle temporal cortex; TPJ: temporoparietal junction; PCC: posterior cingulate cortex; ACC: anterior cingulate cortex;

3.4. *Cultural differences in brain activities underlying believing judgments*

To assess brain activities underlying believing judgments that characterize each cultural group, we conducted whole-brain two-sample t-tests of the contrast images of self-believing vs. valence-judgments, celebrity-believing vs. valence-judgments, and self- vs. celebrity-believing judgments between Chinese and Danes. The results showed that, relative to Danes, Chinese showed greater activations in the left AI/IFG (coordinates of the peak voxel: -45/38/-14), and bilateral occipital cortex (left: -9/-76/-11; right: 9/-73/-11) during self-believing than valence-judgments. Chinese compared to Danes also showed greater activations in left AI/IFG (-42/35/-14) and left middle temporal cortex (-66/-37/-2) during celebrity-believing relative to valence-judgments, and stronger activities the bilateral occipital cortices (left: -6/-76/-8; right: 9/-76/-8) during self- compared to celebrity-believing judgments (voxel-level: $p < 0.001$, uncorrected, cluster-level: $p < 0.05$, FWE corrected, Fig. 6). Reverse comparisons between Danes and Chinese, however, did not show any significant activation.

3.5. *Cultural differences in relationships between brain activity underlying self-believing judgments and behavioral responses during memory retrieval*

Finally, we conducted mediation analyses to explore cognitive processes that mediate the association between brain activity underlying self-believing judgments and behavioral responses during memory retrieval. In particular, we were interested in whether the reverse patterns of RTs in response to self-related trait adjectives in Chinese and Danes were associated with different neurocognitive processes involved in believing judgments. To this end, we first tested whether cognitive processes indicated by the DDM parameters can predict RTs during the memory test. The results of Spearman correlation analyses first showed that non-decision time and threshold separation during self-believing judgments predicted longer RTs during memory retrieval of self-related trait adjectives in both Chinese (r = 0.680 and 0.443, $p < 0.001$ and $p = 0.007$) and Danes (r = 0.549 and 0.430, p = 0.001 and 0.009). Next, we examined whether the mPFC activity underlying self-believing judgments was associated with non-decision time or threshold separa-

Table 3
Correlation results among mPFC activities, DDM parameters and reaction time.

N=36	Chinese mPFC	t_0	a	RT	Danes mPFC	t_0	a	RT
mPFC		.454**	-.239	.184		.187	-.345*	-.003
t_0			-.036	.680**			-.037	.549**
a				.443**				.430**
RT								

** $p < .01$; * $p < .05$

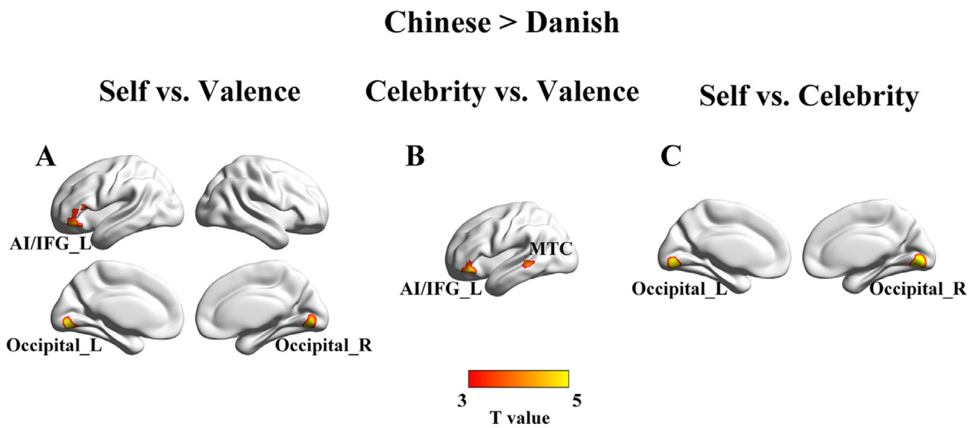

Fig. 6. fMRI results of the whole brain two-sample comparisons. Show are stronger activities observed in Chinese than in Danes. AI: anterior insula; IFG: inferior frontal gyrus; MTC: middle temporal cortex.

