Title

Washing away your sins in the brain: physical cleaning and priming of cleaning recruit different brain networks after moral threat

Abbreviated title

The neural correlates of washing away your sins.

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Abstract

The association between moral purity and physical cleanliness has been widely discussed recently. Studies found that moral threat initiates the need of physical cleanliness, but actual physical cleaning and priming of cleaning have inconsistent effects on subsequent attitudes and behaviors. Here we used resting-state functional magnetic resonance imaging (fMRI) to explore the underlying neural mechanism of actual physical cleaning and priming of cleaning. After recalling moral transgression with strong feelings of guilt and shame, participants either actually cleaned their faces with **a wipe** or were primed with cleanliness through **viewing its pictures**. Results showed that actual physical cleaning reduced the spontaneous brain activities in the right insula and MPFC, regions that involved in embodied moral emotion processing, while priming of cleaning decreased activities in the right SFG and MFG, regions that participated in executive control processing. Additionally, actual physical cleaning also changed functional connectivity between insula/MPFC and emotion **related** regions, whereas priming of cleaning modified connectivity within both moral and sensorimotor areas. These findings revealed that actual physical cleaning and priming of cleaning led to changes in different brain regions and networks, providing neural evidence for the inconsistent effects of cleanliness on subsequent attitudes and behaviors.

Key words: embodiment, physical cleanliness, moral, resting-fMRI, social

Introduction

The metaphorical relationship between physical cleaning and moral purity has been widely discussed in recent years. The most vivid scenario for this association should be the Macbeth effect, that Lady Macbeth wanted to wash her hands after she murdered King Duncan, indicating immoral actions initiate the demand of physical cleanliness. Based on the embodiment theory, the moral purity metaphor is derived from the embodiment of abstract mental morality with concrete sensory experiences (Lakoff and Johnson, 1999; Winkielman *et al.*, 2015; Lee and Schwarz, in press).

Empirical behavioral studies provide evidence for the embodied moral purity metaphor in two directions. One is whether transgression of morality invokes the desirability of physical cleaning, in which researchers gained consistent findings that immorality such as recalling or performing an unethical action increased the preference of cleanliness related products (Zhong and Liljenquist, 2006; Lee and Schwarz, 2010b; Lee *et al.*, 2015). Another is how actual physical cleaning or priming sense of cleaning affects subsequent moral attitudes or behaviors, in which studies have found inconsistent results. For those studies investigated both manipulations, Zhong et al. (Zhong et al., 2010) found that both actual physical cleaning and priming of cleaning harshened moral judgement, but Schnall et al.'s study had inverse results that actual physical cleaning and priming of cleaning weakened the severity of moral judgment (Schnall *et al.*, 2008). For those studies investigated only one manipulation, physical cleaning leads to harsher (Helzer and Pizarro, 2011) or less extreme (Kaspar *et al.*, 2015) moral judgment, reduces moral

emotions and subsequent helping behaviors for both healthy people and obsessive-compulsive disorder patients after moral transgression (Zhong and Liljenquist, 2006; Reuven *et al.*, 2014; Lee *et al.*, 2015), but increases cheating/decreases donation (Lobel *et al.*, 2015). In contrast, priming of cleaning leads to more lenient moral judgment (Huang, 2014), increases reciprocity in trusting and willingness to donate (Liljenquist *et al.*, 2010), and increases fairness and trusting practices after handling and counting clean money compared to dirty money (Yang *et al.*, 2013). These results suggest that actual physical cleaning and priming of cleaning might have different underlying mechanisms, which could lead to mixed effects on subsequent mental states and behaviors.

Recently, researchers also explored the neural mechanisms of embodied moral purity metaphor (Schaefer *et al.*, 2015; Denke *et al.*, 2016). They replicated the behavioral findings in the first direction that immorality led higher desirability for cleaning products and found that the sensorimotor regions of the brain were involved in evaluating cleaning products rather than other products after doing an unethical deed. Since sensorimotor areas are found to be the regions that ground cognitive processes such as metaphor and emotion (Saxbe *et al.*, 2013; Schaefer *et al.*, 2013), these results give direct evidence for the neural correlates of the embodiment of moral purity. However, in the second direction, how physical cleaning and priming of cleaning alter mental states and the associated mechanisms in the brain remain unknown.

