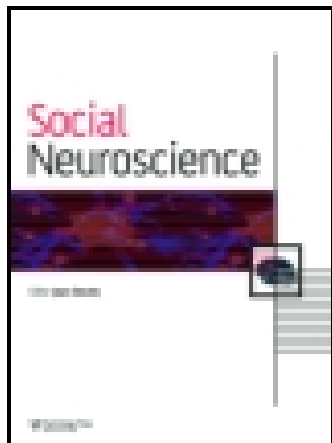


This article was downloaded by: [University of California, San Diego]

On: 23 August 2015, At: 06:58

Publisher: Routledge

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: 5 Howick Place, London, SW1P 1WG



## Social Neuroscience

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/psns20>

### Neural evidence for moral intuition and the temporal dynamics of interactions between emotional processes and moral cognition

Dan-Yang Gui<sup>ab</sup>, Tian Gan<sup>c</sup> & Chao Liu<sup>ab</sup>

<sup>a</sup> State Key Laboratory of Cognitive Neuroscience and Learning & IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing, 100875, China

<sup>b</sup> Center for Collaboration and Innovation in Brain and Learning Sciences, Beijing Normal University, Beijing, 100875, China

<sup>c</sup> Department of Psychology, Zhejiang Sci-Tech University, Hangzhou, China

Accepted author version posted online: 19 Aug 2015.



[Click for updates](#)

To cite this article: Dan-Yang Gui, Tian Gan & Chao Liu (2015): Neural evidence for moral intuition and the temporal dynamics of interactions between emotional processes and moral cognition, *Social Neuroscience*, DOI: [10.1080/17470919.2015.1081401](https://doi.org/10.1080/17470919.2015.1081401)

To link to this article: <http://dx.doi.org/10.1080/17470919.2015.1081401>

Disclaimer: This is a version of an unedited manuscript that has been accepted for publication. As a service to authors and researchers we are providing this version of the accepted manuscript (AM). Copyediting, typesetting, and review of the resulting proof will be undertaken on this manuscript before final publication of the Version of Record (VoR). During production and pre-press, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal relate to this version also.

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

**Publisher:** Taylor & Francis

**Journal:** *Social Neuroscience*

**DOI:** 10.1080/17470919.2015.1081401

# **Neural evidence for moral intuition and the temporal dynamics of interactions between emotional processes and moral cognition**

Dan-Yang Gui<sup>1,2</sup>, Tian Gan<sup>3</sup>, Chao Liu<sup>1,2\*</sup>

<sup>1</sup> State Key Laboratory of Cognitive Neuroscience and Learning & IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing, 100875, China

<sup>2</sup> Center for Collaboration and Innovation in Brain and Learning Sciences, Beijing Normal University, Beijing, 100875, China

<sup>3</sup> Department of Psychology, Zhejiang Sci-Tech University, Hangzhou, China

\*Correspondence to: Chao Liu, State Key Laboratory of Cognitive Neuroscience and Learning & IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing, China. E-mail: [liuchao@bnu.edu.cn](mailto:liuchao@bnu.edu.cn) (C. Liu). Phone: (86)18911121354

**Running head:** Neural evidence for moral intuition

## Abstract

Behavioral and neurological studies have revealed that emotions influence moral cognition. Although moral stimuli are emotionally charged, the time course of interactions between emotions and moral judgments remains unknown. In the present study, we investigated the temporal dynamics of the interaction between emotional processes and moral cognition. The results revealed that when making moral judgments, the time course of the ERP waveform was significantly different between high emotional arousal and low emotional arousal contexts. Different stages of processing were distinguished, showing distinctive interactions between emotional processes and moral reasoning. The precise time course of moral intuition and moral reasoning sheds new light on theoretical models of moral psychology. Specifically, the N1 component (interpreted as representing moral intuition) did not appear to be influenced by emotional arousal. However, the N2 and late positive potential were strongly affected by emotional arousal; the slow wave was influenced by both emotional arousal and morality, suggesting distinct moral processing under different emotional arousal levels.

**Keywords:** moral judgment, right temporoparietal junction, ERP/EEG

## Introduction

Moral stimuli are inherently emotionally charged (i.e., eliciting emotional arousal). A large body of behavioral and neurological research has revealed that emotions influence moral cognition. Research paradigms have ranged from the passive viewing of pictures of moral violations to complex moral decision-making tasks, such as moral dilemmas and theory of mind tasks (Greene, Nystrom, Engell, Darley, & Cohen, 2004; Greene, Sommerville, Nystrom, Darley, & Cohen, 2001; Haidt, 2001; Harenski, Antonenko, Shane, & Kiehl, 2010; Harenski & Hamann, 2006; Moll, de Oliveira-Souza, Eslinger, et al., 2002; Young, Cushman, Hauser, & Saxe, 2007). Moral judgment is a multilevel process involving complex interactions between affective and cognitive processes, wherein affective reactions permeate and influence higher-level cognition (Haidt, 2007; Moll, Zahn, de Oliveira-Souza, Krueger, & Grafman, 2005).

Previous neuroimaging studies have identified a specific cortical network recruited in moral processing, including the medial prefrontal cortex (MPFC), right temporoparietal junction (RTPJ), posterior cingulate, precuneus, and superior temporal sulcus (Greene & Haidt, 2002; Moll & de Oliveira-Souza, 2007; Moll, de Oliveira-Souza, Bramati, & Grafman, 2002; Moll, de Oliveira-Souza, & Zahn, 2008). These neuroimaging studies have also indicated that brain regions involving moral thought overlap with brain networks associated with reasoning and processing social and emotional content (Decety & Cowell, 2014; Moll et al., 2008), suggesting that affective processing plays a significant role in moral judgment.

*Moral intuition* is an intriguing topic that has received much recent attention within the domain of cognitive neuroscience. Haidt (2001, 2007) proposed that moral intuition refers to fast, automatic, and (usually) unconsciously affect-laden processes.

In contrast, moral reasoning—a cognitive process—is a controlled and “cooler” (less affective) process involving conscious mental activity. Moral reasoning is usually a post-hoc process in which an individual searches for evidence to support an initial intuitive reaction.

However, Greene and colleagues proposed a different theoretical perspective on the interactions between moral intuition (presumed to be an emotional process in Haidt’s social-intuitionist model; Haidt, 2001) and moral reasoning (presumed to be a cognitive process). These authors, focusing on fMRI studies of moral dilemmas (Greene et al., 2004), showed that increased cognitive processing in the dorsolateral prefrontal cortex (DLPFC) predicts utilitarian moral judgment behavior. This suggests that cognitive processes can override emotional responses, favoring personal moral violations (utilitarian judgments) when the benefits sufficiently outweigh the costs. Thus, Greene and collaborators proposed that both emotional and cognitive processes are crucial in moral judgments; in other words, moral reasoning not only is a post-hoc process but also overrides or readjusts initial moral intuition.

Greene and colleagues’ dual-process theory of moral judgments (Greene, 2007; Greene et al., 2001; Greene et al., 2004) challenged both the rationalist (Kohlberg, 1969) and emotivist (Haidt, 2001) theories of moral psychology. According to them, cognitive and emotional processes play crucial and sometimes mutually competitive roles in moral judgment, suggesting a synthetic view of moral judgment that acknowledges the crucial roles played by both emotion and cognition.

In contrast to this notion of competition between cognitive and emotional processes in moral judgment, Moll and colleagues (Moll et al., 2005; Moll et al., 2008) proposed an event–feature–emotion complex (EFEC) framework, in which cognition and emotion, instead of competing with each other, are integrated continuously during

moral decision-making. Moll and colleagues postulate that moral cognitive and behavioral phenomena arise from the binding of three main components: (1) structured event knowledge (provided by context-dependent representations in prefrontal subregions), (2) social perceptual and functional features (stored in the posterior and anterior sectors of the temporal cortex), and (3) central motive or basic emotional states (e.g., aggressiveness, sadness, attachment, or sexual arousal) represented in the limbic and paralimbic regions.

Hauser (2006) proposed another model of the sources of moral judgment, where moral events trigger an analysis of the causal and intentional properties underlying the relevant actions and their consequences. This analysis triggers a moral judgment that ultimately evokes the systems of emotion and conscious reasoning, but these systems are not causally responsible for the moral judgment. This model suggests that moral intuition occurs prior to the involvement of our emotions and conscious rational deliberation.

Despite the considerable interest in moral intuition and the wealth of prior research on this topic, the neural correlates of moral intuition are poorly understood. Of specific interest is the time course of information processing in moral cognition, which can be elucidated through event-related potentials (ERPs) due to the high temporal resolution of ERP signals. There are several ERP components related to moral judgment.

