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Original Article

Biasing the neurocognitive processing of videos with the presence of a real cultural other

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Abstract

In the digital age, while short videos present vital events with powerful information, the presence of cultural cues may bias our processing of videos of foreign cultures. However, the underlying neurocognitive processes remain unclear. In this study, we hypothesized that cultural cues might bias video processing by either enhancing cultural perspective-taking or shifting cultural self-schema. To test these hypotheses, we used a novel paradigm in which the cultural cue was a real cultural other (the priming participants) who watched American/Chinese videos together with the primed participants. The results showed that when the cue was present, the right temporoparietal junction (rTPJ) response to videos with other cultural content was shifted, showing a priming effect. Moreover, the activity pattern in the rTPJ was more congruent with the primed culture than with the original culture, reflecting a neural biasing effect. Finally, intersubject representational similarity analysis indicated that the neural biasing effect in the rTPJ was more closely associated with cultural perspective-taking than with cultural self-schema. In summary, these findings support the perspective-taking hypothesis, suggesting that cultural cues can significantly bias our cultural mindset by altering cultural perspective-taking when we are exposed to culture-relevant naturalistic stimuli.

Key words: cultural neuroscience; naturalistic video; fNIRS; intersubject-correlation; perspective-taking.

Introduction

People in the digital age are often exposed to rich media stimuli from various cultures. One type of the most powerful stimuli is short videos that present vital and live events from around the world (Basch et al. 2020; Su et al. 2021). Such stimuli usually contain rich multimodal and dynamic information that represents our daily lived experience, and thus, are termed naturalistic stimuli (Bacha-Trams et al. 2018; Sonkusare et al. 2019; Finn et al. 2020). However, few studies have been conducted on the neurocognitive processing of such culturally relevant naturalistic stimuli, particularly videos.

Previously, 3 lines of research have mainly been conducted on the neurocognitive processing of culturally relevant stimuli. The first line of research focuses on the relationship between the cultural background of an individual and the cultural content of the stimuli (Hedden et al. 2008; Freeman et al. 2009; Adams et al. 2010). For example, there is evidence indicating that Westerners are more sensitive to the local features of an object, whereas East Asians are more sensitive to the global features of an object (Nisbett et al. 2001). When Westerners are asked to focus on the local features, and the East Asians are asked to focus on the global features of an object, the activation of their frontoparietal network will decrease, suggesting less involvement of attentional control. However, if attended features were reversed, i.e. the Westerners focus on global features, whereas the East Asians focus on local features, the activation of the frontoparietal network will increase, suggesting greater involvement of attentional control (Hedden et al. 2008). These findings suggest that the congruency of an individual's cultural background with the cultural feature of a stimulus may facilitate neurocognitive processing. The second line of research focuses on the priming effect of cultural cues, such as an image of the Great Wall or White House, on the processing of stimuli (Hong et al. 2000; Oyserman 2017). For example, evidence has indicated that when Westerners were primed with an East Asian-style cue, their involvement of attention to the global feature of an object was decreased, showing lower amplitude in the early attention-related P1 component of the electroencephalography signals (Lin et al. 2008). This finding suggests that a cue can shift an individual's neurocognitive process from a pattern that is more congruent with their original cultural background to a pattern that is more congruent with the cultural content of cues, showing a neurocognitive biasing effect (Oyserman 2017).

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The 2 aforementioned lines of research have both used strictly controlled stimuli as the target of processing and/or cues, which has limited their ecological validity. To conquer this limitation, a third line of research is expected to employ naturalistic stimuli as cues and the target of processing. Previously, studies have employed the presence of a imaged cultural other as a cue (Briley et al. 2005; Li et al. 2013; Zhang et al. 2013), showing that the presence of the imaged others facilitates picture naming in the language network when the cultural background of the imaged others is congruent with the naming language, suggesting an effective integration when the cultural background of cues and the language used are congruent. No studies, however, have tested the biasing effect when both cues and the target of processing are naturalistic stimuli. The present study aimed to specifically test whether the presence of a real cultural other would prime the neurocognitive processing of videos and produce a neurocognitive biasing effect. For this purpose, we used a new type of cultural cue termed "the presence of a real cultural other," which meant that the cue was a real person from the primed culture who was presented alongside the primed participant during the experiment. Although previous studies have shown that the presence of others influences an individual's cognitive processing even when they are unaware of them (Rueschemeyer et al. 2014; Kampis and Southgate 2020), and to the best of our knowledge, no studies have used the presence of a real cultural other as a cultural cue.

Here, we propose 2 rival hypotheses concerning the underlying neurocognitive mechanisms. First, previous studies have suggested that individuals with different cultural backgrounds have different self-schemas (also termed self-representation or self-construal) (Markus and Kitayama 1991; Kitayama et al. 2009). When primed with a cue from a different culture, individuals' self-schema would be shifted to a mode that is more similar to the primed culture than its original culture (Oyserman and Lee 2008; Cheng et al. 2014). Therefore, we first hypothesize that cultural cues would shift an individual's culturally relevant self-schema to a pattern that is more congruent with the culturally relevant videos (i.e. self-schema hypothesis). Second, there is also evidence showing that cultural cues could shift an individual's perspective to be more congruent with the primed cultures (Luk et al. 2012; Wolgast and Oyserman 2020), and an individual would benefit through better understanding of the mental states of foreign others (Lee et al. 2013; Mor et al. 2013). Thus, the rival hypothesis is that, rather than shifting the cultural self-schema, cultural cues would enhance an individuals' cultural perspective-taking process, allowing them to better shift their perspective to other agents of the primed culture (i.e. cultural perspective-taking hypothesis).

At the neural level, previous studies have shown that the medial prefrontal cortex (mPFC) and right temporoparietal junction (rTPJ) are closely associated with the processing of naturalistic stimuli, such as videos (Yeshurun et al. 2021), and are key hubs of the mentalizing system (Van Overwalle and Baetens 2009; Schurz et al. 2014). Moreover, recent studies have emphasized the importance of and provided evidence for the dissociation of the functions of these 2 brain regions (Van Overwalle 2009; Koster-Hale et al. 2013; Schaafsma et al. 2015). Specifically, evidence has indicated that the mPFC is more closely associated with inferring others' mental states based on self-schema (Mitchell et al. 2006; Mitchell 2009; Tamir and Mitchell 2010). Thus, the mPFC's process of mental state inference is more efficient and accurate if an individual's self-schema is similar to that of the other (Kang et al. 2013; Chavez and Wagner 2020). On the other hand, the rTPJ is found to be more closely associated with perspective-taking (Frith and Frith 2006; Adolphs 2009; Martin et al. 2020). For example, Mano et al. (2009) asked participants to infer the mental state of a character in a short story. Although both the mPFC and rTPJ were activated, only the rTPJ showed stronger activity when the character did not have shared information with the participants (high perspective-taking demands) than when the character had shared information (low perspective-taking demands). Brain stimulation studies additionally showed that stimulating the mPFC modulates the integration of external information with self-schema but would not modulate the perspective-taking process (Martin et al. 2017, 2019). By contrast, stimulating the rTPJ would facilitate the perspective-taking process but not the self-schema-related process (Gooding-Williams et al. 2017; Martin et al. 2020).