In the current study, we aimed to explore the neural mechanisms of actual

physical cleaning compared to priming of cleaning concept through resting-state functional magnetic resonance imaging (fMRI). We measured the changes of spontaneous brain activity and brain network before and after the cleaning/priming manipulation following an unethical recall and report. After recalling and reporting immoral behaviors, the subsequent attitudes and behaviors might be affected by those two cleanliness manipulations through different mechanisms (S. W. Lee & Schwarz, 2016). One is reducing the emotion arousal since cleanliness reduces negative emotional feelings such as guilt and shame (S. W. Lee et al., 2015; Zhong & Liljenquist, 2006). Another is releasing or strengthening the negative effect of moral threat on executive function that affects the control of behaviors (Kalanthroff *et al.*, 2017). In order to find out the corresponding brain mechanisms, we assigned participants randomly into actual physical cleaning and priming of cleaning groups by instructing them to **view pictures of a wet wipe and clean their face with the wet wipe (face was found to be more involved in the moral purity metaphor in Chinese participants) (Lee *et al.*, 2015) or just view pictures of it.** We hypothesized that the mixed effects of embodied purity metaphor on morality depend on whether and how the mental state changed after different cleaning manipulation.

Materials and Methods

Participants

Forty healthy college students from Beijing Normal University with no history of neurological or psychiatric disorders participated in this study and received payment.

Three participants were excluded for exhibiting head motion of >3.0 mm maximum translation during fMRI scan. The final dataset contained 37 participants (Cleaning group: 19 participants (9 females); 23.37 (SD = 1.83) years old; Priming group: 18 participants (12 females); 21.0 (SD = 2.30)). This study was approved by the Institutional Review Board of the State Key Laboratory of Cognitive Neuroscience and Learning at Beijing Normal University. Informed written consent was obtained from all participants.

Procedure

A life-event related questionnaire was used to screen participants about 1-2 weeks before they participated in the study. Participants were asked to recall an unethical deed done by themselves in their life (Zhong and Liljenquist, 2006; Lee *et al.*, 2015) on line, which needs to meet a six-sentence description (Wagner *et al.*, 2011) to ensure participants would be induced more guilt and shame (target emotions) than other filler emotions (anger, disgust, pride, relief, fear, and sadness). Only those participants who rated higher guilt and shame than other emotions participated in the following fMRI scanning.

In the cover story, participants were told to perform a fMRI study on their explicit and implicit attitudes toward consumer products and how their impression of products were generated. They were told to finish one filler recalling task and several different scales to help them focus on the study since they need to keep still without falling asleep in the scanner for more than 30 minutes. Post-experimental probing revealed that none of the participants

found out the real aim of the study.

The experimental fMRI scanning consisted of three sessions **after obtaining structural images**, in which the participants were asked to keep still without thinking about anything systematically or falling asleep in the scanner for 400 secs each. The first session (Baseline) measured the resting state for stabilizing baseline. Next, participants recalled and reported (with voice can be heard by themselves) the most unethical thing they had done in their life, and rated their current emotional feelings about “guilt” “shame” “excitement” “happiness” from 1 (Not strong at all) to 4 (Very strong). After that they finished the second scanning session (Before), and were then **asked to view pictures of a wet wipe and** given an antiseptic wipe allegedly for product evaluation to either try it on their face (Cleaning group) or just view pictures of it on the screen (Priming group) while lying in the scanner and keeping their heads as motionless as possible. **For the Cleaning group, after participants viewed the pictures, they exited the coil to try the wipe given by one experimenter while still lying on the bed of scanner with their head being as motionless as possible.** Finally, all participants finished the third session (After) to capture the state after different cleaning manipulations. After getting out of the scanner, **participants were told to finish several different questionnaires to check their state, including whether they slept or not in the scanner and** their current emotions with a 7-points scale (from 1 (Not at all) to 7 (Very strong)). In addition to guilt, shame, excitement, and happiness, they also rated other filler emotions (anger, disgust, pride, relief, sadness, surprise, pleasure, regret, calm, confidence, and

embarrassment). Here we used the rating scale different from the first one to reduce participants' suspicion of research purpose (that we are targeting the change of specific moral emotions) **and to avoid their automatically comparison between ratings inside and outside the scanner. After the whole experiment, no participants reported suspicions of the goal of the study.** A brief summary of the procedure was shown in Figure 1A.

