How culture gets embrained: Cultural differences in event-related potentials of social norm violations

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Humans are unique among all species in their ability to develop and enforce social norms, but there is wide variation in the strength of social norms across human societies. Despite this fundamental aspect of human nature, there has been surprisingly little research on how social norm violations are detected at the neurobiological level. Building on the emerging field of cultural neuroscience, we combine noninvasive electroencephalography (EEG) with a new social norm violation paradigm to examine the neural mechanisms underlying the detection of norm violations and how they vary across cultures. EEG recordings from Chinese and US participants (*n* = 50) showed consistent negative deflection of event-related potential around 400 ms (N400) over the central and parietal regions that served as a culture-general neural marker of detecting norm violations. The N400 at the frontal and temporal regions, however, was only observed among Chinese but not US participants, illustrating culture-specific neural substrates of the detection of norm violations. Further, the frontal N400 predicted a variety of behavioral and attitudinal measurements related to the strength of social norms that have been found at the national and state levels, including higher culture superiority and self-control but lower creativity. There were no cultural differences in the N400 induced by semantic violation, suggesting a unique cultural influence on social norm violation detection. In all, these findings provided the first evidence, to our knowledge, for the neurobiological foundations of social norm violation detection and its variation across cultures.

culture | social norms | N400 | electroencephalography | EEG

Humans are unique among all species in their ability to develop, maintain, and enforce social norms. It is therefore highly possible that humans have evolved complex neural mechanisms for detecting norm violations quickly to punish violators to enforce the social order. Moreover, although the enforcement of social norms is universal, there is wide variation in the strength of social norms across human groups. Some groups, particularly those that have experienced a high degree of ecological and historical threat, develop stronger norms and punishments of norm violators to coordinate social action (1, 2), and such human adaptations have an evolutionary basis for group survival (3).

Despite the fundamental aspect of human nature, there has been surprisingly little research on how social norm violations are detected at the neurobiological level. To be sure, there is a large amount of literature on how the human brain reacts to semantic violations (e.g., "I like my coffee with cream and dog") (4). Extant EEG research has revealed a notable negative-going deflection with peak around 400-ms poststimulus onset (the component called N400) when detecting unexpected linguistic stimuli across a variety of semantic tasks (5–8). Moreover, N400 effects are not confined to linguistic processing. Seminal research in social neuroscience has shown that the N400 component is observed in a variety of social tasks, including spontaneous trait inferences (9, 10), detection of stereotype incongruities (11), and processing of affective inconsistencies (12). Taken together, the N400 serves as a potent neural index of the detection of unexpected anomalous stimuli and affective and social incongruent information. Here we examine for the first time whether and how the N400 is engaged in social norm violation detection and whether it is distinct from the detection of semantic violations.

Although the existence of social norms is universal across all human cultures, there are large differences around the globe in adherence to social norms and the punishment of norm violators (1). Our second aim is to investigate whether the neural basis of social norm violation detection is sensitive to cultural variation. Human groups that have had high degrees of territorial threats necessitating national defense, low natural resources (e.g., food supply), and high degrees of natural disasters (e.g., floods, cyclones, and droughts) such as China, evolve to be tight, i.e., have strong norms and less tolerance for deviant behavior, to coordinate their social action. Human groups that generally have low threat such as the United States evolve to be loose, i.e., have weaker norms and higher tolerance for deviant behavior (1–3). Thus, individuals in tight compared with loose cultures tend to adhere to social norms and are more sensitive to others' violations. We test the hypothesis that the N400 is a neural marker of norm violation detection and its amplitude in response to social norm violations will be greater in tight (e.g., Chinese) compared with loose (e.g., American) cultures. Building on the findings of cultural (East Asian vs. Western) influences on the N400 in a variety of social incongruity tasks (9, 12–14), we expect that responses to social norm violations will differ between cultures, but responses to nonsocial incongruencies, such as purely semantic

Significance

Despite the fact that social norms are a fundamental aspect of human nature, there has been little research on how social norm violations are detected at the neurobiological level. Combining a new social norm violation paradigm with cross-cultural electroencephalography, we show consistent negative deflection of event-related potential around 400 ms (N400) over the central and parietal regions for both Americans and Chinese in detecting norm violations. However, the N400 at the frontal and temporal regions was evident only among Chinese, illustrating culture-specific neural substrates underlying detecting norm violations. Moreover, the frontal N400 was associated with greater cultural superiority and self-control, as well as lower creativity. The findings shed new light on the neurobiology of the detection of social norm violations.

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violations, will not, illustrating the unique cultural influence on detecting violations of social norms and not just the detection of any incongruity at the linguistic level.