Therefore, we specifically predicted that the presence of a real cultural other would prime the neurocognitive processing of short videos, confirming the priming effect of cultural cues. Moreover, according to the 2 rival hypotheses proposed above, we further predicted that the presence of a real cultural other would shift the rTPJ's or mPFC's activity pattern from a mode of their own culture to that of the primed culture when processing videos, resulting in the neurocognitive biasing effect. The shift in brain activity would be associated with either the cultural perspective-taking process (cultural perspective-taking hypothesis) or the cultural self-schema (self-schema hypothesis).

Materials and methods

Participants

Thirty-one US adults (11 females) were recruited as US culture priming participants and were paired with 31 Chinese (CN) adults (11 females) as primed participants, resulting in 31 intercultural dyads for the US-primed group. Additionally, 35 CN adults (18 females) were recruited as CN culture priming participants and were paired with 35 CN adults (18 females), resulting in 35 intracultural dyads for the CN-primed group. All dyads were same-sex undergraduates or postgraduates (mean of educational years = 15.77, standard deviation

Table 1. Demographic information.

	Participants		Cultural cues	
	US-primed	CN-primed	US-priming	CN-priming
Age (year)	23 (2.99)	22 (2.94)	21 (1.42)	22 (2.38)
Foreign language proficiency scores	4.15 (0.75)	4.34 (0.88)	4.17 (1.00)	4.43 (0.89)
Length of time abroad (month)	0.65 (2.20)	0.54 (1.95)	3.54 (4.17)	0.48 (1.33)
SCS scores (IND—INT)	0.071 (0.838)	−0.107 (0.754)	0.217 (0.855)	−0.124 (0.838)
Perspective-taking scores	3.530 (0.595)	3.633 (0.460)	3.700 (0.614)	3.567 (0.618)

Notes: Means and SDs (in parentheses) are provided. IND indicates the scores on the independence subscale of SCS. INT indicates the scores on the interdependence subscale of SCS.

[SD] = 2.25). The 2 participants of each dyad were not acquainted with each other. All participants were right-handed and had a normal or corrected-to-normal version. All Chinese participants were native Chinese speakers and were proficient in speaking English, and all US participants were native English speakers and were proficient in speaking Chinese, according to the results of the Language History Questionnaire self-assessment (Li et al. 2006). No participants had language, neurological, or psychiatric disorders. For all participants, the accumulated length of time abroad (in the US or CN) ranged from 0 to 18 months. This criterion was selected because previous cultural studies have shown that people will show adaptive changes to the foreign culture when staying abroad for >18 months (Black and Mendenhall 1991; Ward et al. 1998). The length of time abroad did not differ between the primed participants of the US- and CN-primed groups ($t(64) = 0.875$, $P = 0.385$) but did differ between the priming participants, with significantly longer length for the US-priming participants than the CN-priming participants ($t(64) = 3.49$, $P < 0.001$). Thus, in the following statistical analyses, the length of time abroad in the priming participant was controlled as a covariate variable. The demographic information for the participants is provided in Table 1.

The study protocol was approved by the Institutional Review Board of the State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University. All participants provided written informed consent.

Video stimuli

Two 330-s video clips were edited based on the documentary film "2 Million Minutes" to depict typical lives in CN or US high schools. The language of the US video was English, whereas that of the CN video was Mandarin. Both videos had Chinese subtitles to aid the participants' comprehension. The 2 video clips were taken from the same film and were matched in emotional valence and arousal, engagement, comprehensibility, the temporal structure of scenes, and the semantic structure (see the Supplementary Material and Table S1). Two 15-s-long culturally irrelevant videos were inserted at the beginning and end of the experimental video clips to remove transient responses. Data collected during the 15-s intervals were discarded during subsequent analyses. The order of the 2 clips was counterbalanced across dyads.

Task and procedure

The experiment was divided into 2 phases: a 20-min communication phase and a 6.5-min video-watching phase (Fig. 1a). During the communication phase, each dyad engaged in four rounds of 5-minute communication, with two rounds in Mandarin and two rounds in English (Fig. 1a). The communication topics were selected to have cultural differences between CN and US participants, and thus, were expected to facilitate communication between the priming and the primed participants (see Supplementary Material and Table S2). The topics for each round of communication were randomly assigned before the experiment. The order of language in each round was counterbalanced. At the end of the communication phase, the participant was instructed to evaluate the subjective feeling of the communication experience (see Supplementary Material and Table S3).

During the second phase, dyads were asked to watch video clips on an LCD monitor immediately following the behavioral evaluation of the subjective feelings of the communication experience. The priming and primed participants in each dyad sat in a room face to face but watched the video clips independently (Fig. 1a). Additionally, a board was used to separate the 2 participants (Fig. 1b), and no verbal or nonverbal communication was allowed during the video-watching task. After watching the video, both the priming and primed participants completed Singelis's (1994) Self-Construal Scale (SCS) and Davis's (1983) Perspective Taking Scale. Moreover, in previous studies, most cultural cues were only presented at the beginning of tasks, with a potential limitation that the priming effect could decrease as the experiment progresses. Thus, in the present study, the cultural cues (the priming participants) were presented alongside the primed participants throughout the experiment. Hemodynamic concentration changes in each dyad were measured using a functional near-infrared spectroscopy (fNIRS) system during both the communication and video-watching phases. The fNIRS data collected during the communication phase were not of interest here, and thus, are not reported.