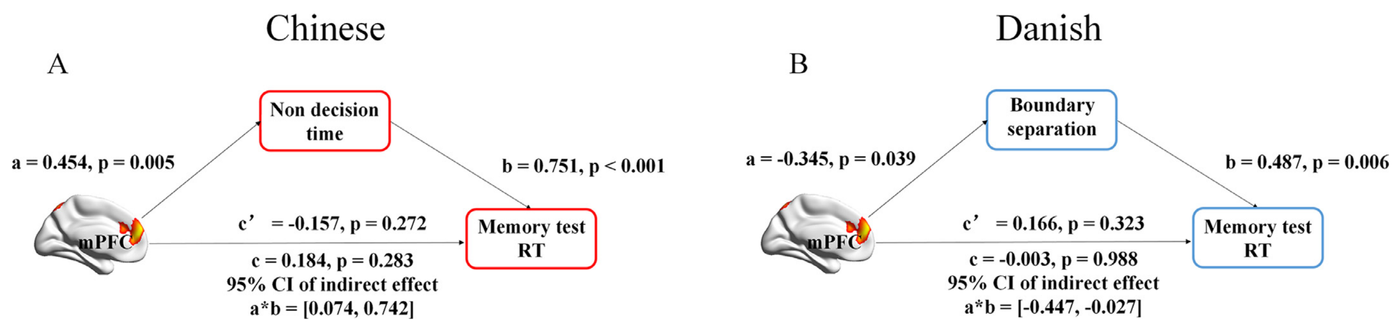

Fig. 7. Results of the mediation analyses. (A) The non-decision time during self-believing judgment mediates the relationship between the mPFC activity and reaction times of memory retrieval of self-related trait adjectives in Chinese participants. (B) The threshold separation during self-believing judgments mediates the relationship between the mPFC activity and reaction times of memory retrieval of self-related trait adjectives in Danes participants. mPFC: medial prefrontal cortex.

tion in two cultural groups. We selected the mPFC because it was activated during self-believing judgments in both cultural groups. Besides, the mPFC has been shown to be involved in beliefs in previous studies (Seitz and Angel, 2012; Kaplan et al., 2016). We extracted the contrast values (self-believing vs. valence judgments) from the mPFC observed in the conjunction analysis (peaking at -6/56/22). The results showed that the mPFC activity evoked during self-believing judgments (-6/56/22) positively predicted non-decision time in Chinese ($r = 0.454$, $p = 0.005$) but negatively predicted threshold separation in Danes ($r = -0.345$, $p = 0.039$, Table 3). Therefore, we further conducted mediation analyses which revealed that non-decision time during self-believing judgments mediated the relationship between the mPFC activity and RTs during the memory retrieval of self-related trait adjectives in Chinese (95% CI of indirect effect = [0.074,0.742], Fig. 7A). By contrast, threshold separation during self-believing judgments mediated the relationship between the mPFC activity and RTs of memory retrieval of self-related trait adjectives in Danes (95% CI of indirect effect = [-0.447, -0.027], Fig. 7B). These results further suggest distinct functional roles of the mPFC activity in self-believing judgments in the two cultural groups.

4. Discussion

The present study investigated cultural differences in neurocognitive processes involved in believing by comparing behavioral performances and brain activity between Chinese and Danes. We compared these two samples as representations of East Asians and Westerners who have been shown to exhibit systematic differences in cognition, emotion, and underlying brain activity (Gelfand et al., 2011; Han and Northoff, 2008; Han et al., 2013; Han and Ma, 2014; Han, 2017; Kitayama and Uskul 2011; Markus and Kitayama, 1991; Nisbett et al., 2001). The samples recruited in our work manifested cultural differences in self-report and behavioral performances similar to those reported in previous studies. For example, questionnaire measures indicate endorsement of interdependent self-construals in Chinese whereas independent self-construals were approved by Danes in our study, which replicated previous findings (Li et al., 2006; Thomsen et al., 2007; Ma et al., 2014). In the memory test after fMRI scanning Danes responded faster to recognition of self-related compared to celebrity-related trait adjectives whereas such a self-superiority effect was not observed in Chinese. These results provide further evidence for East Asian/Western differences in self-construals and implicate distinct neurocognitive processes employed by the two cultural samples during encoding and retrieval of self-/other-related information.