Image Acquisition

MRI data were acquired using a Siemens Trio 3 T MRI scanner. Participants were fixed with straps and foam pads on their heads and lay still, being aware and relaxed with eye closed in the resting-state session. All participants reported in a post-scan questionnaire that they did not fall asleep during scanning. After localizing, a T1-weighted MP-RAGE sequence was used to obtain 3D structural images from each participant with 144 sagittal slices before functional MRI scanning; thickness = 1.33 mm; in-plane resolution = 256 × 256, repeat time (TR) = 2530 ms, echo time (TE) = 3.45 ms, inversion time (TI) = 1100 ms, flip angle = 9°, FOV = 256 × 256 mm. An echo-planar imaging (EPI) sequence was used to obtain functional MRI data with 33 axial slices; thickness = 3.5 mm; gap = 0.7 mm; in-plane resolution = 64 × 64, voxel size = 3.1 × 3.1 × 3.5 mm, repeat time (TR) = 2000 ms, echo time (TE) = 30 ms, flip angle = 90°, field of view (FOV) = 200 × 200 mm, 200 volumes. At the beginning of the third scanning session (After), a new localizing was done to align the data in this session with other two sessions in both groups **since the Cleaning group exited the coil to try the wipe**.

Data Analysis

For the behavioral data, all participants' ratings of four emotions after recalling were transformed to a 7-points scale through a formula "Y=(7-1)×(X-1)/ (4-1)+1", in which "Y" means the transformed rating in the 7-point scale and "X" means the original rating in the 4-point scale (Card, 2011). To test the changes of emotions before and after actual physical cleaning and priming of cleaning, we computed the difference of emotions by subtracting the transformed ratings (Before) from ratings out of scanner (After). Both one-sample t test and two-sample t test were used to see whether the difference of emotions were significantly larger than zero in two groups respectively and to see whether they were different between the two groups.

Then we used SPM8 (www.fil.ion.ucl.ac.uk/spm), Data Processing Assistant for Resting-State fMRI (Yan and Zang, 2010), **and DPABI (Yan *et al.*, 2016)** to process our fMRI data. For the adaptation of the participants to the scanning and signal stability, the first 10 volumes of the functional images were removed before slice timing and head motion correction in each session. Coregistration to the mean functional image and segmentation of structure brain image were done first. Each participant's functional images were then normalized onto the Montreal Neurological Institute space and resampled to a voxel size of 3 × 3 × 3 mm. Then we removed the linear trend of the time courses and filtered data with a band-pass filter (0.01-0.08 Hz) to remove noise and artifacts with extremely low or high frequencies. Spatial noises were reduced through 4 mm FWHM Gaussian kernel spatial smoothing.

Regional ALFF analysis. To capture the changes of brain resting-states, we focused

on the spontaneous brain activity using the low-frequency fluctuations (LFFs) in the blood oxygen level-dependent (BOLD) signal in resting-state fMRI (Cordes *et al.*, 2001; Fransson, 2005). Previous studies found that regional amplitudes of the LFFs (ALFF) was higher in gray matter than in white matter (Biswal *et al.*, 1995), and cognition impaired patients had abnormal ALFF than healthy people (Yu-Feng *et al.*, 2007; Hoptman *et al.*, 2010). Moreover, ALFF is correlated with semantic capacity (Wei *et al.*, 2012) and emotional state of survivors in earthquake (Lui *et al.*, 2009), suggesting its role in reflecting cognitive and emotional processes of mental states. Specifically, ALFF is sensitive to different resting-state conditions (Yan *et al.*, 2009), which would be appropriate to measure the changes of brain states before and after cleaning manipulation.

Analyses of LFFs were based on the grey matter with a probability higher than 0.2 in the SPM8 template, with 45,381 voxels. We extracted the sum of amplitudes within the 0.01-0.08 Hz LFFs as the ALFF value of each voxel (Yu-Feng *et al.*, 2007; Wei *et al.*, 2012). Mean ALFF value of each voxel within the template were computed and tested between sessions that after and before manipulation of cleaning with paired t-test in two groups respectively. Furthermore, to exclude the possibility that results were caused by the difference of the Before session in two groups, we also compared the ALFF of two groups in the After session (treating the ALFF in the Before session as covariates) and in the Before session (treating the ALFF in the Baseline session as covariates) with two-sample t-test.