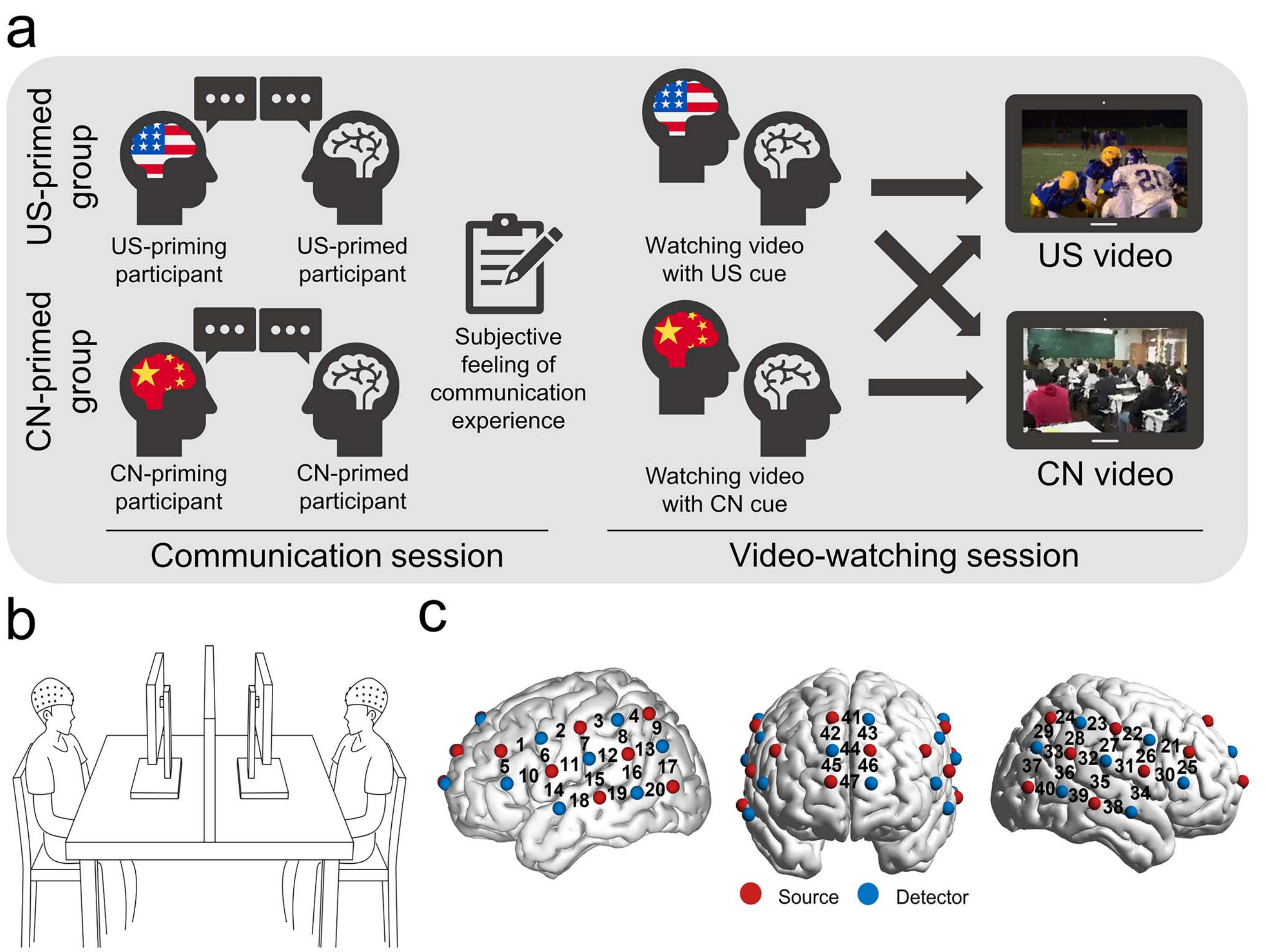

Fig. 1. The setup of the experiment. a) During the experiment, a primed participant communicated with a US adult (for the US-primed group) or a Chinese (CN) adult (for the CN-primed group). Then, the primed participant evaluated the subjective feeling of her or his communication with the priming participants. Immediately after the communication session, both the primed and priming participant watched a CN video and a US video together. b) The experimental setup during the video-watching session. c) The optode probe set was placed on the bilateral frontal, temporal, and parietal cortices. CH18, CH38, and CH47 were placed on T7, T8, and Fpz, respectively, according to the international 10–20 system.

For each dyad in the CN-primed group, all participants were Chinese. Thus, assigning one as the priming participant and another as the primed participants is arbitrary. We assumed that if 2 samples were randomly selected from all Chinese people, the difference between these 2 samples should be random and small. Thus, to choose the optimal assignment, we first generated 10,000 possibilities of role assignments in the CN-primed group (the number of all possible assignments was 2^35), and participants in each dyad were randomly assigned to the 2 groups (i.e. group A and group B). Next, for each assignment, Euclidean distance was calculated between group A and group B using the demographic variables (Table 1) and the subjective feelings of the communication experience. Thus, we could obtain a distribution of the 10,000 Euclidean distances. Finally, based on the distribution, a role assignment with the smallest Euclidean distance was selected. This approach can minimize group differences as much as possible.

Assessment of cultural self-schema and cultural perspective-taking

Singelis's (1994) SCS was used to assess the cultural self-schema of primed participants immediately after the video-watching phase. The SCS assesses both independent self-construal and interdependent self-construal. The interrater consistency was high (US-primed participants: independent SCS, $\alpha = 0.709$, interdependent SCS, $\alpha = 0.774$; CN-primed participants: independent SCS, $\alpha = 0.750$, interdependent SCS $\alpha = 0.662$). According to previous studies (Kitayama et al. 2014; Wang et al. 2017), interdependent SCS scores were subtracted from independent SCS scores to obtain a unidimensional index of cultural self-schema. Higher unidimensional SCS scores are associated with higher independent self-construal and vice versa for interdependent self-construal.

To measure cultural perspective-taking, participants were asked to complete Davis's (1983) Perspective

Taking Scale, a subscale of the Interpersonal Reactivity Index, immediately after the video-watching phase. The interrater consistency was high (US-primed participants $\alpha = 0.715$; CN-primed participants group $\alpha = 0.617$).

fNIRS data acquisition

In this study, fNIRS was used to simultaneously measure the brain activity from participants and cultural cues because it can balance the demands of second-person circumstances, high temporal–spatial resolution, and ecological validity. A LABNIRS system (Shimadzu Corporation, Japan) was used to collect the fNIRS data. Three customized sets of 47 measurement channels (CHs) were used to collect data from each participant (Fig. 1c). Two sets of probes were used to cover the bilateral frontal, temporal, and parietal cortices, whereas the rest were used to cover the prefrontal cortex. The anatomical location of each channel was determined by the international 10-20 system. Specifically, CH18, CH38, and CH47 were placed on T7, T8, and Fpz, respectively. The position of the probe sets was checked and was adjusted before the experiment to ensure consistency between the 2 individuals in a dyad and among dyads.

To confirm the anatomical locations of the optode probes, we obtained magnetic resonance imaging (MRI) data from 2 female and 2 male participants who wore plastic caps on which the probes' true positions had been marked using Vitamin E balls, with a high-resolution, T1-weighted, magnetization-prepared, and rapid gradient-echo sequence (time repetition = 2,530 ms; time echo = 3.30 ms; flip angle = 7°; slice thickness = 1.3 mm; in-plane resolution = 1.3×1.0 m^2; and number of interleaved sagittal slices = 128). Statistical Parametric Mapping 12 (Wellcome Department of Cognitive Neurology, London, UK) was used to normalize the MRI data to the standard Montreal Neurological Institute (MNI) coordinate space (Ashburner and Friston 2005). The MNI coordinates of probes were generated according to the Automated Anatomical Labelling template (Tzourio-Mazoyer et al. 2002) using the NIRS_SPM toolbox (Ye et al. 2009) (see Supplementary Material and Table S4). Based on this information, we were able to check the consistency between the probes' true positions and the expected anatomical positions and to adjust the probes' true positions. This procedure was repeated several times until the true positions and the expected positions reached a high level of consistency, e.g. the difference in probabilities of locating in a specific brain region were <10% between the true and the expected positions for 3 out of 4 scanned participants. In addition, these participants did not participate in the current fNIRS experiment, but they were sampled from the same population as those involved in the fNIRS experiment.

The optical density of near-infrared light (780, 805, and 830 nm) was measured at a sampling rate of 8.33 Hz. Then, changes in oxyhemoglobin (HbO), deoxyhemoglobin, and total hemoglobin concentration were calculated based on the modified Beer–Lambert law. Based on previous results, only HbO concentration changes were used in this study (Hoshi 2007).

fNIRS data analyses

Quality check on the data

To ensure high-quality fNIRS data, a running-window procedure was used to calculate the percentage of motion artifacts (Long et al. 2021). A measurement channel was labeled as bad and was excluded from the analysis if the percentage of time points with suspected motion artifacts exceeded 5% for the entire time course. A participant was excluded if >30% of the channels were labeled as bad. Based on these criteria, the mean percentage of artifacts across all channels and participants was 0.57%, and no participants were removed during this procedure.

