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# Personal and impersonal stimuli differentially engage brain networks during moral reasoning

Shao-Wei Xue [a,1], Yan Wang [a,1], Yi-Yuan Tang [a,b,*]

[a] Institute of Neuroinformatics and Laboratory for Body and Mind, Dalian University of Technology, Dalian 116024, China
[b] Texas Tech Neuroimaging Institute and Department of Psychology, Texas Tech University, Lubbock, TX 79409, USA

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ABSTRACT

Moral decision making has recently attracted considerable attention as a core feature of all human endeavors. Previous functional magnetic resonance imaging studies about moral judgment have identified brain areas associated with cognitive or emotional engagement. Here, we applied graph theory-based network analysis of event-related potentials during moral decision making to reveal the personal/impersonal distinction in the organization of functional connectivity. Our results indicated that the personal task had more larger long-range connections involved in frontal regions and the right hemisphere, and higher network efficiency of some frontal electrodes such as F2 than the impersonal. These might be related to brain resource reorganization contributing to efficient conflict resolution. These findings provide new insights into neural mechanisms of moral dilemmas.



## 1. Introduction

Moral decision making is increasingly coming under scientific scrutiny as a core feature of all human endeavors (Youssef, Dookeeram, Basdeo, et al., 2012). Traditional psychological theories emphasized the role of high-level cognitive processes in moral judgment, whereas a more recent trend placed an increased emphasis on emotional processes (Greene, Nystrom, Engell, Darley, & Cohen, 2004). However, these two processes might be integrative and mutually competitive, even elicit a conflict (Forbes & Grafman, 2010). Executive conflict resolution during moral decision making at various conditions required different efficient information processing in the brain.

Many previous studies (Greene, 2009; Greene, Sommerville, Nystrom, Darley, & Cohen, 2001; Greene et al., 2004) have used functional magnetic resonance imaging (fMRI) to study the neural correlates of moral judgments. Moral dilemmas are divided into personal and impersonal categories. Personal dilemmas have these actions that are likely to cause serious harm to particular person(s), but this harm is not the result of deflecting an existing threat onto a different party; the others were assigned to the impersonal condition. Greene and colleagues (Greene et al., 2001) found that personal moral judgments were more likely to elicit increased activation in some brain areas involved in emotion processing including medial frontal gyrus and amygdale, and during impersonal and non-moral dilemmas some other brain regions (i.e. inferior parietal) associated with cognitive control processes exhibited increased activity. Besides, they also found comparatively little difference between the impersonal-moral and non-moral conditions, suggesting that impersonal moral judgment has less in common with personal moral judgment than with certain kinds of non-moral practical judgment.

In the present study, participants need for making the decision whether or not their actions were appropriate during the personal and impersonal dilemmas, and from new perspective we conducted functional connectivity analysis of event-related potentials (ERPs) data to study their difference. Human brain networks derived from functional connectivity patterns have been observed to exhibit optimal organization patterns in diverse experimental modalities, such as maximal efficiency of information process at minimal wiring costs (Achard & Bullmore, 2007; Driver, Blankenburg, Bestmann, & Ruff, 2010; Sporns, 2011; Stam & Reijneveld, 2007; Wang, Zuo, & He, 2010), and even thought to provide the physiological basis for the efficiency of information processing and mental representations (Bullmore & Sporns, 2009). Many recent studies indicated differences in the network topological parameters associated with an array of factors including age (Micheloyannis, Vourkas, Tsirka, et al., 2009), gender (Gong, Rosa-Neto, Carbonell, et al., 2009), mental diseases (Seeley, Crawford, Zhou, Miller, & Greicius, 2009) and behavioral variability (Bassett, Bullmore, Meyer-Lindenberg, et al., 2009; Moussa, Vechlekar, Burdette, et al., 2011; Xue, Tang, & Posner, 2011).

On the basis of the above studies, we hypothesized that personal and impersonal tasks might differentially engage brain networks during moral decision making. To test the hypothesis, we applied

* Corresponding author. Address: Institute of Neuroinformatics and Laboratory for Body and Mind, Dalian University of Technology, Dalian 116024, China. Fax: +86 411 84706046.
*E-mail address:* yy2100@126.com (Y.-Y. Tang).
[1] These authors contributed equally to this work.

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network analysis approaches to multichannel event-related potentials (ERPs) during the two tasks. Functional connectivity between brain activity at different electrodes was estimated using the synchronization likelihood method (Stam & Van Dijk, 2002). We modeled the whole brain as undirected graphs for each subject and then investigated the network topology of these subjects.

## 2. Methods

### 2.1. Participants

Eighteen healthy Chinese undergraduate or graduate students (14 males, mean age, 25 ± 2.36 (SD) yrs) participated in the study. All participants were right-handed native speakers of Chinese and had normal or corrected-to-normal vision, without history of neurological or psychiatric disorders and experience any severe or prolonged negative life events, and received no psychotropic medications or medicinal herbs based on their self-report. The experiment was approved by the local Institutional Review Board.