Functional connectivity analysis. Based on the results of regional ALFF analysis,

we focused on finding the brain network underlying the actual physical cleaning and priming of cleaning effect. First, six head motion parameters, white matter and cerebrospinal fluid were regressed out. Significant regions founded in the comparison of the ALFF between the After and Before sessions were chosen as seeds to calculate the functional connectivity between them and other voxels in both two sessions respectively. The correlation coefficient (*r*) between the mean time series of the seed regions and other voxels in the brain were transformed into Fisher *z* value, generating a *z*-functional connectivity (*z*-FC) map for each participant. After that, *z*-FC between the After and Before sessions were compared through Resting-State fMRI Data Analysis Toolkit (Song *et al.*, 2011), to find the significantly changed network between the two sessions in two groups respectively.

Multiple comparisons were corrected by **3dClustSim (https://afni.nimh.nih.gov /pub/dist/doc/program_help/3dClustSim.html) (2000 iterations, 45,381 voxels in the mask, two sided) with AFNI (https://afni.nimh.nih.gov/afni) ($p<0.05$). We estimated the smooth kernel of each statistic map based on 4D residuals which is similar to the smoothness in FSL (Yan *et al.*, 2016).** The threshold of regional ALFF and functional connectivity analysis was combined with the voxel wise $p <$ 0.05 **and respectively estimated cluster size. For the table 1, corrected cluster size was >90 for the Cleaning group, >78 for the Priming group, >80 for the comparison between two groups, respectively. For the table 2, corrected cluster size was >111 for the right insula, >104 for the right MPFC, >102 for the right SFG, >101 for the right MFG, respectively.**

Results

Behavioral results

Emotion ratings in the screening questionnaires of "guilt" and "shame" were significantly higher than other emotions ($F_{(1,39)} = 62.69$, $p < 0.001$) and revealed no difference between two groups (ts < 1.21, ps > 0.24), ensuring invoking guilt and shame in the study. In the fMRI sessions, all participants reported higher feelings of guilt (Cleaning: 5.32 ± 1.80 (mean and SD); Priming: 6.11 ± 1.23) and shame (Cleaning: 4.89 ± 1.70; Priming: 6.22 ± 1.22) than happiness (Cleaning: 1.21 ± 0.92; Priming: 1.67 ± 1.19) and excitement (Cleaning: 1.21 ± 0.92; Priming: 1.67 ± 1.19) after recalling the unethical behavior (ts > 5.46, ps < 0.001). After actual physical cleaning and priming of cleaning manipulation, guilt (Cleaning: 2.32 ± 1.34; Priming: 2.61 ± 1.65) and shame (Cleaning: 2.32 ± 1.11; Priming: 2.61 ± 1.88) decreased significantly, happiness (Cleaning: 3.00 ± 1.20; Priming: 2.67 ± 1.33) increased significantly (t*s* > 2.28, $p < 0.03$) compared to emotions in the Before session as results shown in the one-sample t-test of the emotional difference between the After and Before sessions in Figure. 1B. While excitement increased in the Cleaning group (3.16 ± 1.43; $t_{(18)} = 3.32$, $p = 0.004$) but not in the Priming group (1.89 ± 0.96; $t_{(17)} = 0.30$, $p = 0.77$) in the After session than in the Before Session in the one-sample t-test. No difference of changes of guilt, shame, or happiness were found between two groups (t*s* < 1.5, ps > 0.14), and excitement increased more in the Cleaning group than that in the Priming group ($t_{(35)} = 2.31$, $p = 0.03$) (Figure. 1B). These

results indicated that both actual physical cleaning and priming of cleaning successfully reduced guilt and shame, and actual physical cleaning evoked more positive emotions such as excitement than priming of cleaning did. **In addition**, **filter emotions such as anger, disgust, pride, relief and sadness did not show difference between the two groups in the screening questionnaire, ts<1.74, ps>0.09. However, after the third scanning session (After), compared to the Priming group, the Cleaning group reported significantly higher "pride" (Cleaning: 2.68 ±1.73; Priming: 1.56 ±1.15, $t_{(35)}$ = 2.32, p=0.03), marginally higher "disgust" (Cleaning: 2.79 ±1.51; Priming: 1.94 ±1.21, $t_{(35)}$ = 1.87, p=0.07) and marginally lower "regret" (Cleaning: 1.89 ±0.88; Priming: 2.83 ±1.92, $t_{(35)}$ = -1.89, p=0.07). No difference was found for anger, relief, sadness, pleasure, embarrassment between the two groups in the ratings after the After session, ts<0.68, ps>0.50. These results indicated that actual physical cleaning and priming of cleaning could have different effects on pride, disgust and regret.**