Preprocessing

During preprocessing, data from the beginning and end of the video (15 s) were removed. Homer3 functions (Huppert et al. 2009) were used to preprocess the data. Specifically, motion artifacts were detected and corrected using the discrete wavelet transformation filter procedure (Molavi and Dumont 2012), and global physiological noises, like skin blood flow, were removed by using principal component analysis with an 80% variance threshold (Zhang et al. 2005). A band-pass filter was used to remove high- and low-frequency noises (0.01–0.5 Hz). Finally, data for each participant were z-scored over time for each video.

Individual-level analysis

The whole pipeline of data analyses is illustrated in Fig. 2. For studies using naturalistic stimuli, the traditional approach to detecting brain activity is not suitable. In such cases, a novel approach termed as intersubject correlation (ISC) has been proposed and widely applied (Hasson et al. 2004; Nastase et al. 2019). Extensive studies have indicated that the ISC can provide reliable measurements of the neural response to naturalistic stimuli (Hasson et al. 2004, 2010; Chen et al. 2017; Liu et al. 2017). Therefore, in the first step, the ISC among the primed participants was calculated during the video-watching phase to index the neural response to the video with the presence of cultural cues.

To this end, the fNIRS time course of 1 primed participant was correlated with the fNIRS time course averaged across all other primed participants using the Pearson correlation method. This procedure was conducted for all measurement channels within each individual condition. The resulting correlation coefficients were Fisher-z-transformed and were used to index the strength of the ISC.

Group-level statistics

ISC associated with the priming effect

First, to determine which brain regions showed significant brain activity during the video-watching phase, a

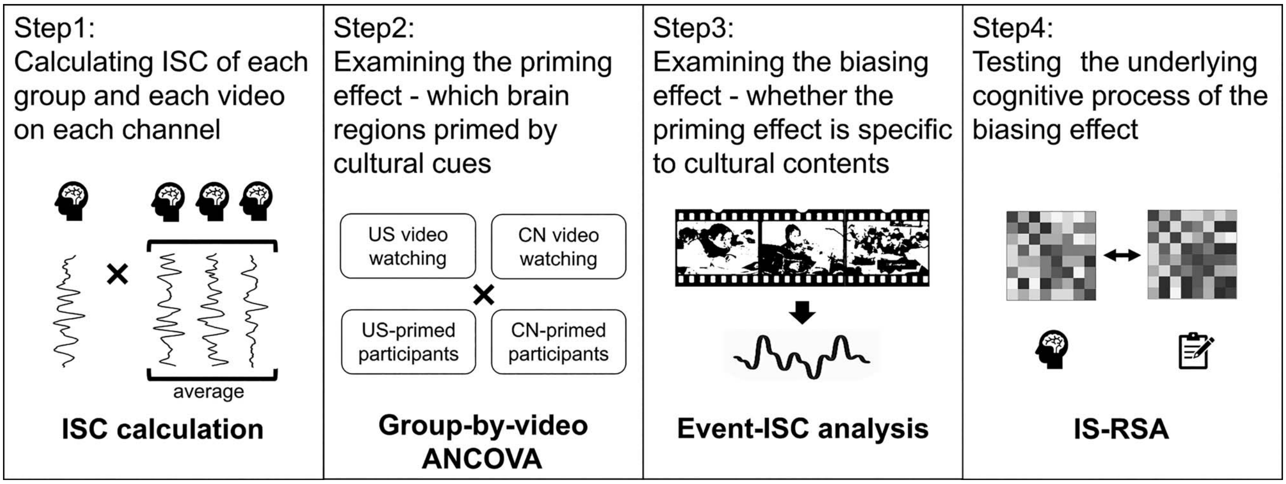

Fig. 2. The whole pipeline of data analyses.

phase-scrambled permutation test was conducted on the ISC for each condition. Specifically, the fNIRS time course of each channel was fast Fourier-transformed, phase-randomized, and invertedly fast Fourier-transformed. This procedure scrambled the phase of the fNIRS signals but left the power spectrum intact. The ISC was then recalculated based on the phase-scrambled data and was averaged within each channel across participants within each condition. This procedure was repeated for 1,000 times, creating a 1,000 ISC map (Regev et al. 2013).

Next, to correct multiple comparison issues, the largest ISC value across all channels was selected for each ISC map, and a 1,000-sample null distribution of the maximum noises of ISC values were generated and were used as the chance level. The family-wise error rate (FWER) was set at $q = 0.05$, which means that only the top 5% of the null distribution of the maximum noise correlation values exceeded the threshold. In other words, only channels with ISC values above the null distribution threshold were considered to be significant at the $P < 0.05$ level. The ISC results are provided in the supplementary materials (see Supplementary Material and Fig. S1). CHs that satisfied the statistical threshold were included in the next step of the analysis (Regev et al. 2013).

To test the priming effect, in the second step, a group (US-primed, CN-primed) × video (USA, CN) analysis of covariance (ACNOVA) was performed on the ISCs across primed participants. Moreover, the ANCOVA was repeated by replacing primed participants in the CN-primed group with their priming participants. This step was done because the roles of individuals in the CN-primed group were randomly assigned (see above). Thus, the roles of individuals (i.e. priming or primed participants) were interchangeable. All results were corrected with the FWER method based on the phase-scrambled permutation test ($P < 0.05$). Finally, CHs with the same ISC patterns and in the same brain regions were combined as regions of interest (ROIs).

ISCs associated with the neural biasing effect

In the third step, to elucidate whether the priming effect identified above reflected the biasing effect, i.e. whether the brain activity has been shifted to a pattern that preferred the primed culture, we tested whether the strength of the primed ISC was related to the degree to which the video contents were consistent with the primed culture. To this end, an event-based ISC analysis was conducted to explore the association between the observed priming effect and the cultural properties of video contents. Previously, the event-based analysis has been used to explore which features of the naturalistic stimulus drive the variance in brain activity (Hasson et al. 2004; Finn et al. 2018; Richardson et al. 2018). Thus, in this study, only when the event–ISC effect was modulated by the cultural consistency of event would it be considered as the biasing effect.

In this study, each video was segmented into 11 events by an annotator based on changes in topic, location, time, etc. Here, we measured the cultural consistency of each event from an etic perspective. Ten additional US raters (5 female, 5 males, mean age = 22.9 ± 0.8) who did not participate in the experiment were recruited from USA to rate how much the CN video events differed from the US culture. Ten additional CN raters (5 females, 5 males, mean age = 23.1 ± 0.9) were recruited from China to rate the events in the US video. To ensure all raters were unfamiliar with the other culture, 2 questions were asked before the rating: (i) " To what extent are you familiar with the Chinese/US culture?"; (ii) "How long have you been in China/USA in total?" All raters reported "Not familiar at all" and "Never been to China/USA." The raters were given sufficient time to watch each event before being asked "To what extent do you think the event shown in the video differs from American (or Chinese) culture?" on a 5-point Likert scale (1 represents the lowest level, and 5 represents the highest level). Interrater reliability was assessed using the Cronbach's alpha coefficient. The coefficients were 0.715 for the US video and 0.732 for the Chinese video, both of which were high. The mean duration of events with high (scores ≥4) and low (scores ≤2) degrees of cultural consistency were 60.24 and 61.68 s in the US video and 54.60 and 59.64 s in the CN video, respectively.