The first component is N1, a negative wave peaking approximately 100 ms after stimulus onset. Some studies have revealed that brain regions such as the posterior superior temporal sulcus (pSTS)/inferior parietal region are recruited during the early stages of moral-related information processing, as quickly as 62 ms post-stimulus (Decety & Cacioppo, 2012; Ortigue, Thompson, Parasuraman, & Grafton, 2009).

Recently, one study found that the N1 could differentiate a morally bad action from a morally good action in a moral picture-viewing task (Yoder & Decety, 2014). These studies suggest that moral intuition is a fast and automatic process and that it might be indexed by N1.

The second component of relevance is N2, a negative wave peaking between 200 and 350 ms after stimulus onset. N2 has been shown to index cognitive control (Folstein & Van Petten, 2008), negative emotional processing (Parasuraman et al., 2009; Yuan et al., 2009), and perceiving others' pain (Chen, Yang, & Cheng, 2012). A previous study reported that scenarios of morally good actions elicited higher N2 amplitudes than did morally bad actions (Yoder & Decety, 2014). Thus, N2 could potentially index emotional responses triggered by moral stimuli. In addition, the P2 component (a positive wave peaking around 200 ms after stimulus onset) was also found to be related to moral processes. A larger P2 was found in the frontopolar and frontal areas when subjects decided on instrumental rather than incidental dilemmas (Sarlio et al., 2012).

The late positive potential (LPP), P3, and slow wave are later components of relevance, occurring around 300 ms to 800 ms post-stimulus. They are purported to represent slow but controlled and elaborative processes (Amodio, Bartholow, & Ito, 2014; Kok, 2001; Polich, 2007), such as evaluation and stimulus categorization, memory encoding and updating, making decisions under complex social contexts, moral evaluations, and moral reasoning (Beste et al., 2012; Chen, Qiu, Li, & Zhang, 2009; Mathes, Schmiedt, Schmiedt-Fehr, Pantelis, & Basar-Eroglu, 2012; Paynter, Reder, & Kieffaber, 2009). For example, prosocial actions, compared to antisocial actions, appear to be associated with greater LPP amplitude than antisocial actions (Yoder & Decety, 2014). Furthermore, individual prosocial personality scores are

correlated with LPP magnitude (Chiu Loke, Evans, & Lee, 2011) and greater LPP magnitude (P350–450) has been reported in moral dilemma decision-making (Chen et al., 2009).

Based on empirical evidences from several studies (Decety & Cacioppo, 2012; Ortigue et al., 2009; Yoder & Decety, 2014), we believe that moral intuition is a fast, initial moral process. However, it remains unclear whether initial moral judgments are predominantly generated by unconscious emotional processes (de Oliveira-Souza, Moll, & Grafman, 2011; Mallon & Nichols, 2011). Previous ERP studies have not specifically addressed emotional responses in early moral processing. Indeed, we still do not know how and when emotions influence moral judgments, whether moral intuition is triggered by emotion or as yet unknown processes, or exactly when moral intuition occurs during moral judgment. For example, does a moral judgment occur before or after the involvement of emotions?

The present study utilizes a picture-viewing task with a modified design based on that used by Harenski and Hamann (2006). The novel feature of our design is that we introduce emotional arousal as an independent variable to create a two-by-two design of moral content by emotional arousal. This enables us to investigate the electrophysiological correlates underlying the interaction of emotional processes with moral reasoning; in this case, emotional arousal is used to manipulate emotional involvement in the moral situation. Importantly, we study ERPs, which overcome the drawback of low temporal resolution inherent to fMRI studies. ERPs allow systematic investigation of the temporal dynamics of the neural activity involved in moral judgments under different degrees of emotional involvement.

We hypothesized that the time course of ERPs during a moral judgment task would be different between a high emotional arousal context and a low emotional



arousal context. According to previous fMRI studies on moral dilemmas (Greene et al., 2001; Greene et al., 2004), moral judgments systematically vary by the extent to which an individual engages in emotional processing. We expected that when stimuli are highly emotionally arousing, an automatic affect-laden process would strongly influence or even interact with moral reasoning. Thus, as moral reasoning distinguishes moral content from non-moral content, making this distinction under high emotional involvement would become more difficult later in the time course.

According to previous ERP studies, the N1 is related to the early stages of moral information processing (Decety & Cacioppo, 2012; Yoder & Decety, 2014). Therefore, we expected that the N1 might serve as an index of moral intuition at an early stage. As the N2 might reflect social-emotional responses triggered by a moral stimulus (Chen et al., 2012; Parasuraman et al., 2009; Yuan et al., 2009), we expected that N2 amplitudes would differ between highly arousing and less arousing pictures. As a prior study found the P2 to be associated with moral decision-making (Sarlio et al., 2012), we expected that it might be related to moral responses. Finally, given that later components of the ERP, such as the LPP and slow wave, were found to reflect moral evaluations (Chiu Loke, Evans, & Lee, 2011; Yoder & Decety, 2014), we expected that these components would reveal specific moral distinctions under each emotional arousal condition. In addition, we investigated the time at which emotional processes begin to interact with moral cognition, determining whether moral intuition occurs before affective responses.

## **Materials and methods**

### **Participants**

Thirty-three right-handed students (19 females; mean age  $21.39 \pm 1.78$  years)

from Beijing Normal University, China, participated in the formal ERP experiment. The behavioral data for 19 participants (11 females) were analyzed; the behavioral data for 14 participants were lost due to a computer fault (no EEG data were lost). Therefore, in order to reconfirm our behavioral results, we also conducted a post-ERP-experiment behavioral study using the same experimental task paradigm. Thirty-two right-handed students (23 females; mean age  $22.03 \pm 2.31$  years) participated in this follow-up study. Each participant was reimbursed for his or her time. All participants had normal or corrected-to-normal vision, reported no history of affective disorders or neurological diseases, and were not taking medication that might influence the central nervous system. All participants signed informed consent documents before the experiment. A local ethics committee approved the study protocol.

### **Procedures**

The participants performed the experimental tasks in a small, sound-attenuated, and electrically shielded room. The stimulus display and behavioral data acquisition were programmed using E-Prime software (Version 1.1, Psychology Software Tools, Inc.) and presented on a CRT monitor with an 80 Hz refresh rate. During the task, the participants sat comfortably approximately 80 cm from the computer screen. The task procedure is shown in Figure 1. For each stimulus, the participants were instructed to determine whether the people or events in the picture represented a moral violation and to rate the severity of the moral violation on a scale from 0 (*no moral violation*) to 3 (*severe moral violation*). All participants were instructed to make moral judgments of the people's behavior in the picture, and to evaluate the picture based on their own system of moral values.

Five sets of colored pictures (25 low arousal moral, 25 low arousal non-moral, 25 high arousal moral, 25 high arousal non-moral, and 50 neutral) were selected, primarily from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999). Several pictures were obtained from the Internet and popular media. All pictures were resized to  $450 \times 335$  pixels at 24-bit color depth. All non-neutral pictures were of negative valence and depicted unpleasant social scenes. Moral pictures contained a moral violation of social orders, whereas non-moral pictures did not. Neutral pictures were of neutral valence and arousal, depicting normal social scenes in daily life.

The entire experiment comprised four blocks. Every picture in each condition was repeated twice. Pictures in each block were randomly selected from the full set of picture stimuli. The order of the four blocks was randomized across participants, and the sequence of trials in each block was pseudo-random, such that identical pictures were not presented twice in succession.

Before the formal experiment, a pilot experiment was conducted, in which 27 subjects (15 females; mean age  $23.04 \pm 2.21$  years) rated all pictures in terms of their degree of moral content and emotional arousal, and rated the social scenes depicted in the pictures in terms of visual complexity, on a scale from 1 (low) to 9 (high). For the formal experiment, we selected the pictures according to the ratings received in the pilot experiment. In the final selection, within each arousal condition (high or low), moral and non-moral pictures differed significantly in moral content, high:  $F(1, 48) = 261.639$ ,  $p < 0.001$ ; low:  $F(1, 48) = 106.116$ ,  $p < 0.001$ , and did not differ significantly in emotional arousal, high:  $F(1, 48) = 2.932$ ,  $p = 0.093$ ; low:  $F(1, 48) = 0.945$ ,  $p = 0.336$ , or complexity, high:  $F(1, 48) = 1.380$ ,  $p = 0.245$ ; low:  $F(1, 48) = 0.284$ ,  $p = 0.596$ .

