

# 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.**

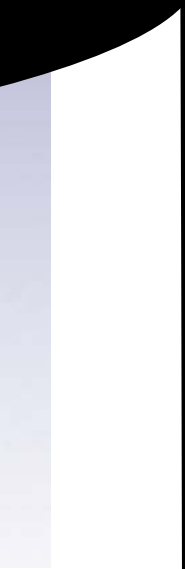
culture | social norms | N400 | electroencephalography | EEG

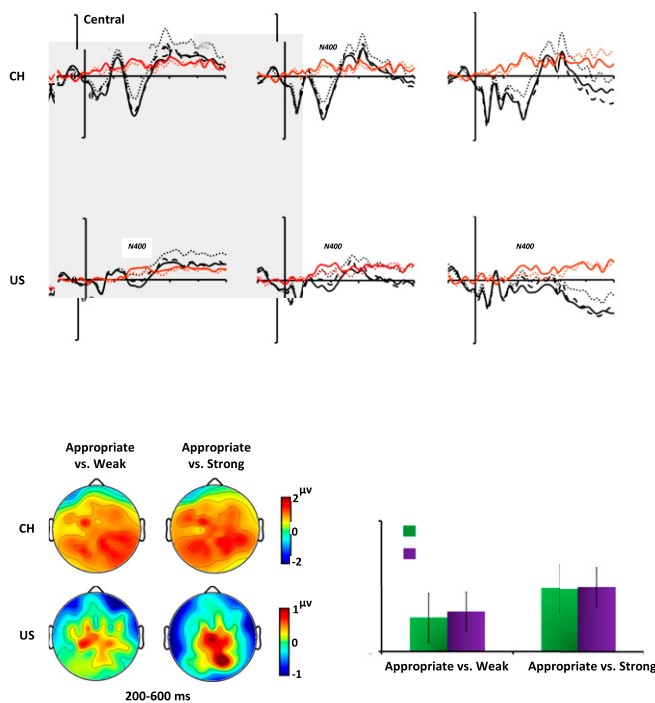
**H**umans are unique among all species in their ability to develop, maintain, and enforce social norms. It is therefore highly possible that humans have evolved complex neural mechanisms for detecting norm violations quickly to punish violators to enforce the social order. Moreover, although the enforcement 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 co-



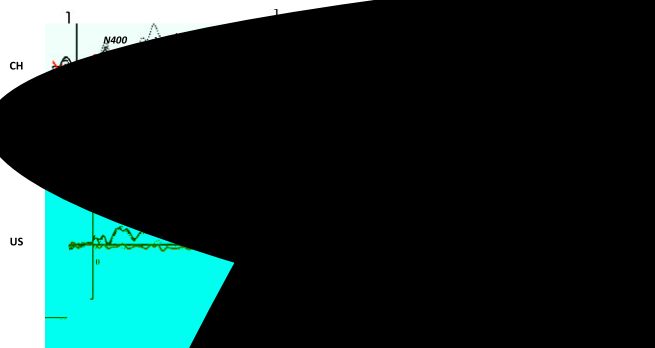


United States, China)  $\times$  3 (violation: strong, weak, and appropriate) ANOVAs of the N400 effect showed the strong and weak violation conditions elicited a greater N400 over the central and parietal regions relative to the appropriate condition [central:  $F(2,96) = 7.87, P < 0.001$ ; parietal:  $F(2,96) = 8.57, P < 0.001$ ]. Separate 2 (culture: United States, China)  $\times$  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. 2B] and weak violation conditions [central:  $F(1,48) = 5.49, P < 0.05$ ; parietal:  $F(1,48) = 9.31, P < 0.005$ ; Fig. 2B], 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. 2C]. 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  $\times$  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. 2B) 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. 3A provides the waveforms for each condition at the frontal and temporal regions. Two (culture: United States, China)  $\times$  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  $\times$  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)  $\times$  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. 3B and C]. The culture (United States, China)  $\times$  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)  $\times$  2 (violation: correct, incorrect) ANOVAs on the N400 (200–600 ms) induced by semantic violation. The ANOVA showed strong main effects of violation,



**Fig. 1.** Grand average ERP waveforms for norm violation N400 effects. The top panel shows waveforms for the CH (China) group, and the bottom panel shows waveforms for the US (United States) group. The y-axis represents amplitude (ranging from -1 to 1), and the x-axis represents time (ranging from 0 to 1000 ms). A vertical dashed line at 400 ms indicates the N400 effect. Error bars represent standard error of the mean.

illustrate the N400 effect. The top panel shows waveforms for the CH (China) group, and the bottom panel shows waveforms for the US (United States) group. The y-axis represents amplitude (ranging from -1 to 1), and the x-axis represents time (ranging from 0 to 1000 ms). A vertical dashed line at 400 ms indicates the N400 effect. Error bars represent standard error of the mean.

To test whether the norm violation N400 and semantic N400 effects were independent, we conducted an analysis between the norm violation N400 and semantic N400 effects at electrodes at the same time window (e.g., 200–600 ms) and the same electrode (e.g., Cz at 200–600 ms and the same electrode at 200–600 ms). Although the N400 elicited by norm violations to have a general overlap with the semantic N400 effects (e.g., central and parietal region), no significant correlation between these two N400 effects were found, indicating that they were independent of each other (all  $P > 0.05$ ; [Table S8](#)).

Moreover, the semantic N400 was not significantly correlated with 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 increased 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 neural basis of social norm violation detection across cultures by using an experimental paradigm and cross-cultural EEG data. Specifically, strong norm violations relative to the

norms elicited the frontal N400 effect, which is related to the detection of social norm violations.

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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. 1A). 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  $\times$  situation combinations. Each run first showed an instruction screen that was followed by 33 trials. As Fig. 1A 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  $\times$  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. S1A) 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 a929Tm[(.1(r853680f973838006(g)-265.)-10.2(g,.84.9(ords)o)26.9(n)18.8(a]

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  $\pm 60 \mu\text{V}$  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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