Next, the preprocessed fNIRS signals corresponding to events with high and low degrees of cultural consistency of each video and condition were extracted and were used to calculate the ISC (i.e. event-based ISC). The event-based ISC were averaged separately across events in the same category (Fig. 4a). A consistency (high consistency, low consistency) × group (US-primed, CN-primed) ANCOVA was conducted on the ISC of each ROI. This procedure was performed separately for the US and CN videos.

Associations between the neural biasing effect and cultural perspective-taking scores and cultural self-schema scores

The final step tested the underlying cognitive process involved in the potential neural biasing effect. For this purpose, associations between the neural biasing effect and scores for cultural perspective-taking or cultural self-schema were examined. According to previous studies (Nguyen et al. 2019; Chen et al. 2020; Finn et al. 2020), the intersubject representational similarity analysis (IS-RSA) can explore how the individual differences in behavioral disposition are related to the intersubject variations in brain dynamics. Compared to the traditional method, IS-RSA has the advantage of capturing as much nuance and variance in brain and behavior as possible and extending the richness of information (Finn et al. 2020). Thus, in this study, the IS-RSA was used to explore whether the individual differences in self-schema and cultural perspective-taking were associated with intersubject variations in ISC in each ROI.

Here, cultural perspective-taking was indexed by the Perspective Taking Scale score, whereas cultural self-schema was indexed by the SCS score of the primed participants in the US-primed group. The similarity matrices of cultural perspective-taking and cultural self-schema were constructed by calculating the Euclidean distance between each pair of primed participants' cultural perspective-taking scores or self-schema scores. Then, the Euclidean distance was subtracted from their maximum to generate the behavioral similarity matrix. Next, to construct the neural similarity matrix for each ROI in the US-primed group while watching the US video, the Pearson correlation between each pair of primed participants' fNIRS signals was calculated for each ROI. Finally, the Spearman correlation was calculated between the behavioral similarity and neural similarity matrices (Fig. 5a).

To assess the statistical significance, we conducted a permutation test following a previous study (Kriegeskorte et al. 2008). First, the rows and columns of the neural similarity matrix were randomly shuffled, generating a random matrix. A null Spearman correlation was calculated with the original behavioral similarity matrix and the shuffled neural matrix. This procedure was repeated for 10,000 times to generate a null distribution. Second, the original Spearman correlation value was compared with this distribution. Only correlation values that exceeded the top or bottom 2.5% of the null distribution (2-tailed) were considered to be significant, which meant that the P values were calculated as: (number of null correlations larger or smaller than the real correlation + 1) × 2/10,000.

Results

Behavioral results

There were no significant differences between the US-primed and CN-primed participants after controlling for demographic variables, as listed in Table 1, either in the unidimensional SCS scores ($t(64) = 0.90$, $P = 0.372$) or in the cultural perspective-taking scores ($t(64) = 0.79$, $P = 0.433$).

The neural priming effect of the presence of a real cultural other

The group (US-primed, CN-primed) × video (USA, CN) ACNOVA revealed significant interactions between group and video in the mPFC (CH44, CH47), rTPJ (CH23), right middle temporal cortex (rMTC, CH37), and left superior frontal cortex (lSFC, CH43) (Fig. 3a).

To validate the priming effect, the ISC was also calculated among CN-priming participants who were originally assigned as CN-primed participants. In this case, the ANOVA showed significant interactions between group and video in the rTPJ (CH23, CH33), mPFC (CH41), and left postcentral gyrus (CH2) (Fig. 3b).

To obtain reliable results, CHs that were roughly in the same anatomical locations and had statistical results that were consistent between the original and validation results were combined (Fig. 3c). This procedure revealed 2 ROIs: the mPFC (CH41, CH44, and CH47) and the rTPJ (CH23, CH33). The ISC was averaged across the CHs within each ROI. The group (US-primed, CN-primed) × video (USA, CN) ANCOVA was repeated on the ISC of these ROIs based on the original participant cohort. The results confirmed a significant interaction between group and video (rTPJ: $F(1, 63) = 5.292$, $P = 0.025$, $\eta^2_P = 0.077$; mPFC: $F(1, 63) = 12.524$, $P < 0.001$, $\eta^2_P = 0.164$; see Fig. 3d).

Further pairwise comparisons were conducted on these ROIs. As expected, when watching the US video, the ISC was significantly greater in the US-primed group than in the CN-primed group (rTPJ: $t(64) = 2.845$, $P = 0.006$; mPFC: $t(64) = 3.847$, $P < 0.001$), but there was no significant difference when watching the CN video. Additionally, in the CN-primed group, where both the primed and priming participants were Chinese, as expected, the ISC was significantly greater when participants watched the CN video than when they