In addition to examining cultural differences in the N400 in detecting social norms violations, this study further aims to examine whether such neurobiological differences are related to cultural differences in a wide variety of attitudes and behaviors. Compared with loose cultures, individuals in tight cultures have more self-control (1), prefer standard vs. creative solutions to tasks (2, 15), place more importance on territorial defense (i.e., maintaining order in one's country), and are more ethnocentric (i.e., believe one's culture is superior to others and dislike deviants who threaten the social order) (1, 2)—human adaptations all of which invariably support and reinforce the strength of social norms. Such correlates of tightness-looseness have been found at the national and the state levels of analysis (1, 2), suggesting a trade-off of greater order, stability, and cohesion in tight groups but greater creativity and openness in loose groups. We test for the first time, to our knowledge, whether these attitudinal and behavioral correlates can be found at the neural level. We expect that N400 activity related to social norm violations will be positively correlated with concerns with territorial defense, feelings of national superiority, and self-control, but will be negatively correlated with creative performance (e.g., "thinking outside of the box"). Importantly, we expect that cultural differences in the N400 in detecting social norm violations but not semantic violations will be predictive of these attitudes and behaviors. To the extent that we can show that cultural differences on these attitudes and behaviors are systematically related to differences in neurobiological processes, we can begin to make inferences regarding the mutual constitution of culture, brain, and behavior. To our knowledge, this is the first empirical study of the neural underpinnings of social norm violation detection across cultures.

We recruited 25 subjects from China and 25 subjects from the US, which have been shown to vary in cultural tightness-looseness (1). We developed a new social norm violation task in which participants were asked to judge whether 34 behaviors (e.g., dancing) were appropriate or not in three situations, which were either strongly inappropriate (e.g., art museum), weakly

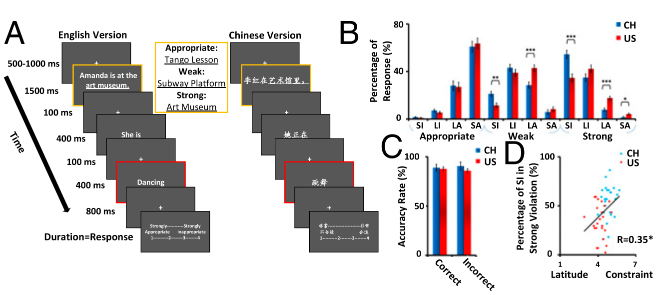

Fig. 1. The paradigm and behavior results. (*A*) The procedure of social norm violation task in which subjects were asked to judge whether certain behavior is appropriate or not in a given situation. Each behavior (e.g., dancing) was set in three situations: appropriate (e.g., tango lesson), weak (e.g., subway platform), and strong conditions (e.g., art museum). Participants were asked to judge whether the behavior was appropriate from 1 (strongly inappropriate) to 4 (strongly appropriate) by using an index and middle finger on the left and right hand on a keyboard. The rectangle with a red frame is the crucial word (e.g., dancing) for generating ERP components. (*B*) The mean values of percentages of the four responses (Strongly Inappropriate = SI, Lightly Inappropriate = LI, Lightly Appropriate = LA, and Strongly Appropriate = SA) in the appropriate/weak/strong condition in the social norm violation task. (*C*) The mean values of accuracy rates of correct and incorrect condition in semantic task. (*D*) The correlation between the percentages of strongly inappropriate and the subjective reports on latitude vs. constraint in daily life scale (higher scores indicate greater constraint).

inappropriate (e.g., subway platform), or appropriate (e.g., tango lesson) while participants' EEG signals were recorded (Fig. 1*A*; see Table S1 for additional examples of the social norm violation task). The appropriate condition was our control condition, as we were interested in comparing neural reactions to norm violation conditions compared with appropriate condition. We focus primarily on the neural difference between the strong violation and appropriate condition given that we expect the strongest N400 effects for this contrast. We also test the weak violation condition to explore whether it would also generate the N400 effects, albeit weaker effects were expected compared with strong violations. To test whether the neural indices are associated with various attitudinal and behavior measurements, participants were also asked about tightness-looseness experienced in their daily lives, concern with territorial defense, beliefs about cultural superiority, and self-control. We also assessed participants' creative performance using the Alternative Uses Task (16). Finally, to examine whether social norm violations are distinct from nonsocial violations (e.g., semantic violation), we included an established semantic violation task (17) in which individuals were randomly presented with 40 correct subject-verb-object segmented sentences (e.g., semantic correct, "Sophia returned bicycle and key" for Americans; "张静/归还了/自行车/和/钥匙" for Chinese) and 40 incorrect subject-verb-object segmented sentences (e.g., semantic violation, "Sophia answered bicycle and key" for Americans; "张静/回答了/自行车/和/钥匙" for Chinese) and were asked to judge whether each sentence was right or wrong. The English and Chinese semantic stimuli were identical in grammatical structure (Fig. S1*A*; see Table S2 for additional examples of the semantic violation task).

