

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

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### ARTICLE INFO

#### Article history:

Accepted 17 September 2012

Available online 17 November 2012

#### Keywords:

Brain networks

Moral judgment

Event-related potentials

Synchronization likelihood

### 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.

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### 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, Vecchlekar, 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

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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,  $25 \pm 2.36$  (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, Mamelì, 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, Lådavas, & 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  $<5$  k $\Omega$ . 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  $x[t_0 + (k - 1)t]$ ,  $k = 1, 2, \dots, N$ , 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.

$$X_i = (X_i, X_{i+L}, X_{i+2 \times L}, X_{i+3 \times L}, \dots, X_{i+(m-1) \times L}), \quad (1)$$

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  $\varepsilon$ :

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

$$W_1 < |j - i| < W_2$$

where  $\theta(x)$  is the Heaviside function:  $\theta(x) = 0$  if  $x \leq 0$  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:

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

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:

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

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

within the network, as its removal would reduce sensibly the overall connectivity.

We likewise defined nodal efficiency as the inverse of the harmonic mean of the shortest path length ( $d_{ij}$ ) between an index node and all other nodes in the network. For each threshold, efficiency  $E(i)$  was computed for each node:

$$E(i) = \frac{1}{N-1} \sum_{i \neq j \in G} \frac{1}{d_{ij}}, \quad (5)$$

nodal efficiency measured the extent to which the node connects all other nodes of a network, its efficiency of integrated information processing and how well information propagates over the network.

### 3. Results

Behavioral data revealed that there were no significant differences in response time and mean proportion for “appropriate” choice for personal and impersonal dilemmas ( $p > 0.05$ ). And there were also no significant differences in response time between “appropriate” and “inappropriate” in personal and impersonal conditions ( $p > 0.05$ ).

In the present study, we used synchronization likelihood to describe functional connectivity between any pair of electrodes. Comparing all the 1540 ( $56 \times 55/2$ ) functional connectivity between the personal task and the impersonal one, we found that there were significant differences in the strength of some functional connectivity between the two tasks (paired  $t$ -test,  $p < 0.05$ ). As shown in Fig. 1, these connectivity which the personal task exhibited significant larger than the impersonal task were mainly long-distance connections associated with frontal regions and the right hemisphere.

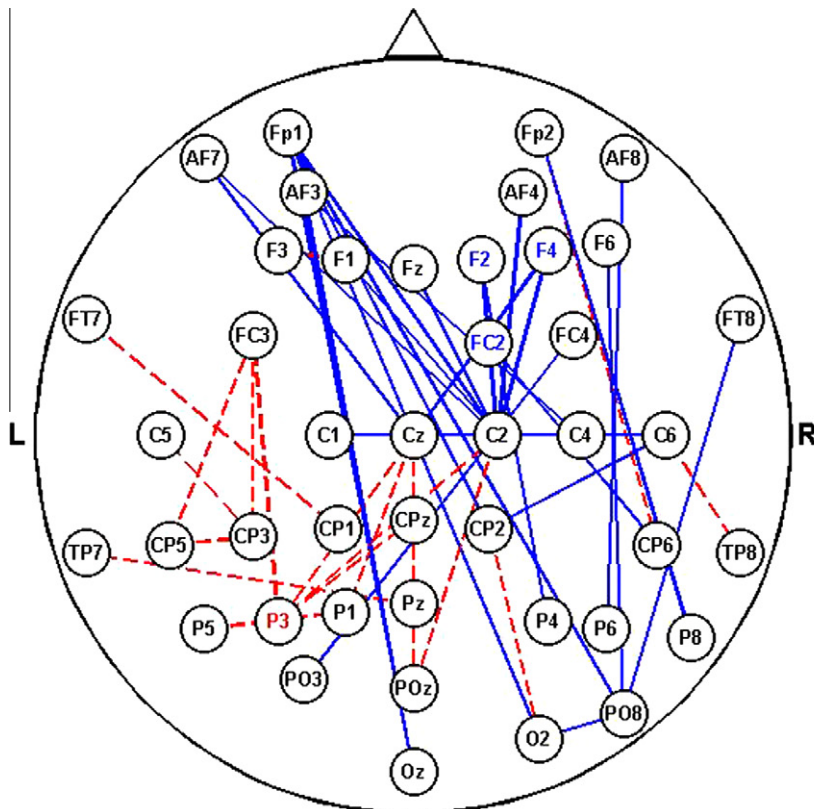
Fig. 2 demonstrates that the personal condition exhibited significantly higher (paired  $t$ -test,  $p < 0.05$ ) nodal efficiency of the frontal

electrode F2 than the impersonal over the connection density ranged between 10% and 40%. Two other network nodes (F4 and FC2) beside F2 showed a similar tendency toward higher efficiency in the personal than impersonal condition. On the other hand, electrode P3 exhibited an opposite trend, with a larger efficiency in the impersonal task than the personal. No statistically significant differences ( $p > 0.05$ ) were found in efficiency of the whole brain network between the two tasks. The space of electrodes was shown in Fig. 1. In line with the efficiency findings, we also found that the personal condition had a greater nodal degree value than the impersonal for these tree electrodes mentioned above, while electrode P3 was the opposite.