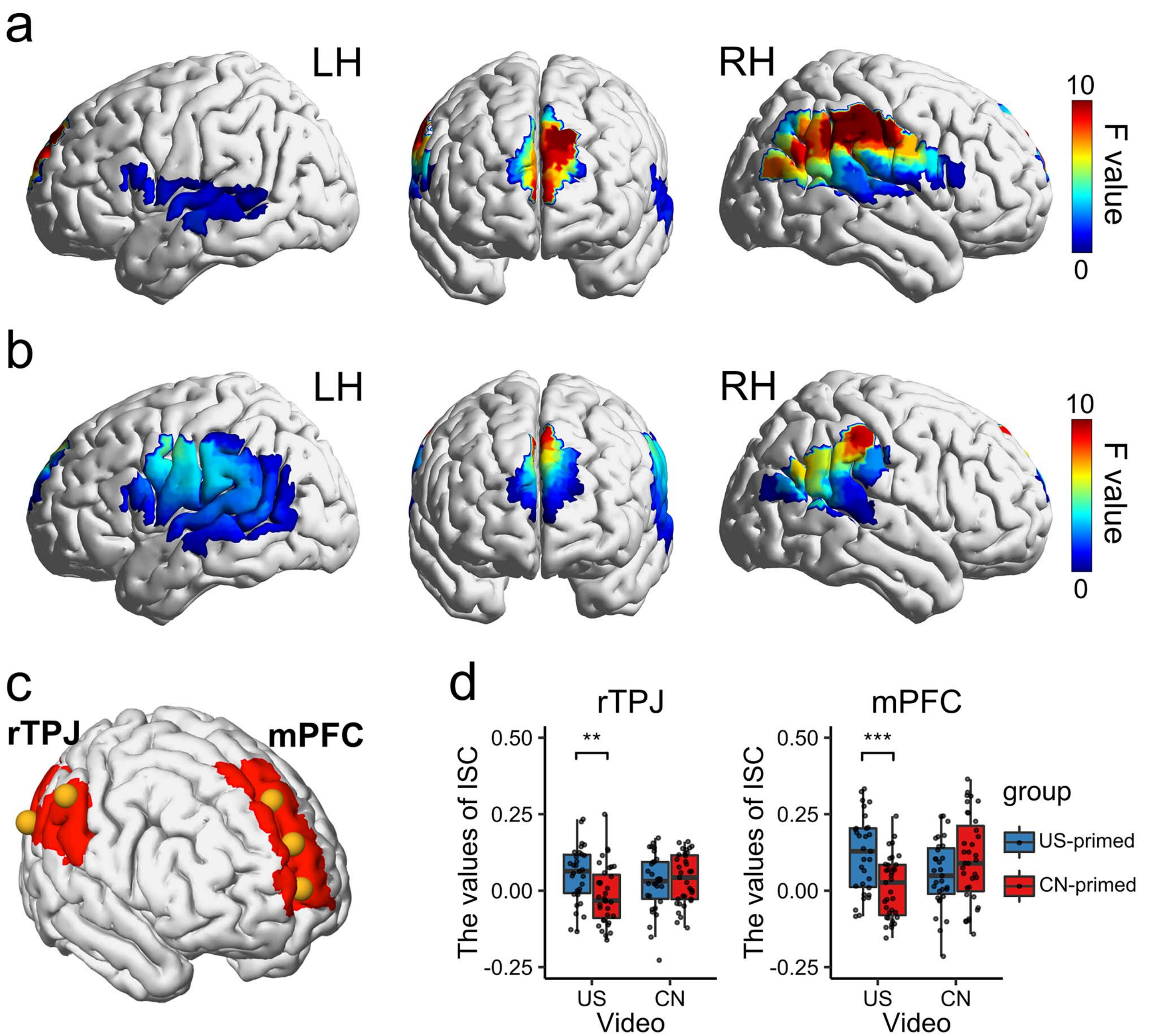

Fig. 3. The results of the group × video ANCOVA on each participant cohort. a) The F-map of the original cohort. Significant interaction effects were found in the mPFC, rTPJ, rMTC, and lSFC. b) The F-map of the validation cohort. Significant interaction effects were found in the mPFC, rTPJ, and left postcentral gyrus. LH = left hemisphere. RH = right hemisphere. c) Brain regions showing overlapping results between the original and validation cohorts. Based on this result, 2 ROIs were selected: the rTPJ and mPFC. The yellow nodes indicate the channels that covered the rTPJ and mPFC. The red areas indicate ROIs based on AAL templates. d) The results of the group × video ANCOVA in the rTPJ and mPFC. Significant effects of interaction between the group and video were found in both ROIs.

watched the US video (rTPJ: $t(34) = 2.355$, $P = 0.024$; mPFC: $t(34) = 2.910$ $P = 0.006$). In the US-primed group where the US cultural cues were present, the ISC was significantly greater when watching the US video than when watching the CN video in the mPFC ($t(30) = 2.111$, $P = 0.043$) but not in the rTPJ ($t(30) = 1.006$, $P = 0.323$). Taken together, these results indicate that the rTPJ and mPFC are both primed by the presence of cultural cues. Hereafter, all subsequent statistical analyses were conducted on the ROI-based ISC and the original participant cohort.

Only the priming effect in the rTPJ reflected the neural biasing effect

When looking at the neural biasing effect, the results showed that, for the US video, a significant interaction was found between cultural consistency and group in the rTPJ ($F(1, 63) = 4.946$, $P = 0.030$, $\eta^2{}_P = 0.073$, Fig. 4b), with a significantly greater ISC in the US-primed group than in the CN-primed group when watching video events with a high degree of cultural consistency ($t(64) = 2.145$, $P = 0.036$), but no significant differences were found when watching video events with a low degree of cultural consistency ($t(64) = 0.972$, $P = 0.335$). No significant main effects were found for cultural consistency or group nor were there any significant effects in the mPFC (Ps > 0.05).

For the CN video, there was a significant main effect of cultural consistency in the rTPJ, with a significantly greater ISC for a high degree of consistency than for a low degree of consistency ($F(1,63) = 4.212$, $P = 0.044$,