Results

Behavioral Results. As Fig. 1*B* illustrates, Chinese compared with Americans identified more behaviors as strongly inappropriate and fewer behaviors as lightly appropriate in both the strong and the weak social norm violation conditions (Fig. 1*B* and Table S3). However, no cultural differences were found in the appropriate condition (all $P > 0.05$; Table S3), illustrating it is a good control condition. With respect to the semantic violation task, the 2 (culture: United States, China) × 2 (violation: correct, incorrect) repeated-measures ANOVA did not show significant effects of culture and violation on accuracy (all $P > 0.05$; Fig. 1*C* and Table S4). With respect to the attitudinal and behavioral measures, as expected, Chinese reported more constraint in their daily lives, stronger beliefs in the importance of territorial defense, more cultural superiority, and less creativity (all $P < 0.05$; Table S5). Although there was no significant difference in self-control, it was in the expected direction. Finally, people who perceived more constraints in their daily lives reported higher percentages of strong inappropriateness in the strong and weak violation conditions (Fig. 1*D* and Table S3).

Event-Related Potential (ERP) Results. As discussed below, there was a prominent negativity around 400 ms poststimulus (N400) in both the strong and weak violation conditions relative to the appropriate condition for widespread regions for both Chinese and Americans. Moreover, whereas both Chinese and Americans showed evidence of the N400 effects at the central and parietal regions, only Chinese exhibited N400 effects at the frontal and temporal regions. To assess the N400 component, the 200- to 600-ms poststimulus-onset window was chosen on the basis of visual inspection of waveforms, as the N400 is typically observed in this time window (4). Previous studies analyzed the N400 effects in the similar time range using sentence-comprehension paradigms that were similar to the current procedure (18–20). Additional statistical analyses on consecutive 50-ms time windows replicated the N400 results (*Materials and Methods*).

Culture-general N400 effects. Fig. 2*A* provides waveforms for each condition at the central and parietal regions. Two (culture:

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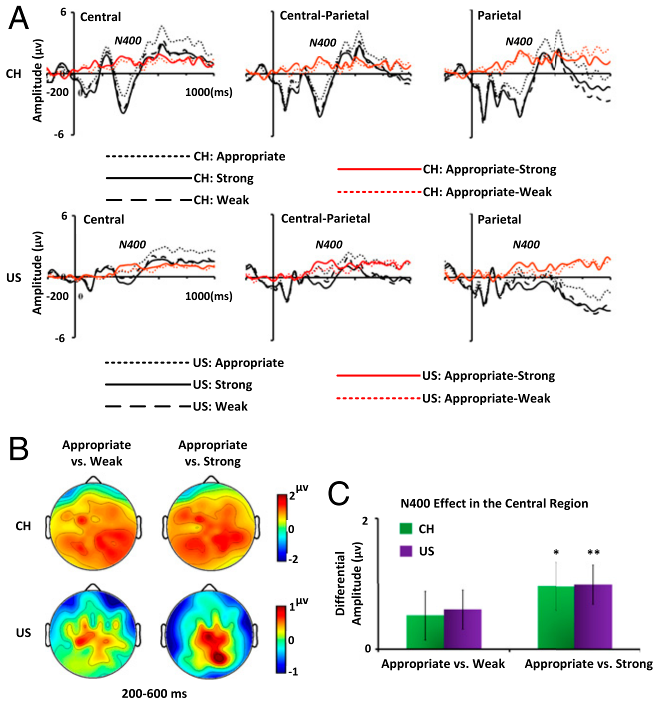

Fig. 2. Culture-general N400 effects of social norm violations. (*A*) Grand average ERPs for the strong, weak, and appropriate conditions and differential ERPs for the contrasts between appropriate and strong/weak conditions at the central/centro-parietal/parietal region. (*B*) The topographies show the distribution of the N400 effect (appropriate vs. strong/weak condition) at 200–600 ms for Chinese (CH) and the United States (US) groups, respectively. (*C*) The bar chart shows the N400 effect (appropriate vs. strong/weak condition) at 200–600 ms in the central region (Cz, a representative electrode in the central region, was chosen) for Chinese and US groups, respectively.