## EEG/ERP recording and analysis

The electroencephalogram (EEG) was recorded from 64 scalp sites using electrodes mounted on an elastic cap (Neuroscan Inc.); the left mastoid was used as a reference. The horizontal electrooculogram (HEOG) was recorded using two electrodes, one next to each eye; the vertical electrooculogram (VEOG) was recorded using electrodes placed above and below the right eye. All inter-electrode impedances were maintained below 5 k $\Omega$ . All signals were sampled at 500 Hz and band-pass filtered within a 0.01–100 Hz frequency range.

During the off-line analyses, all EEG signals were re-referenced to the average of the left and right mastoids. The EEG data were low-pass filtered below 20 Hz (24 dB/oct). Ocular artifacts were removed from the data using a regression procedure implemented with the Neuroscan software (Semlitsch, Anderer, Schuster, & Presslich, 1986). Trials containing EEG sweeps with amplitudes exceeding  $\pm 80 \mu\text{V}$  were excluded. For each stimulus, epochs of 1700 ms duration, including a 200 ms pre-stimulus baseline, were extracted from the continuous EEG record.

Repeated measures analyses of variance (ANOVAs) were conducted using SPSS (SPSS 15.0, SPSS, Inc., Chicago, IL), with separate ANOVAs for the N1, N2, and P2 components. Within-participants factors consisted of arousal (high vs. low), moral content (moral vs. non-moral), and electrodes. The N1 and N2 components were measured as the peak amplitude within a post-stimulus time window of 80–150 ms and 200–300 ms at electrodes F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4. The P2 component was measured as the peak amplitude within a post-stimulus time window of 150–250 ms at electrodes Fz, F3, F4, FCz, FC3, and FC4.

ANOVAs for the LPP and slow wave components were conducted using the

within-participants factors of arousal (high *vs.* low), moral content (moral *vs.* non-moral), and scalp region (frontal sites of Fz, F3, F4, FCz, FC3, and FC4 *vs.* parieto-occipital sites of Pz, P3, P4, CPz, CP3, and CP4). The LPP and slow wave components were measured as the mean amplitudes from 350 to 420 ms and 450 to 650 ms post-stimulus, respectively. The electrode sites and time windows for these components were selected according to the literature (Olofsson, Nordin, Sequeira, & Polich, 2008) and visual inspection of the ERP grand average waveforms for all conditions.

For all statistical analyses, the significance level was set at 0.05. The Greenhouse–Geisser correction for non-sphericity was applied whenever appropriate. Post-hoc tests for multiple comparisons were corrected using the Bonferroni method. Significant interactions were analyzed using simple-effects models. Effect sizes were presented as partial eta-squared.

A source analysis was performed for components that differed between the conditions using standardized low-resolution brain electromagnetic tomography (sLORETA; Pascual-Marqui, 2002), which is a tomographic technique that solves the so-called “inverse problem” (i.e., determining the source of neuronal activity based on extracranial electrical measurements). It has been previously shown that sLORETA can be used to reliably locate the sources of EEG signals (Greenblatt, Ossadtchi, & Pflieger, 2005; Sekihara, Sahani, & Nagarajan, 2005). Paired comparisons at a  $p < 0.05$  were performed for each voxel using statistical non-parametric mapping (SnPM; Holmes, Blair, Watson, & Ford, 1996; Nichols & Holmes, 2002; Pascual-Marqui, 2002); the results are maps of corrected log-F-ratio statistics for each voxel.

## Results

### Behavioral results: ratings for moral violations

For the data from the ERP experiment, repeated measures ANOVAs on moral violation ratings were conducted using arousal (high vs. low) and moral content (moral vs. non-moral) as within-participants factors. Figure 2 shows the mean moral violation ratings of the high- and low-arousal pictures with moral and non-moral contents. There was a main effect of morality,  $F(1, 18) = 492.380$ ,  $MSE = 0.088$ ,  $p < 0.001$ , partial  $\eta^2 = 0.965$ , a main effect of arousal,  $F(1, 18) = 90.466$ ,  $MSE = 0.049$ ,  $p < 0.001$ , partial  $\eta^2 = 0.834$ , and an interaction between arousal and morality,  $F(1, 18) = 7.819$ ,  $MSE = 0.058$ ,  $p = 0.012$ , partial  $\eta^2 = 0.303$ . Moral violation ratings were significantly higher for moral pictures than for non-moral pictures in both the high- and low-arousal contexts. The ratings were significantly higher for high-arousal pictures than for low-arousal pictures in both moral and non-moral contexts.

For the post-ERP-experiment behavioral study, ANOVAs on moral violation ratings were conducted using arousal (high vs. low) and moral content (moral vs. non-moral) as within-participants factors. There was a main effect of morality,  $F(1, 31) = 514.550$ ,  $MSE = 0.120$ ,  $p < 0.001$ , partial  $\eta^2 = 0.943$ , a main effect of arousal,  $F(1, 31) = 66.721$ ,  $MSE = 0.047$ ,  $p < 0.001$ , partial  $\eta^2 = 0.683$ , and an interaction between arousal and morality,  $F(1, 31) = 10.281$ ,  $MSE = 0.054$ ,  $p = 0.003$ , partial  $\eta^2 = 0.249$ . Moral violation ratings were significantly higher for moral pictures than for non-moral pictures in both high- and low-arousal contexts. Furthermore, the ratings were significantly higher for high-arousal pictures than for low-arousal pictures in both moral and non-moral contexts. These results are consistent with the behavioral task results from the ERP experiment.

## ERP Results

Figure 3 shows the grand average ERP waveforms and scalp potential maps for the high- and low-arousal pictures with moral and non-moral content.

### N1 (80–150 ms)

The ANOVAs indicated a significant main effect of morality on N1 peak amplitude,  $F(1, 32) = 10.430$ ,  $MSE = 11.035$ ,  $p = 0.003$ , partial  $\eta^2 = 0.246$ . Specifically, N1 amplitudes elicited by moral pictures were significantly more negative than were those elicited by non-moral pictures. Neither the main effect of arousal nor the interaction between moral content and emotional arousal was significant.

### P2 (150–250 ms)

A significant main effect of both morality,  $F(1, 32) = 8.782$ ,  $MSE = 8.708$ ,  $p = 0.006$ , partial  $\eta^2 = 0.215$ , and emotional arousal,  $F(1, 32) = 6.659$ ,  $MSE = 20.965$ ,  $p = 0.015$ , partial  $\eta^2 = 0.172$ , was found, but there was no significant interaction between these factors. The P2 amplitudes elicited by non-moral pictures were significantly more positive than were those elicited by moral pictures; additionally, the P2 amplitudes elicited by high-arousal pictures were significantly more positive than were those elicited by low-arousal pictures.

### N2 (200–300 ms)

The ANOVAs indicated a significant main effect of emotional arousal on N2 peak amplitude,  $F(1, 32) = 4.543$ ,  $MSE = 22.040$ ,  $p = 0.041$ , partial  $\eta^2 = 0.124$ ; N2 amplitudes elicited by low-arousal pictures were significantly more negative than were those elicited by high-arousal pictures. Neither the main effect of morality nor the interaction between morality and emotional arousal was significant.

#### LPP (350–420 ms)

A significant main effect of emotional arousal was found,  $F(1, 32) = 31.777$ ,  $MSE = 27.838$ ,  $p < 0.001$ , partial  $\eta^2 = 0.498$ , indicating that the LPP component amplitude in response to high-arousal pictures was significantly more positive than was that in response to low-arousal pictures. The main effect of morality was not significant. There was a significant main effect of scalp region,  $F(1, 32) = 164.108$ ,  $MSE = 104.109$ ,  $p < 0.001$ , partial  $\eta^2 = 0.837$ , which showed that the LPP component amplitude at frontal sites was significantly more negative than was that at parieto-occipital sites. No interaction between morality and emotional arousal was found.