fMRI results

Although guilt and shame decreased similarly after the manipulations in both Cleaning and Priming groups, brain regions in which ALFF significantly changed after the manipulations were quite different in two groups, such that the right insula (42, 18, -12) and medial frontal gyrus (MPFC) (9, 54, 15) showed significantly reduced ALFF in the After session than that in the Before session in the Cleaning but not Priming group (Figure. 2A), whereas ALFF of the right superior frontal gyrus (SFG) (15, 51, 48) and right middle frontal gyrus (MFG) (45, 51, 24) decreased

significantly in the Priming but not Cleaning group (Figure. 2B) (Table. 1). These results based on spontaneous brain activity suggested that brain mechanisms of actual physical cleaning and priming of cleaning might be different. In the After session, the spontaneous activities of many brain regions including the right insula still showed significant differences between two groups after controlling the spontaneous activity in the Before session, and **no brain regions showed significant** difference in the comparison of two groups' Before session when controlling the spontaneous activity of the Baseline session, excluding the possibility that the different mechanisms between two groups were caused by differences in the Before session (Table. 1).

We then used the right insula, MPFC, right SFG, and MFG as seeds to explore the underlying brain networks for the Cleaning and Priming group respectively. In the comparison between the After and Before sessions in the Cleaning group, the right insula showed **increased FC with the right precuneus (3, -69, 48) and the left superior parietal lobule (SPL) (-30, -54, 63), showed decreased functional connectivity (FC) with the right MFG (48, 33, 21).** The MPFC showed increased FC with the left middle cingulate gyrus (MCC) (-9, 9, 42) (Figure. 3, Table 2). In the comparison between the After and Before sessions in the Priming group, the right SFG showed decreased FC with the **right postcentral gyrus (42, -30, 42).** On the other hand, **the right MFG showed increased FC with the superior medial frontal gyrus (0, 33, 39)** (Figure. 4, Table 2). These results further highlight the different brain networks involved in actual physical cleaning and priming of

cleaning.

Discussion

The moral purity metaphor, which means the link between physical cleaning and moral purity, has been discovered to affect moral cognition, emotion and behaviors. The current study examined the neural mechanisms of the moral purity metaphor through both actual physical cleaning and priming of cleaning. We found that participants showed different brain activity changes between actual physical cleaning and priming of cleaning after they recalled a personal unethical behavior, although their moral emotions (shame, guilt) were similarly reduced in both groups. That is, actual physical cleaning reduced the spontaneous brain activities in the right insula and MPFC, regions that involved in embodied moral emotion processing, while priming of cleaning decreased the spontaneous activities in the right SFG and right MFG, regions that activated in executive control tasks. Furthermore, actual physical cleaning and priming of cleaning led to changes in different neural networks related to these regions, which further indicated different brain mechanisms for these two cleaning manipulations.

The reduced activity in the right insula and MPFC after actual physical cleaning might provide explanation for why cleaning decreased moral behaviors. The insula and MPFC have been found to be involved in negative emotion and cognition processing, such as reminding feeling of guilt and shame (Wagner *et al.*, 2011; Michl *et al.*, 2014; Bastin *et al.*, 2016), and moral judgment (Decety *et al.*, 2012). Evidence

that individuals with psychopathic traits have decreased activity of MPFC in moral processing (Harenski *et al.*, 2009), and patients with MPFC lesion ignore emotion-related conflicts in moral dilemma and make more utilitarian judgment (Koenigs *et al.*, 2007) highlight the role of the MPFC in moral emotion processing. These two regions are also thought to be related to regulating negative moral emotions in moral violation (Harenski and Hamann, 2006; Kim and Hamann, 2007). Furthermore, previous findings showed that physical cleaning decreased the pupil size, which was regarded as an indicator of facilitating emotional regulation (Kaspar *et al.*, 2015), and insula and MPFC are involved in trusting behaviors after physical experience in different temperature (Kang *et al.*, 2011). Consistent with these findings, we propose that actual physical cleaning released the negative emotional state caused by unethical recalling through reducing the spontaneous activities of the insula and MPFC, and then decreased the motivation to behave more morally by strengthening the emotional regulation related to these two regions. This possibility was further supported by the results that actual physical cleaning evoked more positive emotions such as excitement than priming of cleaning did.