United States, China) × 3 (violation: strong, weak, and appropriate) ANOVAs of the N400 effect showed the strong and weak violation conditions elicited a greater N400 over the central and parietal regions relative to the appropriate condition [central: $F(2,96) = 7.87$, $P < 0.001$; parietal: $F(2,96) = 8.57$, $P < 0.001$]. Separate 2 (culture: United States, China) × 2 (violation: strong/weak, appropriate) ANOVAs further confirmed the greater N400 at the central and parietal regions was respectively observed in the strong [central: $F(1,48) = 17.01$, $P < 0.0002$; parietal: $F(1,48) = 16.21$, $P < 0.0002$; Fig. 2*B*] and weak violation conditions [central: $F(1,48) = 5.49$, $P < 0.05$; parietal: $F(1,48) = 9.31$, $P < 0.005$; Fig. 2*B*], relative to the appropriate condition. Post hoc analyses showed the significant central and parietal N400 effects (appropriate vs. strong) among both Chinese [central: $F(1,24) = 6.79$, $P < 0.02$; parietal: $F(1,24) = 6.69$, $P < 0.02$] and US subjects [central: $F(1,24) = 11.16$, $P < 0.005$; parietal: $F(1,24) = 15.55$, $P < 0.001$; Fig. 2*C*]. Similar but weaker N400 effect of the weak violation (vs. appropriate condition) was shown by separate post hoc analyses for each group [Chinese: $F(1,24) = 1.96$, $P = 0.17$; United States: $F(1,24) = 3.95$, $P = 0.06$ for central region; Chinese: $F(1,24) = 7.61$, $P < 0.02$; United States: $F(1,24) = 2.18$, $P = 0.15$ for parietal region]. No culture × violation interaction was found for the central and parietal regions [central: $F(2,96) = 0.01$, $P = 0.99$; parietal: $F(2,96) = 0.65$, $P = 0.52$], suggesting the generality of the N400 component at the central and parietal regions in the detection of social norm violations across cultures. Although N400 was stronger in the strong violation condition than in the weak violation condition, the difference between the two violation conditions was not statistically significant (*SI Results*).

Culture-specific N400 effects. As noted above, the visual inspection of the relevant topographic maps (Fig. 2*B*) suggested that the magnitude of N400 at the frontal and temporal regions was stronger in the violation conditions than in the appropriate condition among Chinese subjects but not US subjects. Fig. 3*A* provides the waveforms for each condition at the frontal and temporal regions. Two (culture: United States, China) × 3 (violation: strong, weak, and appropriate) ANOVAs performed on the N400 at the frontal and temporal regions showed no violation effect [frontal: $F(2,96) = 1.99$, $P = 0.14$; temporal: $F(2,96) = 0.92$, $P = 0.40$]. However, the culture × violation was significant at the frontal and temporal regions [frontal: $F(2,96) = 3.20$, $P < 0.05$; temporal: $F(2,96) = 4.69$, $P < 0.02$].* This cultural difference in the N400 was further assessed by the 2 (culture: United States, China) × 2 (violation: strong, appropriate) ANOVAs in the frontal and temporal regions [frontal: $F(1,48) = 7.94$, $P < 0.01$; temporal: $F(1,48) = 8.48$, $P < 0.005$]. Post hoc analysis confirmed a robust N400 effect in the frontal and temporal regions in the strong violation relative to the appropriate condition for Chinese subjects [frontal: $F(1,24) = 12.17$, $P < 0.002$; temporal: $F(1,24) = 5.10$, $P < 0.05$] but not for US subjects [frontal: $F(1,24) = 0.45$, $P = 0.51$; temporal: $F(1,24) = 1.19$, $P = 0.28$; Fig. 3 *B* and *C*]. The culture (United States, China) × violation (weak, appropriate) interaction at the same regions was not significant [frontal: $F(1,48) = 1.71$, $P = 0.20$; temporal: $F(1,48) = 2.30$, $P = 0.14$].

Attitudinal and behavioral correlates of N400. To test whether the N400 may be associated with attitudes and behaviors that are supportive of the strength of norms, we examined correlations between cultural superiority, self-control, and creativity and the N400 effect at the four regions (frontal/temporal/central/parietal) by subtracting the mean amplitudes of strong violation condition from those in the appropriate condition. We focused here on the N400 effect of the strong vs. appropriate contrast given that it was the most sensitive neural measurement of detecting of norm violations across cultures. For convergent validity, results first showed that the culture-specific N400 effect in the frontal region positively correlated with participants' reports of constraint in daily life, concern with territorial defense, and with percentages of strongly inappropriate ratings, and negatively correlated with the percentages of lightly appropriate ratings in the violation conditions (all $P < 0.05$; Table S6). Moreover, we examined whether the N400 responses to norm violations were related to attitudes and behaviors that are associated with the strength of norms, including higher cultural superiority and self-control but lower creative performance. The results showed strong support for this. The culture-specific N400 in the frontal region was correlated with these measurements (all $P < 0.05$; Table S6). Further mediation analyses showed that the culture-specific N400 effect in the frontal region mediated the positive effect of culture on cultural superiority and self-control, and mediated the negative effect of culture on creative performance (*SI Results* and Fig. S2). Although the frontal N400 was particularly influential in predicting these attitudes and behaviors, the temporal N400 showed fewer correlations and the central/parietal N400 showed no correlations with them (Tables S6 and S7).