#### Slow wave (450–650 ms)

A significant main effect of emotional arousal was observed,  $F(1, 32) = 60.135$ ,  $MSE = 31.203$ ,  $p < 0.001$ , partial  $\eta^2 = 0.653$ , indicating that the slow wave activity in response to high-arousal pictures was significantly more positive than was that in response to low-arousal pictures. The main effect of morality was also significant,  $F(1, 32) = 14.349$ ,  $MSE = 18.505$ ,  $p = 0.001$ , partial  $\eta^2 = 0.310$ , indicating that the slow wave activity elicited by moral pictures was significantly more positive than was that elicited by non-moral pictures. The three-way interaction between morality, emotional arousal, and scalp region was significant,  $F(1, 32) = 5.799$ ,  $MSE = 2.686$ ,  $p = 0.022$ , partial  $\eta^2 = 0.153$ . Additional simple effects analyses revealed that, at the frontal sites, for low-arousal pictures, the slow wave activity for moral pictures was significantly more positive than for non-moral pictures ( $p < 0.001$ ). However, for high-arousal pictures, there was no significant difference observed between moral and non-moral pictures ( $p = 0.385$ ). At parieto-occipital sites, for low-arousal pictures, the slow wave activity of moral pictures was significantly more positive than was that for non-moral



pictures ( $p < 0.003$ ); for high-arousal pictures, moral pictures were marginally significantly more positive than were non-moral pictures ( $p = 0.055$ ).

### **Source analysis**

As shown in Figure 4 and Table 1, the sLORETA results indicated significant source differences in the estimated current density based on the grand-averaged ERP waves of the N1, P2, N2, LPP components, and the slow wave. During the time period of the N1 component, the difference between the moral and non-moral conditions was primarily located in the right inferior parietal lobule (specifically Brodmann area [BA] 40; Talairach coordinates: 40, -42, 39), postcentral gyrus (BA 3), and posterior cingulate (BA 30). Specifically, in these areas, the moral condition showed increased activity as compared with the non-moral condition. During the time period of the P2 component, we did not find significant source differences.

During the time range of the N2 and LPP components (350–420 ms), the difference between the high- and low-arousal conditions was primarily located in the parahippocampal gyrus (specifically BA 34; Talairach coordinates: 15, -1, -17) and the uncus (BA 28). For the slow wave (450–650 ms), the difference between the moral and non-moral conditions with low emotional arousal was primarily located in the middle frontal gyrus (specifically BA 10/11; Talairach coordinates: -35, 58, -11) and the precuneus (BA 7). In this case, the moral condition showed greater activity than did the non-moral condition.

### **Discussion**

In the present study, we investigated how processing moral content is influenced by emotional arousal in order to investigate the neural correlates underlying the

interaction between emotional processes and moral reasoning and the temporal dynamics of the neural activity associated with moral judgment under different degrees of emotional involvement. We found that the time course of the ERP waveform during moral judgments was significantly different between high emotional arousal and low emotional arousal contexts. Different stages of processing and interaction between emotional processes and moral reasoning were identified in this study.

In the first stage, moral content is distinguished from non-moral content at an early time stage (approximately 80–150 ms after stimulus onset), suggesting that moral intuition may occur at a very early time. In the second stage, an effect of emotional arousal was observed (at approximately 150–200 ms after stimulus onset), but this did not appear to influence initial moral thinking. In the third stage, emotional arousal had a large impact on moral judgment. Specifically, emotional processing affected cognition in a time-dependent manner, beginning approximately 200–400 ms after stimulus onset. In the final stage, complex moral reasoning began, which exhibited an effect on the timeline of moral judgment (approximately 450 ms and later). At this point, the stimuli are well evaluated, with clear separation of moral and non-moral content and different degrees of emotional involvement.

### **Moral intuition**

The early frontal N1 peak amplitudes elicited by pictures with moral content were significantly more negative than were those elicited by pictures without moral content. This suggests that moral-related thoughts occur at early stages of moral decision-making.

The fact that moral stimuli are processed at such an early stage is consistent with

the findings of several previous studies. Decety and Cacioppo (2012) found that intentionally and accidentally harmful actions can be distinguished as fast as 62 ms after participants viewed morally laden scenarios. More recently, it was shown that N1 could differentiate bad and good actions in a moral picture-viewing task (Yoder & Decety, 2014). In light of these previous results and our own, we propose that moral intuition, as a fast and automatic process, might be indexed by the early ERP component N1, which is not necessarily influenced by emotional arousal.

Moral intuition is a crucial part of three highly influential frameworks for understanding moral psychology. First, the social intuitionist model (SIM; Haidt, 2001, 2007), which states that moral judgment is generally the product of quick, automatic, emotion-laden intuitions, and moral reasoning is usually a post hoc construction. In contrast, the dual-process model (DPM) (Greene, 2007; Greene et al., 2001; Greene et al., 2004) states that moral judgment is driven by both intuitive emotional and controlled cognitive responses. Third, the model proposed by Hauser (2006) states that moral judgment is generated by its sources (moral intuition) prior to the involvement of our emotions and conscious rational deliberation.

Until recently, moral intuition was merely a presumption derived from numerous behavioral studies (Cushman, Young, & Hauser, 2006; Greene, Morelli, Lowenberg, Nystrom, & Cohen, 2008; Haidt, 2001; Valdesolo & DeSteno, 2006; Wheatley & Haidt, 2005; Wright & Baril, 2011). The empirical existence of moral intuition has not been shown via fMRI, because the intuitive processes occur at an early time stage, which cannot be captured by fMRI due to its low temporal resolution. The current study provides evidence of the neural underpinnings of moral intuition, and indicates that moral intuition may occur before affective responses. Although the SIM and DPM frameworks differ in the role that moral intuition plays in moral judgment, the

current results do not directly favor one model over the other, because neither specifies that moral intuition occurs prior to affective responses. Instead, the current results are consistent with the Hauser model, which proposes that moral events trigger a causal intentional analysis prior to the involvement of emotion and rational reasoning. However, although we did not find an effect of emotional arousal on moral intuition, this does not necessarily indicate that emotions play no role, given how complex and multidimensional emotions are (Bradley, Codispoti, Cuthbert, & Lang, 2001; Ekman & Davidson, 1994; Lazarus, 1994; Markus & Kitayama, 1991).

The sLORETA analysis showed that the most likely source of the N1 component was in the right inferior parietal lobule (BA 40), a brain area critical for causal intentional analysis, which underlies the process of moral judgment in the Hauser model. The posterior STS/inferior parietal region is associated with the perception and representation of socially important information, such as bodily motion, action detection, and inferences regarding the intentions of others (Claeys, Lindsey, De Schutter, & Orban, 2003; Schaich Borg, Hynes, Van Horn, Grafton, & Sinnott-Armstrong, 2006; Sinke, Sorger, Goebel, & de Gelder, 2010). This area also plays a critical role in moral judgments (Greene & Haidt, 2002; Moll, de Oliveira-Souza, Bramati, et al., 2002). Harenski et al. (2010) found that the ventromedial prefrontal cortex (vmPFC) may contribute more to moral deliberation than to moral intuition, whereas the temporo-parietal junction may contribute more to moral intuition than to moral deliberation. Some studies have revealed that these associative brain areas could be recruited during the early stages of information processing (starting at 60 ms; Decety & Cacioppo, 2012; Ortigue et al., 2009). This suggests that the posterior STS/inferior parietal region serves to initially detect and infer the intentions of others—a key node of moral intuition.

The posterior cingulate cortex (PCC) is a key node in the default mode network (Buckner, Andrews-Hanna, & Schacter, 2008). It is known to be involved in internally directed cognition (e.g., self-awareness, autobiographical memories), regulating the focus of attention, and signaling environmental change (Leech & Sharp, 2014; Pearson, Heilbronner, Barack, Hayden, & Platt, 2011). In the very early stage of moral cognition, we speculate the PCC may serve as a bridge between internally mental representation and externally sensory information. The postcentral gyrus is located in the primary somatosensory cortex, and the involvement of the somatosensory cortex found in our study is consistent with previous studies suggesting that abstract thoughts regarding moral concepts are grounded in sensory experiences (Denke, Rotte, Heinze, & Schaefer, 2014a, 2014b). Therefore, moral intuition may also be represented in the early somatic perception of the external world, because physical and moral experiences are psychologically interwoven (Kang, Williams, Clark, Gray, & Bargh, 2011; Zhong & Liljenquist, 2006). Based on the current results, we speculate that moral intuition is an intuitive detection of social norms entrenched in the minds of social animals, and derived from social evolution.

### **Impact of emotional arousal on morality**

The frontal P2 component was influenced by morality and emotional arousal. This result suggests that emotional processes are initiated at this stage of moral judgment. Previous studies have suggested that the emotional arousal effect occurs at the early stage of attention allocation (Carretie, Hinojosa, Martin-Loeches, Mercado, & Tapia, 2004; Huang & Luo, 2006; Schupp, Flaisch, Stockburger, & Junghofer, 2006). This allocation of attention can be automatically modulated through one or two ERP components reflecting attention toward affective pictures within 200 to 300 ms.

Affective processing may occupy a great deal of attentional resources, and thus intrude into moral thinking. Our results showed an influence of both morality and emotional arousal on the P2 component.