### 2.2. Task and procedure

The stimulus materials were based on a battery of dilemmas developed by Greene et al., which was previously used in some fMRI studies (Fumagalli, Ferrucci, Mameli, et al., 2010; Greene, Morelli, Lowenberg, Nystrom, & Cohen, 2008; Greene et al., 2001; Walter, Montag, Markett, et al., 2012). We made use of 40 dilemmas including personal and impersonal ones in Chinese version. The dilemmas were presented on the computer monitor as text through a series of three different screenshots; the first two described the scenario of the problem and in the last the participants were required to provide a morally appropriate or inappropriate response to actions described in scenario. The black words were presented in the center against a grey background. The screens remained visible for only pressing a button before the program automatically loaded the next dilemma whether or not a response was provided. In order to familiarize participants with the task, experiment started with three practice trials. Participants were seated comfortably, with their eyes about 57 cm from a computer screen and instructed to minimize eye movements to avoid excessive artifact. Stimulus generation and presentation were controlled by a PC running E-Prime software (version 1.1; Psychology Software Tools, Pittsburgh, USA).

An example of personal moral dilemma was the footbridge dilemma which decided whether or not to push and sacrifice a stranger onto the track of an oncoming trolley to save five people (Moll & de Oliveira-Souza, 2007). In a quite similar situation, an impersonal moral dilemma involved having to decide whether or not to hit a switch that would turn the trolley to an alternate set of tracks, where it would kill one person instead of five (the trolley dilemma) (Ciaramelli, Muccioli, Làdavas, & Di Pellegrino, 2007).

### 2.3. Data acquisition and preprocessing

Electroencephalography was recorded continuously from 64 Ag/AgCl scalp electrodes recording system (Brain Products GmbH, Munich, Germany) at a rate of 500 Hz and bandpass filtered between 1 Hz and 40 Hz. The electrode was placed according to International 10-20 System nomenclature. Skin resistance at each site was <5 kΩ. The EEG data was re-referenced to both ear lobes (average signals of TP9 and TP10). The vertical eye movements were monitored with electrodes placed above and below the left eye.

Off-line EEG data analysis was performed with commercially available software (Vision Analyzer, Brain Products GmbH, Germany). ERP epochs began 200 ms prior to stimulus onset and continued for 2000 ms thereafter. Baseline correction was performed relative to the 200 ms before the question arousing screen onset after averaged. Individual ERP averages were created for each stimulus category in each dilemma condition respectively (personal or impersonal).

For the purpose of network analysis, the following 56 electrode points were chosen: FP1, FP2, F7, F3, FZ, F4, F8, FC1, FC2, T7, C3, CZ, C4, T8, CP5, CP1, CP2, CP6, P7, P3, PZ, P4, P8, O1, OZ, O2, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FT7, FC3, FC4, FT8, C5, C1, C2, C6, TP7, CP3, CPZ, CP4, TP8, P5, P1, P2, P6, PO7, PO3, POZ, PO4 and PO8.

### 2.4. Synchronization likelihood

Synchronization likelihood is a general measure of the temporal correlation between two time series sensitive to linear as well as non-linear statistical interdependencies (Stam & Van Dijk, 2002).

A time series of $N$ samples is converted $x[t_0+(k-1)t]$, $k = 1, 2, \cdots, N$, as a series of state space vectors using the method of time delay embedding where $L$ is the time lag and m the embedding dimension.

$$x_i = (x_i, x_{i+L}, x_{i+2\times L}, x_{i+3\times L}, \ldots, x_{i+(m-1)\times L}), \tag{1}$$

where $(N - m \times L)$ vectors can be reconstructed.

For channel number a, each time $i$ and the probability $P_{a,i}$ embedded vectors are closer to each other than a distance $\varepsilon$:

$$P_{a,i} = \frac{1}{2(W_2 - W_1)} \sum_{\substack{j=1 \\ W_1 < |j-i| < W_2}}^{N} \theta(\varepsilon - |X_{a,i} - X_{a,j}|), \tag{2}$$

where $\theta(x)$ is the Heaviside function: $\theta(x) = 0$ if $x \leqslant 0$ and $\theta(x) = 1$ if $x > 0$. The vertical bars $|\cdot|$ represent the Euclidean distance between the vectors.

The synchronization likelihood between two electrodes (i.e. a and b) can now be formally defined as:

$$S_i = \frac{1}{2 \times (W_2 - W_1) + 1} \sum_{|i-j|=W_1}^{W_2} \theta(\varepsilon_a - |X_{a,i} - X_{a,j}|) \times \theta(\varepsilon_b - |X_{b,i} - X_{b,j}|), \tag{3}$$

The following parameters were used: $L = 10$, $m = 10$, $W_1 = 100$, $W_2 = 500$, and $P_{ref} = 0.01$.

### 2.5. The construction of brain networks

In the present study, we regarded brain networks as graph representations of brain activity acquired by ERP data, where the vertices represented channels and the edges described their synchronization likelihood between each pair of electrodes. The synchronization likelihood matrices were thresholded into a set of undirected binary graphs with the connection density values ranged from 0.1 to 0.4 (with an increment of 0.01), whose element was 1 if there was large coefficient between the two channels; and 0 otherwise. A threshold could ensure that each network had the same number of edges or wiring cost. The range of threshold was chosen here to allow prominent topological properties in brain functional networks to be observed (Liu, Liang, Zhou, et al., 2008).

We mainly focused on the two network properties including degree and efficiency at the nodal level. In graph theory, the degree $k$ was the number of edges linking it to the rest of the network, which was also equal to the number of neighbors of the node, and was defined as follows:

$$k(i) = \sum_{i \neq j \in G} A_{i,j}, \tag{4}$$

where $A$ was the binary adjacency matrix. A high degree indicates that a node had a central role for the communication spreading