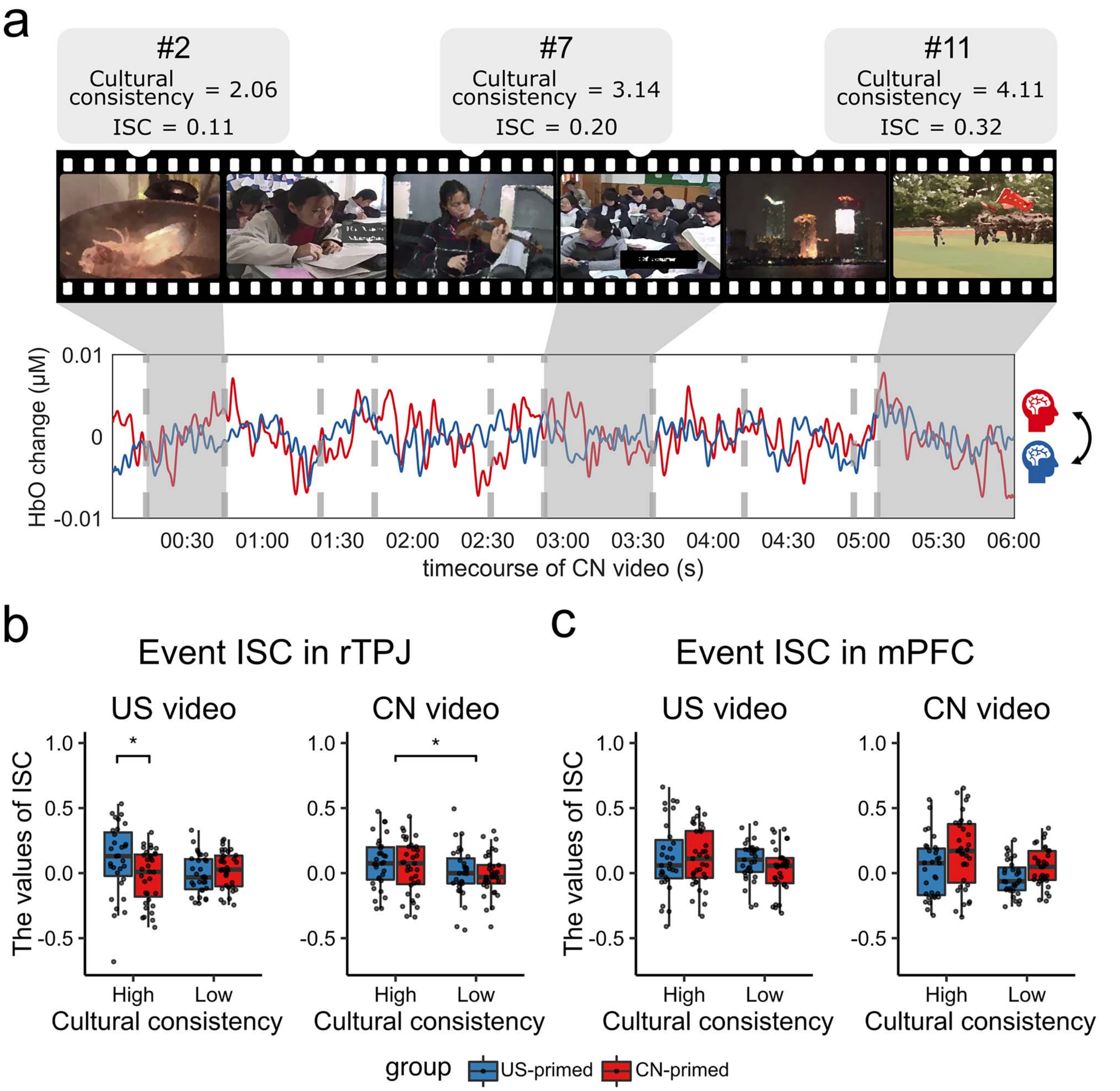

Fig. 4. Event-based analysis and results. a) An illustration of the event-based ISC analysis procedure. The US and CN videos were segmented into 11 events (separated by the gray dashed lines). For each event, the cultural consistency was rated. Then, the time course of the fNIRS signal corresponding to events with high and low degrees of cultural consistency was extracted and the event-based ISC was calculated. b) The group × cultural consistency ANCOVA results in the rTPJ. A significant interaction effect was found in the rTPJ for the US video. c) The group × cultural consistency ANCOVA results in the mPFC. No significant interaction effect was found in the mPFC.

$\eta^2_P = 0.063$, Fig. 4b). However, there was no significant group main effect or interaction effect between group and cultural consistency in the rTPJ. In the mPFC, a significant main effect was found only for group, with a greater ISC in the CN-primed group than in the US-primed group ($F(1,63) = 8.851$, $P = 0.004$, $\eta^2_P = 0.123$, Fig. 4c). There were no other significant effects found for the mPFC. Taken together, these findings suggest that the priming effect in the rTPJ reflects the neural biasing effect, which shifted video processing from a pattern of the individual's original culture (CN) to that of the primed culture (USA). However, the priming effect in the mPFC is unlikely to be associated with the neural biasing effect.

Finally, the neural biasing effect was further confirmed by the cultural typicality of cues and subjective feeling of the prior communication experiences with cues (see Supplementary Material and Fig. S2).

The neural biasing effect in the rTPJ was associated with cultural perspective-taking rather than cultural self-schema

To further test the cognitive processes underlying the neural biasing effect, IS-RSAs were conducted. The

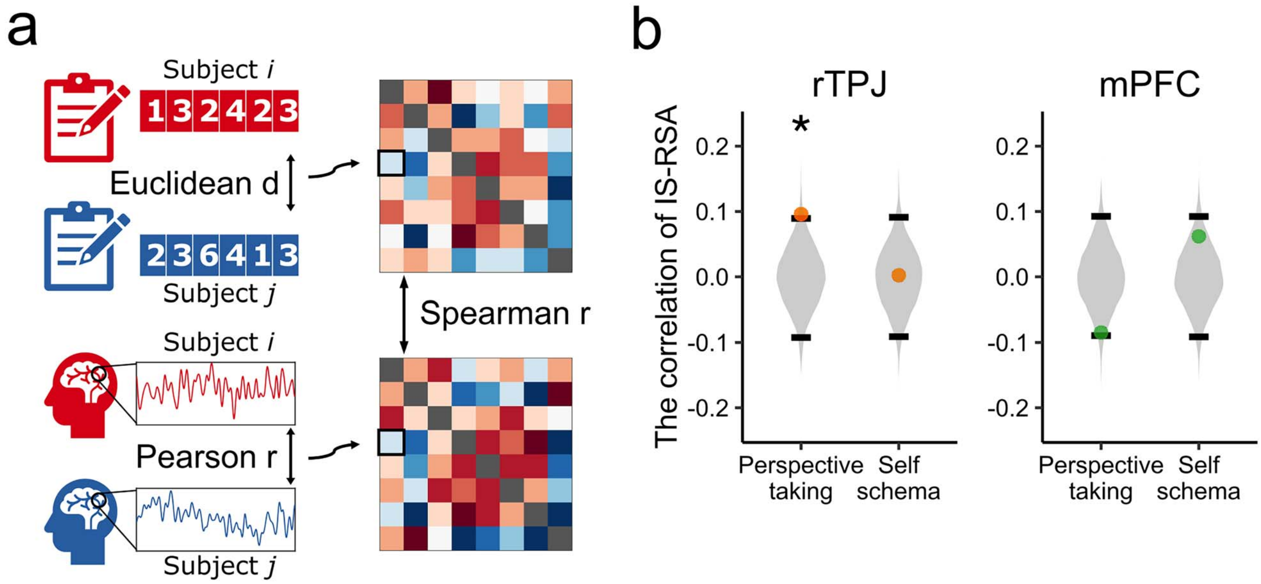

Fig. 5. The results of IS-RSA. a) An illustration of the IS-RSA procedure. The neural similarity matrix was constructed by calculating the Pearson correlation between the fNIRS signals of pairs of participants. The behavioral similarity matrix was constructed by calculating the Euclidean distance between the perspective-taking or self-schema scores of pairs of participants. The spearman correlation was used to calculate the correlation between the neural similarity matrix and the behavioral similarity matrix. b) The left panel shows the results of the IS-RSA in the rTPJ. The perspective-taking similarity matrix was significantly correlated with the neural similarity matrix in the rTPJ. The right panel shows the results of the IS-RSA in the mPFC. No significant correlations were found. The gray violin shapes indicate null distributions. Horizontal bars indicate the 1-sided, 2.5% positions.

results showed that the neural similarity matrix of the rTPJ positively correlated with the behavioral similarity matrix of cultural perspective-taking (Spearman $r = 0.096$, $P = 0.038$) but slightly negatively correlated with self-schema (Spearman $r = -0.002$, $P = 0.959$), whereas the mPFC positively correlated with self-schema (Spearman $r = 0.619$, $P = 0.07$) but negatively correlated with perspective-taking (Spearman $r = -0.848$, $P = 0.068$) (Fig. 5b). As only the rTPJ showed a culture-related neural biasing effect, these correlation patterns suggest that the association between the rTPJ and perspective-taking reflects the neurocognitive biasing effect, whereas the association between the mPFC and self-schema does not.

Discussion

To better understand the digital age and to adapt to a globalized society, it is important to understand the underlying neurocognitive mechanisms involved in the way we process culturally relevant naturalistic stimuli that occur in our daily lives. For this purpose, the current study examined the processing of short videos when a real cultural other was present. The results showed that when a real cultural other was present, the rTPJ's response to videos from other cultures changed to a pattern that was more congruent with the primed culture than the original culture, indicating the neural biasing effect. This result not only confirms previous findings based on strictly controlled stimuli (Chiao et al. 2010; Wang et al. 2013; Knyazev et al. 2018; Salvador et al. 2020) but also extends previous findings to naturalistic stimuli.

First, based on previous perspectives and findings, we proposed 2 hypotheses of the underlying neurocognitive mechanism of the potential biasing effect in processing videos from foreign cultures. The cultural self-schema hypothesis proposed that an individual's cultural self-schema would be shifted from the original culture to the primed culture. The cultural perspective-taking hypothesis proposed that, rather than shifting an individual's cultural self-schema, only the process of cultural perspective-taking was enhanced to better infer the hidden mental states of individuals in the primed culture. Our results supported the second hypothesis, showing neural biasing effects in the rTPJ but not in the mPFC. Most importantly, the IS-RSA results showed that the neural biasing effect in the rTPJ was more closely associated with cultural perspective-taking than with cultural self-schema.