The widely distributed N2 and LPP (350–420 ms) were influenced by emotional arousal, indicating that emotions have a high impact on moral thinking at this stage of processing. Previous studies addressing the N2 and P3 components have shown that the effects of emotional arousal not only occur during the early attention-related stage but also during the late evaluative stage, thereby modulating cognitive processes (Carretie et al., 2004; Huang & Luo, 2006; Kok, 2001). During this stage, different emotional arousal effects were clearly distinguished. This suggests that clear differentiation of emotional arousal may serve to tag salient features of moral thinking (Huebner, Dwyer, & Hauser, 2009). However, the levels of emotional arousal between moral and non-moral pictures were not differentiated, suggesting that moral cognitive processing might be more complicated and was not fully completed until late stages. Because emotions are complex and multidimensional (Bradley et al., 2001; Ekman & Davidson, 1994; Lazarus, 1994; Markus & Kitayama, 1991), emotional arousal is just one aspect of emotions, the impact of emotions on moral cognition should be investigated further with other tasks in future studies.

The sLORETA analysis of the N2 and LPP (350–420 ms) showed that the source of the maximal difference between high- and low-emotional arousal conditions was located in the parahippocampal gyrus (BA 28, BA 34). The parahippocampal gyrus and amygdala are located in the medial temporal lobes of the limbic system, and have been shown in many studies to play a primary role in the processing of memory and emotional reactions (Pare, Collins, & Pelletier, 2002). The parahippocampal gyrus has dense interconnectivity with the amygdala, and plays an important role in emotional

picture perception (Sabatinelli, Keil, Frank, & Lang, 2013) and emotional memories (Kilpatrick & Cahill, 2003; Phelps, 2004). The emotional processes indexed by the LPP are considered late, memory-related processes evoking rich associations (Ergen, Yildirim, Uslu, Gurvit, & Demiralp, 2012; Mathes et al., 2012; Wright et al., 2002). The results of the present study suggest that emotion-modulated moral judgments not only involve an emotional-arousal-related response in the amygdala, but also engage emotional-memory-associated hippocampal activities.

### **Complex distinction of morality**

The widely distributed slow wave (450–650 ms) was jointly influenced by morality and emotional arousal, indicating subtle and specific distinctions in morality under different emotional arousal levels. At frontal sites, the slow wave activities in response to low emotion-arousing moral and non-moral stimuli differed, but high emotion-arousing moral and non-moral stimuli did not. At parieto-occipital sites, the slow wave activities of both high- and low-arousal moral and non-moral stimuli could almost be discriminated, although the distinction between high emotion-arousing moral and non-moral stimuli was marginally significant ( $p = 0.055$ ). The P300 component and P3-related late activity in ERP studies are usually thought to represent higher-order cognitive processes (Amodio et al., 2014; Polich, 2007). Previous studies have shown that P3-related late activity and the slow wave are associated with moral cognition and moral decision-making (Chen et al., 2009; Chiu Loke et al., 2011; Yoder & Decety, 2014).

In our study, emotion-related processes influenced brain activity from 180 ms to 450 ms. This indicates the subtle and specific distinction of morality in the context of a given level of emotional arousal is maintained at a comparatively late time stage

(i.e., approximately 450 ms) after stimulus onset, when emotion-related processes integrate cognition-related moral judgments, particularly in frontal areas.

The sLORETA analysis of slow wave activity (450–650 ms) showed that for low-arousal stimuli, the greatest difference between the moral and non-moral conditions was located in the middle frontal cortex (BA 10 and BA 11). These results are consistent with previous fMRI studies on moral judgment of emotional pictures (Harenski et al., 2010; Harenski & Hamann, 2006) and moral dilemmas (Greene et al., 2001; Greene et al., 2004). For example, Harenski et al. (2010) found that participants performing an explicit (but not an implicit) moral judgment task showed increased ventromedial prefrontal cortex activity while viewing negative moral pictures. The precuneus (BA 7) is another crucial brain region associated with moral cognition (Greene & Haidt, 2002; Moll et al., 2005). Its role may involve the integration of emotion and memory evoked by social interaction (Cavanna & Trimble, 2006; Fletcher et al., 1995). A recent study showed that the precuneus reacts to violations of social conventions, suggesting that it plays an important role in interpreting others' interactions from a third-person perspective (Petrini, Piwek, Crabbe, Pollick, & Garrod, 2014).

Previous fMRI studies on moral dilemmas have shown that variations in emotional engagement influence moral judgments; personal moral dilemmas (with considerable emotional engagement) generate increased activity in areas associated with social/emotional processing (i.e., the vmPFC and posterior cingulate gyrus) as compared with less emotionally engaging, impersonal dilemmas (Greene et al., 2001; Greene et al., 2004).

The vmPFC is crucial not only for social/emotional processing but also for value-based decision-making (Burke, Franz, Miller, & Schoenbaum, 2008;



Padoa-Schioppa & Assad, 2006; Schoenbaum, Roesch, & Stalnaker, 2006). Some studies, including Greene's model, have suggested that the vmPFC plays a role in the integration of emotion into decision-making and planning (Baena, Allen, Kaut, & Hall, 2010; Greene & Haidt, 2002; Lim, O'Doherty, & Rangel, 2013; Wagar & Thagard, 2003).

There was no direct conflict between emotion and moral judgment in our study's paradigm, because we did not use moral dilemmas as stimuli. However, we still believe emotion could influence moral judgments via integration and interaction between cognitive and affective processes. Such an interaction was suggested by the presence of the three-way interaction between morality, emotional arousal, and scalp region in our analysis.

Greene's dual-process theory predicts that people favor non-utilitarian choices in the context of high emotional involvement (Greene, 2007; Greene et al., 2001; Greene et al., 2004). According to the aforementioned three-way interaction, at frontal sites, slow wave activity under low arousal differed between moral and non-moral stimuli; however, moral and non-moral stimuli did not differ under high arousal. This suggests that high emotional arousal has a considerable impact on moral recognition and that the frontal areas are particularly susceptible to such emotion-related diversion in moral processing. Highly emotionally arousing stimuli occupy more attentional resources, disturb resource allocation during cognitive processing, integrate emotional responses into early cognitive processes, and eventually modulate moral judgments. In contrast, the controlled cognitive processing of moral reasoning might occupy more attentional resources in the context of low emotional involvement, which result in more utilitarian decisions (i.e., superior cost-benefit analyses).

We speculate that in the final moral cognition stage, moral judgments integrating

emotion and cognition are made, which is consistent with the EFEC framework suggesting that moral cognition arises from the integration of emotions with knowledge and perceptual features (Moll et al., 2005; Moll et al., 2008).

One limitation of the present study is that the subjects were limited to a single cultural background and a single age range. Different people might have different feelings about the same stimulus, and some people may not conform to normal moral values. People of different ages, personalities, and different cultures might exhibit divergent patterns of moral cognition in both the temporal and spatial dynamics of neural activity. Thus, future research should investigate developmental or individual differences and cross-cultural diversity in moral judgments. Another limitation is that our results and conclusions are limited to the scope of one moral task and a single aspect of emotion (i.e., emotional arousal). Because emotions are complex and multidimensional (Bradley et al., 2001; Ekman & Davidson, 1994; Lazarus, 1994; Markus & Kitayama, 1991), the impact of emotions on moral cognition should be interpreted with caution, and further investigated using other moral tasks that assess different emotional dimensions.

## **Conclusions**

Our results provide empirical evidence that when making moral judgments, the temporal dynamics of neural activity depend on the extent of emotional involvement. Different stages of processing, showing distinctive interactions between emotional processes and moral reasoning were clearly distinguished. These findings reveal the precise time course of moral intuition and moral reasoning in the current paradigm and shed new light on the theoretical models of moral psychology. In particular, the early-stage N1 component, which we considered to represent moral intuition, was not

influenced by emotional arousal, whereas the later-stage N2 and LPP components were strongly affected by emotional arousal. The slow wave was affected by emotional arousal and morality, suggesting specific distinctions in moral processing under different emotional arousal levels, which is in line with the dual-process model and the EFEC model.

### **Acknowledgements**

This research was supported by National Basic Research Program of China (2011CB711000, 2013CB837300), National Natural Science Foundation of China (NSFC) (31170971, 61210010), and Major Project of National Social Science Foundation (12&ZD228). The authors thank Tianli Chen, Hao Zhang, and Boqi Du for help with data acquisition; Tingting Wu for data analysis, Zheng Li for helpful comments, and anonymous reviewers for their constructive comments.