### 4. Discussion

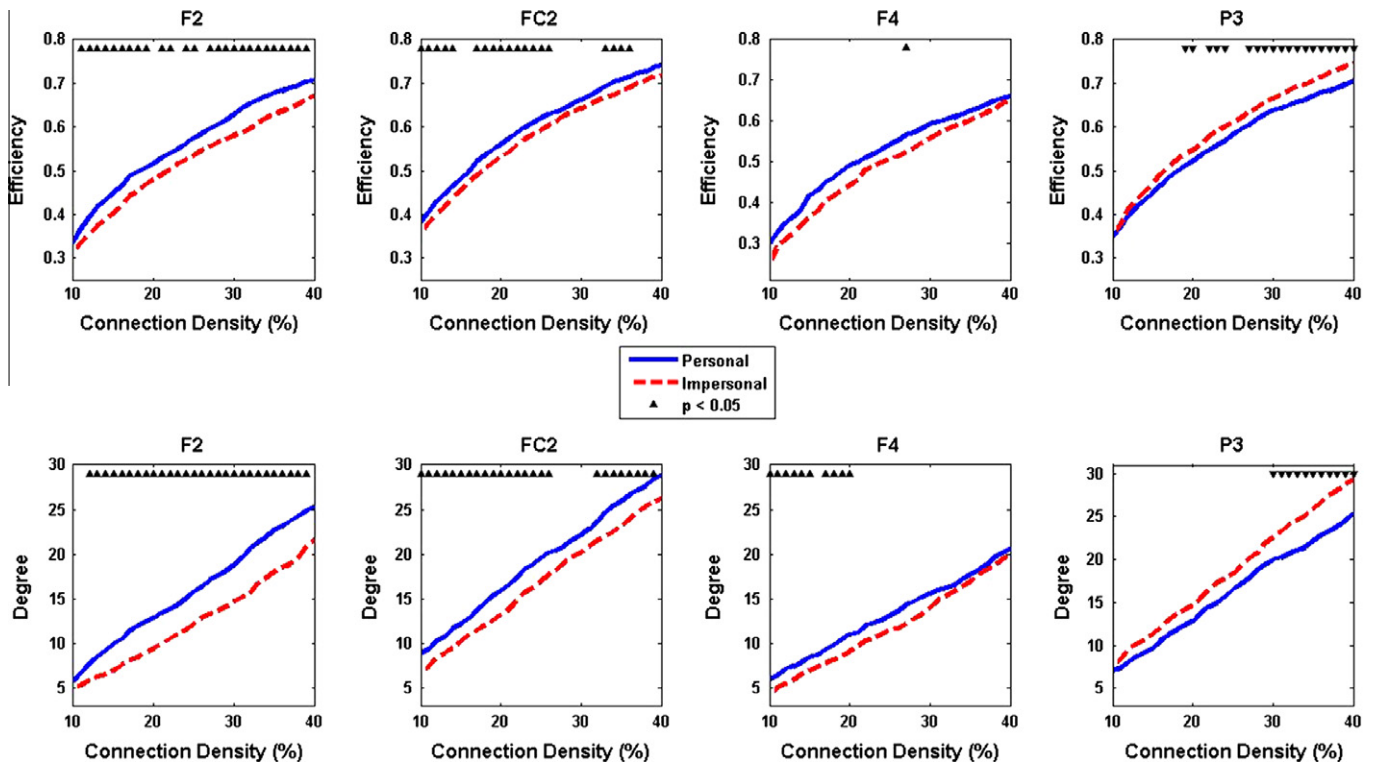
Unlike most previous studies (Greene, 2009; Greene et al., 2004) of moral reasoning that focused on brain regions identified to be involved in moral cognition by fMRI, we investigated the differences of functional connectivity representing by synchronization likelihood throughout the entire brain derived from ERP data and then focused on the differences in topological parameters of network nodes. The connectivity patterns were used to describe the distinction between personal and impersonal moral dilemmas.