The present study employed a believing judgment task that required participants to make a yes or no responses to questions whether they believe a trait adjective describe the self or a celebrity. A valence judgment task was used to control effects of perceptual/semantic processing and motor responses on brain activity. DDM analyses of reaction times and response types allowed us to disentangle the processes of stimulus estimation (indexed by drift rate (v)), conservative strategy (indexed by threshold separation (a)), non-decisional processes including stimulus encoding and response execution as indexed by t_0) (Ratcliff and McKoon, 2008; White and Poldrack, 2014; Voss et al., 2015). The results of DDM analyses revealed three differences in cognitive processes that characterize believing-judgments in Chinese and Danes, respectively. First, positive and negative trait adjectives shifted the posterior distributions of the drift rate either lower or larger than zero during both self- and celebrity-believing in Chinese. This finding suggests that, for Chinese, processes underlying information acquisition during believing were sensitive to emotion contexts produced by semantic meanings of trait adjectives. By contrast, word valence did not influence the posterior distributions of the drift rate in Danes, indicating that information acquisition during believing was independent of semantic contexts of trait adjectives. Previous cultural psychology and cultural neuroscience studies have shown evidence for context-dependent processing in East Asians but context-independent processing in Westerners in perception/attention (Kitayama et al., 2003; Hedden et al., 2008; Kühnen and Oyserman, 2002; Lin et al., 2008; Lin and Han, 2009; Lao et al., 2013) and in social/physical causal attribution (Morris and Peng, 1994; Norenzayan and Nisbett, 2000; Han et al., 2011). The current findings extend the East Asian/Western cultural differences in contextual processing to an additional mental process, i.e., believing, and provide further evidence for similar patterns of cultural differences in believing in terms of contextual sensitivity.

Second, our analyses of the non-decision time (t_0) in the DDM suggest that there are overlapping non-decision processes involved in self- and celebrity-believing judgments in Chinese. By contrast, there may be separation of non-decisional processes engaged in self- and celebrity-believing judgments in Danes. East Asian/Western cultural differences in self/other processing have been documented in studies of both face perception and memory retrieval. For instance, British compared to Chinese students showed a larger difference in reaction times to discriminate images of own face versus a friend's face (Sui et al., 2009). Priming independent (vs. interdependent) self-construals increased right frontal activity in response to one's own face (Sui and Han, 2007). Chinese (but not American) graduate students responded slower to their own faces that were presented in a context with presence of a significant other (i.e., a supervisor) compared to a nonsignificant other (Ma and Han, 2009; Liew et al., 2011). The superiority of memory retrieval of self-related over other-related information is weaker in Chinese compared to Western students (Zhu and Zhang, 2002). Memory encoding of personality traits of oneself and close others (i.e., mother, spouse, child) engages overlapping mPFC activity in Chinese but not Western students (Wang et al., 2012; Zhu et al., 2007; Han et al., 2009, 2016). These behavioral and neuroimaging findings unraveled overlapping neurocognitive processes of the self and significant others in visual perception and memory and are consistent with the theory of interdependent self-construals in East Asian cultures but independent self-construals in Western cultures (Markus and Kitayama, 1991). Our results of the non-decision time further suggest that self-construal as a key cultural trait may exert similar influences on the non-decision processes engaged in believing, i.e., East Asian compared to Western cultures facilitate overlapping of non-decision processes of oneself and a significant other during believing.

Third, our DDM analyses of threshold separation (a) uncovered opposite patterns of decision-making strategies during believing judgments in the two cultural groups. Chinese were more cautious during celebrity- than self-believing judgments whereas Danes showed a reverse pattern, i.e., being more cautious during self- than celebrity-believing judgments. Similarly, these results are consistent with the cultural group differences in self-construals in that Chinese participants gave priority to a significant other in decision-making strategies during believing. By contrast, Danes assigned priority to oneself in their decision-making strategies during believing. The results of threshold separation in the two cultural groups are consistent with a global pattern of East Asian/Western cultural differences in cognitive processes involved in believing. In particular, it is likely that interdependent/independent self-construal may play an important role in shaping these cognitive processes involved in believing, providing further support to the claim that self-construal as a pivotal cultural trait provides a basis for formation of cognitive styles (Han and Humphreys, 2016).