## References

- Amodio, D., Bartholow, B. D., & Ito, T. A. (2014). Tracking the dynamics of the social brain: ERP approaches for social cognitive and affective neuroscience. *Social Cognitive and Affective Neuroscience*, 9(3), 385–393. doi: 10.1093/scan/nst177
- Baena, E., Allen, P. A., Kaut, K. P., & Hall, R. J. (2010). On age differences in prefrontal function: the importance of emotional/cognitive integration. *Neuropsychologia*, 48(1), 319–333. doi: 10.1016/j.neuropsychologia.2009.09.021
- Beste, C., Ness, V., Lukas, C., Hoffmann, R., Stuwe, S., Falkenstein, M., & Saft, C. (2012). Mechanisms mediating parallel action monitoring in fronto-striatal circuits. *NeuroImage*, 62(1), 137–146. doi: 10.1016/j.neuroimage.2012.05.019
- Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: defensive and appetitive reactions in picture processing. *Emotion*, 1(3), 276–298.
- Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network: anatomy, function, and relevance to disease. *Annals of the New York Academy of Sciences*, 1124, 1–38. doi: 10.1196/annals.1440.011
- Burke, K. A., Franz, T. M., Miller, D. N., & Schoenbaum, G. (2008). The role of the orbitofrontal cortex in the pursuit of happiness and more specific rewards. *Nature*, 454(7202), 340–344. doi: 10.1038/nature06993
- Carretié, L., Hinojosa, J. A., Martin-Loeches, M., Mercado, F., & Tapia, M. (2004). Automatic attention to emotional stimuli: Neural correlates. *Human Brain*

*Mapping*, 22(4), 290–299. doi: 10.1002/hbm.20037

Cavanna, A. E., & Trimble, M. R. (2006). The precuneus: a review of its functional anatomy and behavioural correlates. *Brain*, 129(Pt 3), 564–583. doi: 10.1093/brain/awl004

Chen, P., Qiu, J., Li, H., & Zhang, Q. (2009). Spatiotemporal cortical activation underlying dilemma decision-making: an event-related potential study. *Biological Psychology*, 82(2), 111–115. doi: 10.1016/j.biopsycho.2009.06.007

Chen, C., Yang, C.-Y., & Cheng, Y. (2012). Sensorimotor resonance is an outcome but not a platform to anticipating harm to others. *Social Neuroscience*, 7(6), 578–590. doi: 10.1080/17470919.2012.686924

Chiu Loke, I., Evans, A. D., & Lee, K. (2011). The neural correlates of reasoning about prosocial-helping decisions: an event-related brain potentials study. *Brain Research*, 1369, 140–148. doi: 10.1016/j.brainres.2010.10.109

Claeys, K. G., Lindsey, D. T., De Schutter, E., & Orban, G. A. (2003). A higher order motion region in human inferior parietal lobule: evidence from fMRI. *Neuron*, 40(3), 631–642. doi: [http://dx.doi.org/10.1016/s0896-6273\(03\)00590-7](http://dx.doi.org/10.1016/s0896-6273(03)00590-7)

Cushman, F., Young, L., & Hauser, M. (2006). The role of conscious reasoning and intuition in moral judgment: testing three principles of harm. *Psychological Science*, 17(12), 1082–1089. doi: 10.1111/j.1467-9280.2006.01834.x

de Oliveira-Souza, R., Moll, J., & Grafman, J. (2011). Emotion and social cognition: Lessons from contemporary human neuroanatomy. *Emotion Review*, 3(3), 310–312. doi: 10.1177/1754073911402399

Decety, J., & Cacioppo, S. (2012). The speed of morality: a high-density electrical neuroimaging study. *Journal of Neurophysiology*, 108(11), 3068–3072. doi: 10.1152/jn.00473.2012

- Decety, J., & Cowell, J. M. (2014). The complex relation between morality and empathy. *Trends in Cognitive Sciences*, *18*(7), 337–339. doi: 10.1016/j.tics.2014.04.008
- Denke, C., Rotte, M., Heinze, H.-J., & Schaefer, M. (2014a). Belief in a just world is associated with activity in insula and somatosensory cortices as a response to the perception of norm violations. *Social Neuroscience*, *9*(5), 514–521. doi: 10.1080/17470919.2014.922493
- Denke, C., Rotte, M., Heinze, H.-J., & Schaefer, M. (2014b). Lying and the subsequent desire for toothpaste: activity in the somatosensory cortex predicts embodiment of the moral-purity metaphor. *Cerebral Cortex*. doi: 10.1093/cercor/bhu170
- Ekman, P., & Davidson, R. (1994). *The nature of emotion: Fundamental questions*. New York: Oxford University Press.
- Ergen, M., Yildirim, E., Uslu, A., Gurvit, H., & Demiralp, T. (2012). P3 response during short-term memory retrieval revisited by a spatio-temporal analysis. *International Journal of Psychophysiology*, *84*(2), 205–210. doi: 10.1016/j.ijpsycho.2012.02.009
- Fletcher, P. C., Frith, C. D., Baker, S. C., Shallice, T., Frackowiak, R. S. J., & Dolan, R. J. (1995). The mind's eye—precuneus activation in memory-related imagery. *NeuroImage*, *2*(3), 195–200. doi: 10.1006/nimg.1995.1025
- Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, *45*(1), 152–170. doi: 10.1111/j.1469-8986.2007.00602.x
- Greenblatt, R. E., Ossadtchi, A., & Pflieger, M. E. (2005). Local linear estimators for the bioelectromagnetic inverse problem. *IEEE Transactions on Signal*

*Processing*, 53(9), 3403–3412. doi: 10.1109/TSP.2005.853201

Greene, J. D. (2007). Why are VMPFC patients more utilitarian? A dual-process theory of moral judgment explains. *Trends in Cognitive Science*, 11(8), 322–323; author reply 323–324. doi: 10.1016/j.tics.2007.06.004

Greene, J. D., & Haidt, J. (2002). How (and where) does moral judgment work? *Trends in Cognitive Science*, 6(12), 517–523. doi: [http://dx.doi.org/10.1016/s1364-6613\(02\)02011-9](http://dx.doi.org/10.1016/s1364-6613(02)02011-9)

Greene, J. D., Morelli, S. A., Lowenberg, K., Nystrom, L. E., & Cohen, J. D. (2008). Cognitive load selectively interferes with utilitarian moral judgment. *Cognition*, 107(3), 1144–1154. doi: 10.1016/j.cognition.2007.11.004

Greene, J. D., Nystrom, L. E., Engell, A. D., Darley, J. M., & Cohen, J. D. (2004). The neural bases of cognitive conflict and control in moral judgment. *Neuron*, 44(2), 389–400. doi: 10.1016/j.neuron.2004.09.027

Greene, J. D., Sommerville, R. B., Nystrom, L. E., Darley, J. M., & Cohen, J. D. (2001). An fMRI investigation of emotional engagement in moral judgment. *Science*, 293(5537), 2105–2108. doi: 10.1126/science.1062872

Haidt, J. (2001). The emotional dog and its rational tail: a social intuitionist approach to moral judgment. *Psychological Review*, 108(4), 814–834. doi: <http://dx.doi.org/10.1037/0033-295x.108.4.814>

Haidt, J. (2007). The new synthesis in moral psychology. *Science*, 316(5827), 998–1002. doi: 10.1126/science.1137651

Harenski, C. L., Antonenko, O., Shane, M. S., & Kiehl, K. A. (2010). A functional imaging investigation of moral deliberation and moral intuition. *NeuroImage*, 49(3), 2707–2716. doi: 10.1016/j.neuroimage.2009.10.062

Harenski, C. L., & Hamann, S. (2006). Neural correlates of regulating negative

emotions related to moral violations. *NeuroImage*, 30(1), 313–324. doi: 10.1016/j.neuroimage.2005.09.034

Hauser, M. D. (2006). The liver and the moral organ. *Social Cognitive and Affective Neuroscience*, 1(3), 214–220. doi: 10.1093/scan/nsl026

Holmes, A. P., Blair, R. C., Watson, G., & Ford, I. (1996). Nonparametric analysis of statistic images from functional mapping experiments. *Journal of Cerebral Blood Flow & Metabolism*, 16(1), 7–22. doi: 10.1097/00004647-199601000-00002

Huang, Y.-X., & Luo, Y.-J. (2006). Temporal course of emotional negativity bias: an ERP study. *Neuroscience Letters*, 398(1-2), 91–96. doi: 10.1016/j.neulet.2005.12.074

Huebner, B., Dwyer, S., & Hauser, M. (2009). The role of emotion in moral psychology. *Trends in Cognitive Sciences*, 13(1), 1–6. doi: 10.1016/j.tics.2008.09.006

Kang, Y., Williams, L. E., Clark, M. S., Gray, J. R., & Bargh, J. A. (2011). Physical temperature effects on trust behavior: the role of insula. *Social Cognitive and Affective Neuroscience*, 6(4), 507–515. doi: 10.1093/Scan/Nsq077

Kilpatrick, L., & Cahill, L. (2003). Amygdala modulation of parahippocampal and frontal regions during emotionally influenced memory storage. *NeuroImage*, 20(4), 2091–2099.