Differential results of social norm violation and semantic violation. To further test whether there are culture differences in processing nonsocial violation stimuli in the semantic task, we ran 2 (culture: United States, China) × 2 (violation: correct, incorrect) ANOVAs on the N400 (200–600 ms) induced by semantic violation. The ANOVA showed strong main effects of violation,

*The culture-specific N400 effect was found in the lateral frontal and temporal regions (see the details of subdivision for lateral and midline region in *Materials and Methods*). There were no cultural effects for the midline frontal electrodes. It is possible that the culture general effect localized at the electrodes in the midline central region may diffuse into the adjacent midline frontal region, overriding a potential cultural difference in detection of norm violation in the midline frontal electrodes.

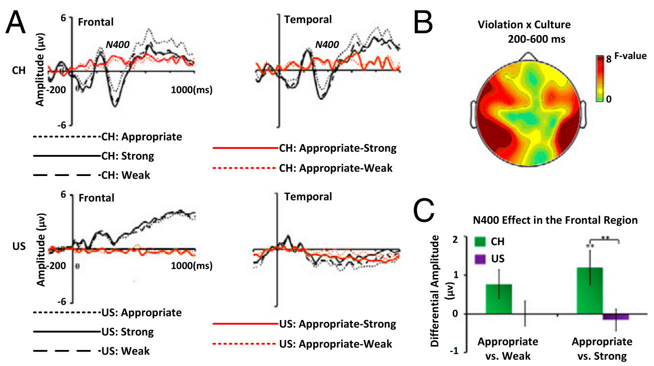

Fig. 3. Culture-specific N400 effects of social norm violations. (*A*) Grand average ERPs for the strong, weak, and appropriate conditions and differential ERPs for the contrasts between appropriate and strong/weak condition at the frontal and temporal regions. (*B*) The *F*-value topography shows the culture (United States, China) × violation (strong, appropriate) effect at 200–600 ms. (*C*) The bar chart shows the N400 effect (appropriate vs. strong/weak condition) at 200–600 ms in the frontal region (F4, a representative electrode in the frontal region, was chosen) for Chinese and US groups, respectively.

illustrating that the semantic incorrect condition elicited larger N400 over widespread regions for both US and Chinese subjects [frontal: $F(1,48) = 7.82$, $P < 0.01$; central: $F(1,48) = 8.25$, $P < 0.01$; temporal: $F(1,48) = 7.06$, $P < 0.01$; parietal: $F(1,48) = 6.50$, $P < 0.02$; Fig. S1 *B* and *C*] relative to the semantic correct condition. There was no culture effect [frontal: $F(1,48) = 2.11$, $P = 0.15$; central: $F(1,48) = 0.46$, $P = 0.50$; parietal: $F(1,48) = 0.08$, $P = 0.77$; temporal: $F(1,48) = 0.63$, $P = 0.43$], nor a culture × violation interaction [frontal: $F(1,48) = 1.66$, $P = 0.20$; central: $F(1,48) = 0.59$, $P = 0.44$; parietal: $F(1,48) = 0.04$, $P = 0.84$; temporal: $F(1,48) = 0.11$, $P = 0.74$], illustrating the effect of semantic violation was observed equally for Americans and Chinese.

To test whether the N400 effects induced by these two tasks are independent with each other, we conducted correlation analysis between the social norm N400 (strong vs. appropriate) and semantic N400 effect (incorrect vs. correct) from the same electrodes at the same time window (e.g., the semantic N400 of Cz at 200–600 ms and the social norm N400 of Cz at 200–600 ms). Although the N400 elicited by semantic violation appears to have a general overlap with the N400 elicited by social norm violations both temporally (e.g., peaks around 400 ms) and spatially (e.g., central and parietal region), no significant correlations between these two N400 effects were found, illustrating that they were independent of each other (all $P > 0.05$; Table S8).

Moreover, the semantic N400 was not significantly related to any of the attitudinal and behavioral measurements (all $P > 0.05$; Table S9). Interestingly, the semantic N400 increased as a function of higher socioeconomic status (SES) ($P < 0.05$; Table S9), suggesting that this ERP signal could reflect variations in executive function in language processing (21). This correlation is in stark contrast with the frontal norm violation N400, which in fact decreased as a function of higher SES ($P < 0.05$; Table S6). The latter correlation is in line with the hypothesis that higher SES is associated with less tight enforcement of social norms (22).