Personal moral dilemmas are driven largely by social-emotional responses, while impersonal ones are driven less by social-emotional responses and more by cognitive processes (Greene et al., 2004). During moral decision making, utilitarian values induce personal moral violations, which have previously reported to relate to increased activity in emotion-related brain regions (i.e. ventromedial prefrontal cortex) (Huebner, Dwyer, & Hauser, 2009). In this sense, both utilitarian reasoning and emotional intuition might play crucial and, in some cases, mutually competitive roles (Greene, 2009). Personal moral dilemmas involve a conflict be-



Synchronization likelihood					
Personal > Impersonal			Personal < Impersonal		
Electrode 1	Electrode 2	P value	Electrode 1	Electrode 2	P value
Fp1	Cz	0.049	Fp2	CP6	0.047
Fp1	CP2	0.007	F3	F1	0.007
Fp1	Oz	0.012	Cz	P3	0.012
Fp1	O2	0.008	Cz	P1	0.044
Fp1	C2	0.016	Cz	POz	0.041
Fp1	PO8	0.017	CP5	FC3	0.010
Fp2	P8	0.017	CP5	CP3	0.026
Fz	C2	0.024	CP1	FT7	0.019
F4	Cz	0.046	CP2	O2	0.018
F4	C2	0.008	P3	FC3	0.039
FC2	CP6	0.024	P3	C2	0.021
Cz	AF7	0.041	P3	CPz	0.016
C4	AF3	0.006	Pz	TP7	0.033
P4	F2	0.026	FC3	CP3	0.041
Oz	AF3	0.018	C5	CP3	0.027
AF7	C2	0.004	C2	POz	0.044
AF4	C2	0.022	C6	TP8	0.033
AF8	P6	0.007	P5	P1	0.047
F1	C2	0.033	C2	POz	0.044
F2	C2	0.035	C6	TP8	0.033
F6	PO8	0.021	P5	P1	0.047
FC4	PO3	0.034			
FT8	PO8	0.021			
C1	C6	0.010			
Cz	C6	0.032			
CP2	C6	0.031			
O2	PO8	0.047			

Fig. 1. The comparisons of the strength of functional connectivity between the moral personal and impersonal conditions (paired  $t$ -test,  $p < 0.05$ ). R = right hemisphere and L = left hemisphere.



**Fig. 2.** Nodal topological properties of brain functional networks. Network measures of the four electrode nodes (y axis) are shown as a function of connection density (x axis). Black triangles upright indicate where the difference between the personal and impersonal conditions is significant (paired *t*-test,  $p < 0.05$ ).

tween social-emotional responses that drive people to disapprove of personal moral violations and cognitive processes that drive people to approve of such violations in the relevant contexts (Youssef et al., 2012). These puzzling patterns are usually explained in commonsense moral thought using a dual-process theory of moral judgment proposed by Greene and colleagues (Joshua, 2007).

In the present study, the interpretations of our finding are that the personal task might be more emotionally salient and need more brain resources in the right hemisphere to process emotional information (Schwartz, Davidson, & Maer, 1975), and more long-distance connections involved in frontal regions appearing stronger indicated higher functional integration (Supekar, Musen, & Menon, 2009) contributing to conflict processing (Forbes & Grafman, 2010) because of inflicting direct harm to a person, compared with the impersonal condition.

We found the personal condition had some electrode nodes with higher efficiency and degree value than the impersonal, while these electrode nodes were able to record neuronal activity from the brain areas associated with processing conflict including anterior cingulate cortex (Badzakova-Trajkov, Barnett, Waldie, & Kirk, 2009; Botvinick, Braver, Barch, Carter, & Cohen, 2001; Kim, Kroger, & Kim, 2011), and so the personal condition might need more brain resources of effectively conflict resolution between cognitive and emotional process to be mediated (Pochon, Riis, Sanfey, Nystrom, & Cohen, 2008). The results are consistent with the previous finding that personal moral dilemmas exhibited increased anterior cingulate activity (Greene et al., 2004).

## 5. Conclusion

In summary, we have applied graph theory-based network analysis of ERP data in moral decision making to study the personal/impersonal distinction in organization of functional connectivity. Our results indicated that the personal task had some larger long-range connections involved in frontal regions and the right

hemisphere than the impersonal and higher network efficiency of some frontal electrodes. This may be related to brain resource reorganization contributing to efficient conflict resolution. These findings might provide new insights into neural mechanisms of moral dilemmas. Future research is needed to explore intelligence-related differences in moral judgments.

## Acknowledgments

The authors thank Prof. Dr. C.J. Stam for providing source code of synchronization likelihood. The authors also thank the Institute of Neuroinformatics staff for assistance with data collection. This work was supported by National Natural Science Foundation of China 60971096, 973 Program 2012CB518200.

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