Kohlberg, L. (1969). Stage and sequence: The cognitive-developmental approach to socialization. In D. Goslin (Ed.), *Handbook of socialization theory and research* (pp. 347–480). New York: Rand McNally.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, 38(3), 557–577. doi: 10.1017/S0048577201990559



- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). *International affective picture system IAPS: technical manual and affective ratings*. Gainesville, FL: NIMH Center for the Study of Emotion and Attention. Retrieved from: [http://www.bcn-nic.nl/txt/research/research\\_Pharmaco\\_fMRI/bibliography/lang2008.pdf](http://www.bcn-nic.nl/txt/research/research_Pharmaco_fMRI/bibliography/lang2008.pdf)
- Lazarus, R. S. (1994). *Emotion and adaptation*. New York: Oxford University Press.
- Leech, R., & Sharp, D. J. (2014). The role of the posterior cingulate cortex in cognition and disease. *Brain*, *137*, 12–32. doi: 10.1093/Brain/Awt162
- Lim, S.-L., O'Doherty, J. P., & Rangel, A. (2013). Stimulus value signals in ventromedial PFC reflect the integration of attribute value signals computed in fusiform gyrus and posterior superior temporal gyrus. *Journal of Neuroscience*, *33*(20), 8729–8741. doi: 10.1523/JNEUROSCI.4809-12.2013
- Mallon, R., & Nichols, S. (2011). Dual processes and moral rules. *Emotion Review*, *3*(3), 284–285. doi: 10.1177/1754073911402376
- Markus, H. R., & Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review*, *98*(2), 224–253. doi: <http://dx.doi.org/10.1037/0033-295x.98.2.224>
- Mathes, B., Schmiedt, J., Schmiedt-Fehr, C., Pantelis, C., & Basar-Eroglu, C. (2012). New rather than old? For working memory tasks with abstract patterns the P3 and the single-trial delta response are larger for modified than identical probe stimuli. *Psychophysiology*, *49*(7), 920–932. doi: 10.1111/j.1469-8986.2012.01372.x
- Moll, J., & de Oliveira-Souza, R. (2007). Moral judgments, emotions and the utilitarian brain. *Trends in Cognitive Sciences*, *11*(8), 319–321. doi: 10.1016/j.tics.2007.06.001

- Moll, J., de Oliveira-Souza, R., Bramati, I. E., & Grafman, J. (2002). Functional networks in emotional moral and nonmoral social judgments. *NeuroImage*, *16*(3 Pt 1), 696–703.
- Moll, J., de Oliveira-Souza, R., Eslinger, P. J., Bramati, I. E., Mourão-Miranda, J., Andreiuolo, P. A., & Pessoa, L. (2002). The neural correlates of moral sensitivity: a functional magnetic resonance imaging investigation of basic and moral emotions. *Journal of Neuroscience*, *22*(7), 2730–2736. doi: <http://www.jneurosci.org/content/22/7/2730.long>
- Moll, J., de Oliveira-Souza, R., & Zahn, R. (2008). The neural basis of moral cognition: sentiments, concepts, and values. *Annals of the New York Academy of Sciences*, *1124*, 161–180. doi: 10.1196/annals.1440.005
- Moll, J., Zahn, R., de Oliveira-Souza, R., Krueger, F., & Grafman, J. (2005). The neural basis of human moral cognition. *Nature Reviews Neuroscience*, *6*(10), 799–809. doi: 10.1038/nrn1768
- Nichols, T. E., & Holmes, A. P. (2002). Nonparametric permutation tests for functional neuroimaging: a primer with examples. *Human Brain Mapping*, *15*(1), 1–25. doi: 10.1002/hbm.1058
- Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: an integrative review of ERP findings. *Biological Psychology*, *77*(3), 247–265. doi: 10.1016/j.biopsycho.2007.11.006
- Ortigue, S., Thompson, J. C., Parasuraman, R., & Grafton, S. T. (2009). Spatio-temporal dynamics of human intention understanding in temporo-parietal cortex: a combined EEG/fMRI repetition suppression paradigm. *PLoS One*, *4*(9), e6962. doi: 10.1371/journal.pone.0006962
- Padoa-Schioppa, C., & Assad, J. A. (2006). Neurons in the orbitofrontal cortex encode

economic value. *Nature*, 441(7090), 223–226. doi: 10.1038/nature04676

- Parasuraman, R., de Visser, E., Clarke, E., McGarry, W. R., Hussey, E., Shaw, T., & Thompson, J. C. (2009). Detecting threat-related intentional actions of others: effects of image quality, response mode, and target cuing on vigilance. *Journal of Experimental Psychology: Applied*, 15(4), 275–290. doi: 10.1037/a0017132
- Paré, D., Collins, D. R., & Pelletier, J. G. (2002). Amygdala oscillations and the consolidation of emotional memories. *Trends in Cognitive Sciences*, 6(7), 306–314. doi: [http://dx.doi.org/10.1016/S1364-6613\(02\)01924-1](http://dx.doi.org/10.1016/S1364-6613(02)01924-1)
- Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. *Methods and Findings in Experimental and Clinical Pharmacology*, 24(Suppl D), 5–12.
- Paynter, C. A., Reder, L. M., & Kieffaber, P. D. (2009). Knowing we know before we know: ERP correlates of initial feeling-of-knowing. *Neuropsychologia*, 47(3), 796–803. doi: 10.1016/j.neuropsychologia.2008.12.009
- Pearson, J. M., Heilbronner, S. H., Barack, D. L., Hayden, B. Y., & Platt, M. L. (2011). Posterior cingulate cortex: adapting behavior to a changing world. *Trends in Cognitive Sciences*, 15(4), 143–151. doi: 10.1016/j.tics.2011.02.002
- Petrini, K., Piwek, L., Crabbe, F., Pollick, F. E., & Garrod, S. (2014). Look at those two!: The precuneus role in unattended third-person perspective of social interactions. *Human Brain Mapping*, 35(10), 5190–5203. doi: 10.1002/hbm.22543
- Phelps, E. (2004). Human emotion and memory: interactions of the amygdala and hippocampal complex. *Current Opinion in Neurobiology*, 14(2), 198–202. doi: 10.1016/j.conb.2004.03.015
- Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical*

*Neurophysiology*, 118(10), 2128–2148. doi: 10.1016/j.clinph.2007.04.019

Sabatinelli, D., Keil, A., Frank, D. W., & Lang, P. J. (2013). Emotional perception: correspondence of early and late event-related potentials with cortical and subcortical functional MRI. *Biological Psychology*, 92(3), 513–519. doi: 10.1016/j.biopsycho.2012.04.005

Sarlo, M., Lotto, L., Manfrinati, A., Rumiati, R., Gallicchio, G., & Palomba, P. (2012). Temporal dynamics of cognitive-emotional interplay in moral decision-making. *Journal of Cognitive Neuroscience*, 24(4), 1018–1029. doi: 10.1162/jocn\_a\_00146

Schaich Borg, J., Hynes, C., Van Horn, J., Grafton, S., & Sinnott-Armstrong, W. (2006). Consequences, action, and intention as factors in moral judgments: an fMRI investigation. *Journal of Cognitive Neuroscience*, 18(5), 803–817. doi: 10.1162/jocn.2006.18.5.803

Schoenbaum, G., Roesch, M. R., & Stalnaker, T. A. (2006). Orbitofrontal cortex, decision-making and drug addiction. *Trends in Neurosciences*, 29(2), 116–124. doi: 10.1016/j.tins.2005.12.006

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghofer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in Brain Research*, 156, 31–51. doi: 10.1016/S0079-6123(06)56002-9

Sekihara, K., Sahani, M., & Nagarajan, S. S. (2005). Localization bias and spatial resolution of adaptive and non-adaptive spatial filters for MEG source reconstruction. *NeuroImage*, 25(4), 1056–1067. doi: 10.1016/j.neuroimage.2004.11.051

Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP.