Discussion

The development and enforcement of social norms is a unique feature of human sociality that transcends time and groups. This study is, to our knowledge, the first study to illustrate the neurobiology of social norm violation detection across cultures by combining a new experimental paradigm and cross-cultural EEG techniques. Particularly, strong norm violations relative to the appropriate condition elicited stronger N400 at the central and posterior regions. This effect was observed equally in both Chinese and Americans, suggesting that this component of detecting norm violation reflects psychological processes that are recruited equally in both cultures. Such processes may involve the detection of social incongruence and the processing of various anomalous social cues (9–12, 23, 24). It may be the case this culture-general ERP component signifies increased cognitive processes recruited to integrate the mismatched information engendered when perceiving other people engaging in inappropriate behavior in specific social situations.

An ability to detect norm violators is arguably particularly important in contexts of high threat where coordination among humans is critical for survival. Indeed, detecting and punishing norm violators in such contexts may have had an important evolutionary advantage (3), and thus, under such conditions, we expect that neural mechanisms of norm violation detection would be especially likely to be recruited. Along these lines, a novel finding from the current work concerns N400 at the frontal and temporal regions. This N400 component also responded to norm violation, but it was observed only for Chinese. Previous work has shown that the frontal N400 might be functionally distinct from the central-parietal N400 (25). In particular, the frontal N400 is implicated in the evaluation of the appropriateness of different human actions, such as the meaning of hand postures (26), appropriateness of tool use (27), and semantic anticipation of action sequences (28). Further the frontal N400 has been source-localized in regions encompassing a mentalizing neural network (i.e., inferior frontal cortex, superior frontal gyrus, superior temporal gyrus) (28, 29). One conjecture might be that, whereas both Americans and Chinese are equally likely to detect discrepancies between an observed behavior and the behavior normatively expected (as revealed in the centro-parietal N400), only Chinese go beyond the detected norm violation to infer the mental state of the person violating the norms. Recent cross-cultural research has shown that Chinese are much more tuned into others' perspective than Americans (30), which lends some support for this notion. We might even go as far as to argue that Chinese might consider different punishment options for the violator. Future functional MRI (fMRI) work focusing on areas that have been implicated in humans' punishment decisions [prefrontal regions such as the dorsal lateral prefrontal cortex (31) and ventral medial prefrontal cortex (32)] might shed some further light on this issue.

It is of note that the magnitude of the frontal N400 was related to a variety of attitudes and behaviors associated with the strength of social norms, including greater cultural superiority and self-control but also lower creativity. It is possible that the tightness of culture (which is likely fostered by various historical threats) (1, 2) sensitizes the members of tight cultures to norm violations (as revealed in the strong frontal N400), which might in turn influence certain abilities and functions including creativity and, more generally, inclination toward intellectual and social openness. Thus, our findings extend former work conducted at the national and state levels (1, 2, 15), which illustrate trade-offs of tightness and looseness, namely of greater order, stability, and cohesion in tight groups but greater creativity and openness in loose groups. Our findings add to this multilevel research agenda by providing evidence for the mutual constitution of culture and neural systems underlying norm detection and behavior.

We note that ERP is particularly well suited to examining the time-lock nature of responses to social norm violations but has inherent limitations with respect to spatial resolution. Thus, future research should localize the relevant brain regions involving in detecting social norms by using fMRI techniques. Research should also extend the current work to examine potential genetic pathways of neural responses to social norm violations. Detection of norm violation may require close social attunement and if so, it may be linked to polymorphic variants of oxytocin genes (33). Or, alternatively, norm violation detection may require error processing involving discrepancies between normative expectations and observed behaviors. If so, one might anticipate possible involvement of polymorphic variations in dopamine-system genes (34). Future work along these lines may even reveal how the adaptive task of norm violation might have played a significant role in selecting certain genetic variants in different historical or evolutionary contexts.

Another issue that deserves concerted research attention in future work relates to a potential relationship between social norm violation and moral violations (35–38). We would expect that they may have some neural overlap because they both involve recruiting prior knowledge about a behavior. However, social norm violation detection, which involves the detection of discrepancies between normative expected and observed behaviors, is likely to be distinct from moral violation judgments, which involve matching observed behaviors with moral values such as harm and justice. Last, but not least, the current results should be extended to other populations. Consistent with previous findings that tightness-looseness varies within the United States (2), it would be interesting to examine whether N400 responses are stronger in tight states (i.e., Kansas) compared with loose states (i.e., California). Future research should also examine situational factors that affect N400 responses to norm violations. We would predict, for example, that after a temporary territorial threat (e.g., 9/11 in the United States), the evolved brain mechanisms for social norm detection would be enhanced to help strengthen the cohesion of groups in the face of threats. In all, the cultural neuroscience of social norm detection can help us to address numerous basic and applied research questions about our unique human nature.