The present study investigated cultural group differences in brain activities underlying believing by contrasting neural responses to believing judgments with those to valence judgments to control relevant but non-essential processes such as encoding of semantic meaning of the stimuli and motor selection/execution. The results of two-sample whole brain analyses uncovered stronger activations in the left AI/IFG during self-believing (vs. valence) judgments and greater activations in the left AI/IFG and left middle temporal cortex during celebrity-believing (vs. valence) judgments in Chinese compared to Danes participants. In our previous work the left AI/IFG and middle temporal activities were quantified by contrasting believing with thinking judgments (Han et al., 2017), which specified believing-related neural responses by controlling potential effects of intentions to make affirmative responses or task difficulty. Because self-specific stimuli activate the left AI/IFG whereas non-self-specific or personal familiar stimuli do not (Northoff et al., 2006), it was assumed that the left AI/IFG activity might manifest enhanced feelings of self-relevance of the stimuli used for believing judgments. If this assumption is correct, one may speculate, based on the findings of the current work, that Chinese compared to Danes may experience greater feelings of self-relevance of perceived stimuli during believing regardless of the believing target. In addition, if the left TP/MTC plays a key role in semantic memory and supports social conceptual knowledge (Simmons and Martin, 2009), our results may be interpreted as that other-related believing depends on deeper processing of semantic and social knowledge about others in Chinese than in Danes.

We found common activations in the PCC during celebrity-believing relative to valence judgments in the two cultural groups. Because the PCC is the hub of the neural network underlying episodic memory (Benoit and Schacter, 2015; Lega et al., 2017; Natu et al., 2019), our results might be interpreted as reflecting similar retrieval of information from episodic memory during other-related believing in Chinese and Danes. Our fMRI results also revealed brain activity in the mPFC that was commonly engaged in self-believing to a greater degree compared to celebrity-believing in the two cultural groups. However, this does not implicate that the mPFC necessarily mediates the same function during believing in the two cultural groups because the mPFC activity evoked during self-believing judgments was associated with non-decision time in Chinese but with threshold separation in Danes. In addition, we showed evidence that RTs during memory retrieval of self-related trait adjectives might be attributed to non-decision time during self-believing judgments in Chinese but to threshold separation during self-believing judgments in Danes. These results imply different functional roles of the mPFC activity in self-believing judgments through which self-related memory retrieval was affected by distinct cognitive processes involved in believing.

It has been speculated that multiple mental operations including perception, valuation, information storage, and prediction are engaged during the process of believing (Angel and Seitz, 2016) and believing shapes functional organization of brain during evolution (Seitz and Angel, 2020). The present study provided empirical behavioral and neuroimaging results that advance our understanding of neurocognitive processes involved in believing by conducting cross-cultural DDM analyses of individuals' behavioral performance and cross-cultural comparisons of brain activity during believing judgments. Particularly, cultural group differences in patterns of behavioral performances during believing judgments suggest that believing may be decomposed into separate processes such as information acquisition, non-decision processes, and response strategy (e.g., degree of cautiousness) that respectively undergo influences of individuals' cultural experiences. In addition, even the same brain region (e.g., mPFC) that was observed to be activated during believing in both cultural groups may be linked to different processes of believing.

Unlike previous research that explored how existing beliefs are affected by decision outcomes (e.g., Nassar et al., 2010), our design did not include feedback upon participants' believing judgments. Therefore, our design does not allow trial-by-trial examination of dynamic variation of processes during believing. Believing an individual's personality traits (of either one's own or a familiar other) may consist of processes that are more stable compared to belief update during decision making that results in unexpected outcomes. It remains an open issue whether targets for believing influence cognitive processes engaged in believing that are mediated by distinct neural underpinnings. This can be addressed in future work by quantifying brain activities involved in believing tasks that are performed on different targets with trial-by-trial feedback. The current work only compared behavioral and fMRI measures of believing judgments from two cultural groups. Although our questionnaire measures confirmed differences in self-construals between Chinese and Danes, it is unclear whether or not our findings regarding cultural differences in neurocognitive processes underlying believing also characterize other cultural groups (e.g., Japanese, Koreans, North Americans). It is thus necessary to test other cultural groups to testify East Asian/Western cultural differences in believing and neural underpinnings.

In conclusion, the current study examined cultural differences in neurocognitive processes involved in believing by integrating behavioral and fMRI measures during believing judgments on personality traits of oneself and a celebrity. Our behavioral results highlight distinct processes from information acquisition to response strategy in Chinese and Danes. Our fMRI results suggest both enhanced anterior insular and ventral frontal activations in Chinese individuals and different functional associations of the mPFC activity in the two cultural groups. Our findings extend previous cultural neuroscience research, which has revealed East Asian/Western cultural differences in neural underpinnings of perception, attention, memory, self-representation, empathy, etc. (Han and Northoff, 2008; Han, 2017).

Data/code availability statement

Behavioral and imaging data that support the findings of this study are available at osf (https://osf.io/zp6kv/). The code used to analyze the data are available at github.com (https://github.com/Tianyugao526/CultureDifference_ChineseDanish_Belive).

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Further reading

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