*Psychophysiology*, 23(6), 695–703.

Sinke, C. B. A., Sorger, B., Goebel, R., & de Gelder, B. (2010). Tease or threat?

Judging social interactions from bodily expressions. *NeuroImage*, 49(2),

1717–1727. doi: 10.1016/j.neuroimage.2009.09.065

Valdesolo, P., & DeSteno, D. (2006). Manipulations of emotional context shape moral

judgment. *Psychological Science*, 17(6), 476–477. doi:

10.1111/j.1467-9280.2006.01731.x

Wagar, B. M., & Thagard, P. (2003). Using computational neuroscience to investigate

the neural correlates of cognitive-affective integration during covert decision

making. *Brain and Cognition*, 53(2), 398–402. doi:

[http://dx.doi.org/10.1016/s0278-2626\(03\)00153-2](http://dx.doi.org/10.1016/s0278-2626(03)00153-2)

Wheatley, T., & Haidt, J. (2005). Hypnotic disgust makes moral judgments more

severe. *Psychological Science*, 16(10), 780–784. doi:

10.1111/j.1467-9280.2005.01614.x

Wright, J. C., & Baril, G. (2011). The role of cognitive resources in determining our

moral intuitions: Are we all liberals at heart? *Journal of Experimental Social*

*Psychology*, 47(5), 1007–1012. doi: 10.1016/j.jesp.2011.03.014

Wright, M. J., Luciano, M., Hansell, N. K., Geffen, G. M., Geffen, L. B., & Martin, N.

G. (2002). Genetic sources of covariation among P3(00) and online

performance variables in a delayed-response working memory task. *Biological*

*Psychology*, 61(1-2), 183–202.

Yoder, K. J., & Decety, J. (2014). Spatiotemporal neural dynamics of moral judgment:

A high-density ERP study. *Neuropsychologia*, 60, 39–45. doi:

10.1016/j.neuropsychologia.2014.05.022

Young, L., Cushman, F., Hauser, M., & Saxe, R. (2007). The neural basis of the

interaction between theory of mind and moral judgment. *Proceedings of the National Academy of Sciences*, 104(20), 8235–8240. doi: 10.1073/pnas.0701408104

Yuan, J., Luo, Y., Yan, J. H., Meng, X., Yu, F., & Li, H. (2009). Neural correlates of the females' susceptibility to negative emotions: an insight into gender-related prevalence of affective disturbances. *Human Brain Mapping*, 30(11), 3676–3686. doi: 10.1002/hbm.20796

Zhong, C.-B., & Liljenquist, K. (2006). Washing away your sins: threatened morality and physical cleansing. *Science*, 313(5792), 1451–1452. doi: 10.1126/science.1130726

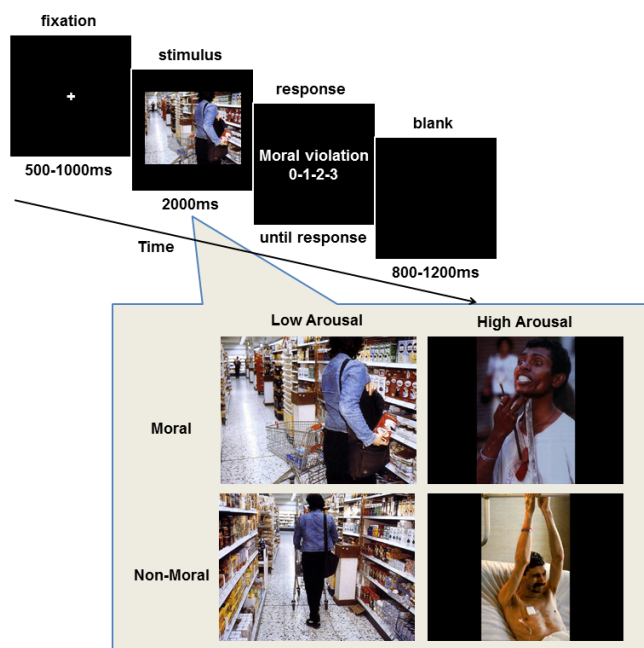
**Table 1.**

**Anatomical regions and locations of N1, N2, LPP, and slow-wave components obtained from the sLORETA analysis.**

<b>Anatomical regions</b>	<b>Brodmann area</b>	<b>Talairach coordinates (x, y, z)</b>	<b>Voxel Value (Peak)</b>
<b>N1 time window</b>			
<b>Moral &gt; Non-moral</b>			
Inferior parietal lobule	40	(40, -42, 39)	3.95
Postcentral gyrus	3	(35, -27, 52)	3.36
Posterior cingulate	30	(0, -43, 21)	3.20
<b>N2 time window</b>			
<b>High arousal &gt; Low arousal</b>			
Parahippocampal Gyrus	34	(15, -1, -17)	4.84
Uncus	28	(20, -6, -25)	4.81
Parahippocampal Gyrus	28	(15, -5, -12)	4.73
<b>LPP time window</b>			
<b>High arousal &gt; Low arousal</b>			
Parahippocampal gyrus	34	(20, -11, -16)	4.79
Parahippocampal gyrus	28	(20, -11, -20)	4.66
Uncus	20	(30, -16, -24)	4.39
<b>Slow wave time window</b>			
<b>Moral low arousal &gt; Non-moral low arousal</b>			
Middle frontal gyrus	11	(-35, 58, -11)	7.65
Middle frontal gyrus	10	(-35, 58, -7)	7.59
Precuneus	7	(0, -61, 45)	5.28

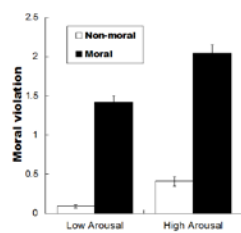
## Figure captions

**Figure 1. Time course of a single trial.** Each trial began with a fixation point presented for 500 to 1000 ms, followed by the stimulus for 2000 ms. A screen displaying the rating scale (0 to 3) was shown until the participant responded. The inter-trial interval was randomized between 800 and 1200 ms. For each stimulus, the participants were instructed to determine whether people or events in the pictures represented a moral violation.

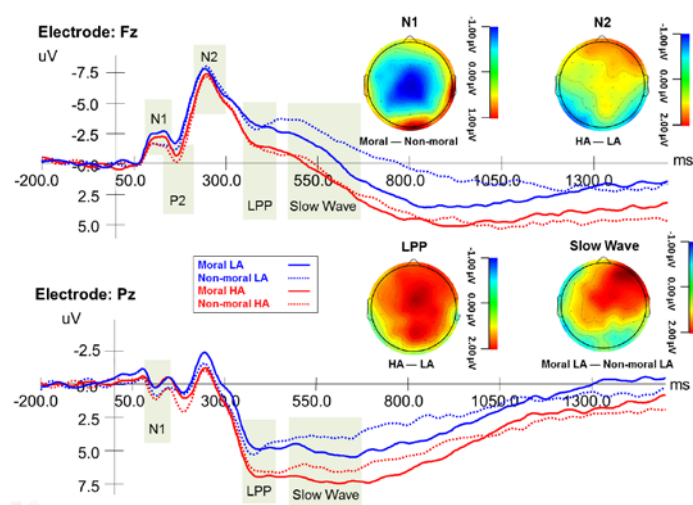




**Figure 2. Mean moral violation ratings of high- and low-arousal pictures with moral and non-moral content. The error bars show  $\pm$  one standard error.**



**Figure 3. Grand-averaged ERP waveforms at the Fz and Pz recording sites, as evoked by high- and low-arousal pictures in moral and non-moral contexts. Topographic maps of difference waves are shown for the N1, N2, LPP, and slow-wave components for selected contrasts. ERPs were recorded time-locked to the stimulus onset, which is the time point 0 in the plot. (Key: LA: low-arousal; HA: high-arousal; Moral–Non-moral: difference wave of moral and non-moral conditions).**



**Figure 4. sLORETA source differences in estimated current density of the N1 (a), N2, LPP (b), and slow-wave (c) components. a.** The moral condition showed significantly increased N1 activity in the right inferior parietal lobule (Brodmann area [BA] 40), postcentral gyrus (BA 3) and posterior cingulate (BA 30) as compared with the non-moral condition; **b.** The high-emotional-arousal condition showed significantly increased N2 and LPP activity in the parahippocampal gyrus and uncus (BA 34, 28) as compared with the low-emotional-arousal condition; **c.** The low-arousal moral condition showed increased activity as compared with the low-arousal non-moral condition in the middle frontal gyrus (BA 10/11) and precuneus (BA 7).