Previous studies have shown that the rTPJ is a core hub region of the perspective-taking system (Frith and Frith 2006; Adolphs 2009; Martin et al. 2020). For instance, Mano et al. (2009) found a close relationship between the rTPJ and narrative processing, which required more perspective-taking processes than the other brain regions. Moreover, when compared to strictly controlled stimuli, naturalistic stimuli contain temporally highly dynamic features, such as dynamic changes in individuals' mental states and intentions. Similarly, previous evidence suggests that the rTPJ is more involved in the temporal social inference, such as goals, intentions, and desires, than in the other brain regions, such as the mPFC, which is more closely associated with the processing of static features such as traits and dispositions (Van Overwalle 2009). Moreover, previous findings have also suggested that the rTPJ is more sensitive to information in short time intervals ranging from seconds to minutes, whereas the mPFC is more sensitive to information on longer timescales (Wagner et al. 2015; Baldassano et al. 2018). Consistent with these findings, our results also showed the biasing effect in the rTPJ for segmented culturally relevant events lasting approximately for 1 minute. Together, our results suggest that when processing naturalistic stimuli with temporally highly dynamic features, the presence of cultural others can significantly enhance an individual's perspective-taking process and enable individuals to better infer the hidden mental states of other individuals from other cultures.

Additionally, previous researchers have speculated on the potential role of cultural perspective-taking in crosscultural and intercultural processing, such as crosscultural differences in perspective-taking (Wu and Keysar 2007; Wu et al. 2013; Chopik et al. 2017), cultural perspective-taking in intercultural situations (Lee et al. 2013; Mor et al. 2013), and the effect of cultural priming on perspective-taking (Luk et al. 2012; Wolgast and Oyserman 2020). However, to the best of our knowledge, no empirical neural evidence has been provided to support these claims. Thus, the present results provide preliminary empirical evidence for the specific role of the rTPJ-related perspective-taking process in the processing of culturally relevant naturalistic stimuli.

Second, considering the fact that most cultural experiences are shaped by live person-to-person interactions in social contexts (Tomasello et al. 1993). Here, a new paradigm was proposed in which a novel type of cultural cue, namely, the presence of a real cultural other, was proposed. Previous evidence has shown that even when no interaction occurs, the mere presence of others has an effect on people's individual cognitive processing, such as perception (Conson et al. 2012), decision (Guterstam et al. 2019), memory (Shteynberg 2010), and even language (Rueschemeyer et al. 2014). For example, in an ERP study (Jouravlev et al. 2019), participants were asked to read some implausible sentences (such as "The girl had a little beak") alone. Contextual information was provided that made these sentences seem plausible. In this situation, participants did not have any comprehension issues (i.e. no N400 effect). However, when a person who did not receive the contextual information was present, participants had comprehension difficulties (i.e. N400 effect), even when they were instructed not to notice the other person. This finding suggests that the presence of others may have shifted the perspectives of participants away from themselves and toward others. Researchers have summarized these findings in that unconscious influence by others is a kind nature of human cognition, which can be termed "Altercentrism" and can facilitate interpersonal communication, group dynamics, and cumulative culture (Kampis and Southgate 2020). The present findings support such an "Altercentrism" perspective and extend it to the field of cultural processing, providing a new perspective for studying the neurocognitive role of cultural cues.

Third, we also explored the neurocognitive biasing effect from a continuous perspective along the levels of typicality of cultural cues. According to culture-as-situated cognition theory, cultural mindsets are associated with cultural representations and computation networks, and the probability that the cultural mindset is primed is largely determined by how typical the cue is relative to such a network (Mourey et al. 2015; Oyserman 2017). However, most previous cultural priming studies did not directly test the neural biasing effect of cultural cues from this perspective. The present findings provide the initial neural evidence for this perspective. Moreover, prior experiences with cues were found to modulate the relationship between cues' cultural typicality and the biasing effect. Previous research on interpersonal communication has indicated that individuals' attention perspectives, representations, and internal interpretation frames synchronize over time (Pickering and Garrod 2004; Hasson and Frith 2016; Jiang et al. 2021) and that the synchronization of neural and mental activities during interpersonal communication significantly strengthens affiliative bonds between individuals (Zheng et al. 2020). It has been posited that the perceived typicality of a cultural cue differs from its original attribute because individuals' prior experiences with the cues may play a significant role (Alter and Kwan 2009). Our results directly support this claim by showing that the correlation between the typicality of cultural cues and the biasing effect is significant for participants with a strong subjective feeling of the prior communication experiences but not for participants with a weak subjective feeling of the prior communication experiences. Our results also suggest that the prior experiences with cultural cues should be measured when employing the "presence of a real cultural other" paradigm. Future research should compare the biasing effects when a real cultural other is present versus when simple cultural icons are used.

In this study, we only tested the cultural self-schema and cultural perspective-taking hypotheses. It should be acknowledged that it remains unclear exactly which cognitive processes were affected by the rTPJ-related perspective-taking process. There are many possibilities that could explain this issue. For example, 1 potential process is the scope of visual attention (Nisbett et al. 2001). Previous studies have found that when processing visual stimuli, the Western cultural mindset preferred a local attention style, whereas the East Asian cultural mindset preferred a global attention style. In this study, it is also possible that US cues shifted the primed participants' attention from a global style to a local style. Additionally, in this study, we did not find a significant ISC difference between the US-primed and CN-primed groups when they watched the CN video. Previously, evidence has indicated that shifting a perspective from a more other-oriented mode to a more self-oriented is easier than from reversed direction, and this process is associated with the rTPJ (Bradford et al. 2019). This interesting finding might suggest that the neurocognitive biasing effect was asymmetrical, meaning that the shift from the other-culture mode to the own-culture mode was relatively easier than vice versa. Finally, our IS-RSA results showed that the rTPJ positively correlated with cultural perspective-taking but slightly negatively correlated with self-schema, whereas the mPFC positively correlated with self-schema but negatively correlated with perspective-taking. The distinct patterns of the rTPJ and mPFC are consistent with previous reports of the distinct functions of the rTPJ and mPFC and further suggest that their functions may be complementary (Koster-Hale et al. 2017). However, the interpretation of negative correlation of IS-RSA should be cautious. These possibilities need to be further investigated in future studies.

Conclusion

In this study, we confirmed the hypothesis that the presence of real cultural others could significantly bias our cultural mindset, particularly cultural perspective-taking, when processing culturally relevant videos. It can also shift our neurocognitive process to a pattern that is more congruent with the primed culture than with our own culture. Our mindsets may be explicitly or implicitly reshaped as such experiences are accumulated in daily life. Together, these findings provide new insights into the processing of naturalistic cultural stimuli and into how cultural experiences shape our neurocognitive processes in the digital age.

Supplementary material

Supplementary material is available at *Cerebral Cortex Journal* online.

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Conflict of interest statement. The authors declare no competing financial interests.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability

All analyses were performed using MATLAB R2019b, with standard functions and toolboxes. All code is available upon request.

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