Materials and Methods

Participants. Twenty-nine subjects in Beijing and 29 subjects in the United States were recruited through the Internet for participation in this study. Four Chinese participants and one US participant were ruled out because of excessive artifacts in their EEG signal, which contaminated more than 50% of trials. Only individuals who were born in their native countries were included, excluding three students from India in the United States. This left a final sample size of 25 Chinese subjects (11 females; mean age, 23.2 y; range, 20–28 y; all Asian) and 25 US subjects (13 females; mean age, 21.4 y; range, 18–49 y; 5 African American, 3 Asian, 12 European American, and 5 Hispanic). There were no age differences between two groups [$t(48) = 0.19$, $P > 0.05$]. All participants had normal or corrected-to-normal vision. All participants, except three, were right-handed. All individuals gave their written informed consent before starting experiment and participated for monetary compensation.

Stimuli and Procedure. We developed a new social norm violation task in which subjects were asked to judge whether certain behaviors were appropriate or not in different situations (Fig. 1*A*). Thirty-four behaviors (e.g., dancing) were presented in three kinds of situations: appropriate (e.g., tango lesson), weakly inappropriate (e.g., subway platform), and strongly inappropriate (e.g., art museum). Participants were asked to judge the level of appropriateness for all behavior × situation combinations. Each run first showed an instruction screen that was followed by 33 trials. As Fig. 1*A* illustrates, each trial began with 500–1,500 ms of fixation. Thereafter, the first sentence depicting a situation (e.g., Amanda is at the art museum) was presented for 1500 ms, followed by a fixation of 100 ms. Then the second sentence (e.g., She is dancing) depicted a specific behavior, which was separated into two successive 400-ms screens with a 100-ms fixation. After an 800-ms fixation, a response screen was shown during which participants were asked to judge whether the behavior was appropriate from 1 (very inappropriate) to 4 (very appropriate) by using an index and middle finger on the left and right hand on a keyboard. Ten behaviors were randomly chosen for each participant to present twice. As a result, there were 44 behaviors × 3 situations in total. The 132 trials were randomly assigned into four runs, with each run lasting about 3.5 min. All of the stimuli used in the social norm violation task were piloted extensively by independent US and Chinese samples and the piloting results can be obtained from the authors.

The semantic violation task (Fig. S1*A*) was based on an established paradigm in which participants were randomly presented with a number of semantically correct or incorrect sentences and asked to judge whether they were right or wrong. There were 40 subject-verb-object segmented sentences for the correct condition (e.g., "Sophia returned bicycle and key" for the United States; "张静/归还了/自行车/和/钥匙" for Chinese), and another 40 for the semantic violation condition (e.g., "Sophia answered bicycle and key" for the United States; "张静/回答了/自行车/和/钥匙" for Chinese). The verb of the correct sentence (e.g., returned) was replaced with a semantically incongruent one (e.g., answered), inducing a semantic violation in relation to both object noun phrases. The paradigm and material has been used in previous semantic studies and has been shown to elicit N400 component (17). To make it comparable with the social norm violation task, we used the same duration for the presentation of crucial stimuli and a similar number of trials for each condition. Each run first showed an instruction screen which was followed by 40 trials. Each trial began with a varied fixation of 600–1,000 ms. Then the sentence was segmented into several words or short phrases that appeared for 400 ms, with an additional 100-ms blank. After presenting the whole sentence, an 800-ms blank was shown, followed by a response screen during which participants were asked to judge whether the sentence was right or wrong by pressing a button. This response screen was presented until the participant had responded or for maximum 3 s.

The assignment of the response button in the two different tasks was counterbalanced across subjects. The program for running the study was written in Presentation. All English stimuli and material used in the study was translated into Chinese Mandarin by a native Chinese-native speaking bilingual scientist. The back-translation was performed by a different native Chinese-speaking bilingual scientist. The back-translation was compared with the original version by native English-speaking individuals and minor changes were made.

Before the EEG session, participants were given a new latitude vs. constraint in daily life scale to assess the frequency with which individuals are chronically exposed to a wide range of behaviors, disorder, and a lack of conformity in their daily lives compared with being exposed to a restricted range of behavior, order, and conformity in their daily lives (e.g., Do people play loud music in public? Are books misplaced on library shelves? Do people obey posted signs? Do people jaywalk even when other cars are around? Do people dye their hair unnatural colors?). Participants made their ratings on a scale from 1 (never = 0% of the time) to 7 (always = 100% of the time) (α = 0.74 in China, 0.78 in the United States).

After the EEG session, participants were asked to respond to a number of attitudinal and behavioral measures that have been shown to be related to the strength of social norms in previous research (1, 2, 15). Beliefs about the importance of territorial defense was assessed using a World Values Survey item "Government should maintain the defense of our territory," ranging from 1 (not at all important) to 7 (very much important) (39). Attitudes regarding cultural superiority were assessed using five items derived in part from the Pew Global Attitudes Survey (2002) (e.g., Our people are not perfect, but our culture is superior to others) on a scale from 1 (strongly disagree) to 7 (strongly agree) (α = 0.80 in China, 0.76 in the United States) (40). Self-control (cautiousness) was measured by 10 items derived in part from Goldberg's International Personality Item Pool Scale (e.g., I am very careful to avoid making mistakes; I stick to my plans; I reflect on things before acting) on a scale from 1 (very inaccurate) to 5 (very accurate) (α = 0.81 in China, 0.81 in the United States) (41). The Alternative Uses Task was used to assess their creative performance wherein they were asked to list as many original and creative uses for different items (e.g. brick, paperclip) within 1 min (16). Social economic status was measured with McArthur's Self-Anchoring Scale in the form of a 10-rung ladder (42). All measures are available from the authors.

EEG Recording and Analysis. We collected continuous EEG signals as participants were performing the social norm violation task and semantic violation task by using 60 scalp electrodes mounted on an elastic electrode cap that were from a 10–20 system (Neuroscan system in China and Brain Products in the United States). EEG was referenced to the electrodes at the right mastoid and rereferenced to the averaged reference off-line. Eye blinks and vertical eye movements were monitored with two electrodes located above and below the left eye. The horizontal electro-oculogram was recorded from two electrodes placed 1.5 cm lateral to the left and right external canthi. The electrode impedance of each electrode was kept less than 5 kOhms. EEG was amplified (band pass 0.01–100 Hz), digitized at a sampling rate of 250 Hz, and stored for off-line analysis. During the off-line analysis, EEG was treated with band-pass filtering (0.1–30 Hz). Continuous data were algorithmically corrected for the possible artifacts (eye movements and blinks, cardiac signals, muscle noise, and line noise) by independent component analysis (ICA), which has been proved to effectively detect and remove contamination from a wide variety of artifacts (43, 44). The corrected data were epoched into a 1,200-ms time window with a 200-ms prestimulus baseline in the social norm violation and semantic task. The epochs with peak-to-peak amplitudes not exceeding $\pm 60\ \mu V$ were kept for further analyses, resulting in the retention of at least 90% of trials across participants (92% appropriate condition, 90% strong violation, 92% weak violation). The artifact-free epoched EEG for each participant was averaged for each condition, resulting in ERPs which used for further statistical analyses. In the semantic task, the artifact-free correct trials in which participants responded correctly were used for further analysis.

Repeated-measures ANOVAs were conducted with two factors: culture (two levels: China, United States) and violation (three levels in the social norm violation task, strong, weak and appropriate; two levels in the semantic task, incorrect and correct) for each electrode from the frontal/central/parietal/temporal regions (F1, F3, F5, F7, Fz, F2, F4, F6, F8, FC1, FC3, FC5, FCz, FC2, FC4, and FC6 for frontal; C1, C3, Cz, C2, C4, CP1, CP3, CPz, CP2, and CP4 for central; P1, P3, Pz, P2, P4, PO3, PO7, POz, PO4, PO8, O1, Oz, and O2 for parietal, and T7, T8, TP7, TP8, FT7, and FT8 for temporal) at every 50-ms time bin from 0 to 1,000 ms after stimuli onset. The electrodes (F1, F2, Fz, FC1, FC2, FCz, C1, C2, Cz, CP1, CP2, CPz, P1, P2, Pz, POz, O1, O2, and Oz) were chosen to represent the midline part of different regions, whereas the rest representative electrodes listed above were chosen to represent the lateral parts of different regions. The mean amplitude of each electrode site at the given time window was the dependent measure. To correct for inhomogeneity of variances, the Greenhouse-Geisser was performed. The time windows for ERP components were first chosen by visual inspection of the waveforms from the grand average of all subjects. To calculate the N400 effect in social norm violation task, we subtracted neural response to the strong and weak conditions from those from the appropriate condition for each brain region at the 200- to 600-ms time window, which has been viewed as a conventional time interval for the N400 component in previous studies (4, 18–20). To check the consistency of the N400 component in this time window, we also performed ANOVAs on adjacent 50-ms time bins (i.e., 200–250, 250–300, 300–350, 350–400, 400–450, 450–500, 500–550, and 550–600 ms) at each of the regions mentioned above. These tests showed consistent and reliable N400 effects at any three consecutive time bins. Representative electrodes were chosen for post hoc analysis. Similarly, the N400 effect in the semantic task was calculated by subtracting neural responses to the semantic incorrect from the semantic correct conditions. When comparing the neural activity between the semantic and social norm tasks, we extracted the same time window of 200–600 ms in these two tasks. In addition, to keep correlation analysis comparable and consistent between tasks, we used the same representative electrodes between tasks (e.g., N400 at the Cz in the semantic task with N400 at the Cz in the social norm violation).

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