The increased functional connectivity between the insula and precuneus, **SPL**, MPFC**, as well as MPFC and MCC** after actual physical cleaning provided more information for this process. Previous studies showed that the precuneus and MCC are associated with self-blaming moral emotions (guilt, shame, and embarrassment) (Fourie *et al.*, 2014; Bastin *et al.*, 2016). **The precuneus is also** engaged in contextual emotional retrieval (Maratos *et al.*, 2001), emotion processing in personal

moral stimuli judging (Greene *et al.*, 2004), evaluation of moral transgression (Parkinson *et al.*, 2011), and processing self attribution of negative situations with insula and MPFC (Cabanis *et al.*, 2013). **The SPL has been found in mental imaging of human bodies (Blanke *et al.*, 2010) and the MCC is involved in emotion regulation (Kohn *et al.*, 2014), integration of emotion, bodily state and environmental information with insula in resting state (Taylor *et al.*, 2009).** In the current study, **the precuneus** could contribute to dealing with the self reflection and moral evaluation in recalling unethical personal experience, and constructing the motivation to behave more morally to compensate the threatened moral self (Sachdeva *et al.*, 2009; Merritt *et al.*, 2010; Jordan *et al.*, 2011); **while the SPL and MCC integrated the embodied information and regulated the negative emotion.** Since actual physical cleaning strengthened the regulation between the insula, MPFC and these regions, the moral threat caused by unethical actions was released (Zhong and Liljenquist, 2006; Veit *et al.*, 2012; Reuven *et al.*, 2014), reducing the motivation to behave more morally (Merritt *et al.*, 2010; Jordan *et al.*, 2011).

Priming of cleaning activated quite different brain network compared to actual physical cleaning. First, priming of cleaning decreased the spontaneous activities in the right SFG and MFG, two core regions in executive control processing. For instance, the SFG and MFG are activated in controlling and monitoring episodic memory retrieval (Dobbins *et al.*, 2002), guiding approach and avoidance motivations in goal related tasks (Spielberg *et al.*, 2011), inhibiting behaviors (Aron *et al.*, 2003), and dealing conflicts in emotion information (Ferstl *et al.*, 2005). These

two regions have also been engaged in cognitive control in moral judgment (Greene *et al.*, 2004) and been activated more strongly in viewing non-moral stimuli than moral stimuli (Harenski and Hamann, 2006). Therefore, results in the current study might suggest that priming of cleaning weakened the executive control in these brain regions, then would impair cognitive performance (Kalanthroff *et al.*, 2017) and increase the desirability of cleaning and lessen moral judgment (Schnall *et al.*, 2008; Huang, 2014), as found in previous behavioral and neuroimaging studies.

Previous studies found that acting immorally led participants to prefer cleaning products more than other products (Zhong and Liljenquist, 2006; Lee and Schwarz, 2010b; Lee *et al.*, 2015; Schaefer *et al.*, 2015; Denke *et al.*, 2016), and sensorimotor brain regions were strongly activated in this process (Schaefer *et al.*, 2015; Denke *et al.*, 2016). Consistent with these studies, our results showed that priming of cleaning decreased functional connectivity between the SFG and **the right postcentral gyrus**, supporting the embodiment theory that moral purity metaphor is concreted into the brain through sensory motor experiences (Lakoff and Johnson, 1999; Winkielman *et al.*, 2015; Lee and Schwarz, in press). These results might indicate that priming of cleaning releases the somatosensory area from the executive control processed by the prefrontal cortex, and then invokes the embodied moral purity metaphor, leading to high desirability for cleaning in subsequent behaviors and compensation with moral behaviors (Liljenquist *et al.*, 2010).

Our results that actual physical cleaning and priming of cleaning have different influences on the brain network of emotion processing and executive control might

explain why they led to different subsequent behaviors. **Emotion related regions, including the MPFC, MCC and precuneus**, are more active in personal than impersonal moral judgment, and will lead to more utilitarian choices when damaged (Koenigs *et al.*, 2007), while cognitive regions in the prefrontal cortex such as the SFG and MFG have the contrary tendency and have stronger activation in utilitarian judgments (Greene *et al.*, 2001; Greene *et al.*, 2004). In the current study, actual physical cleaning decreased the connectivity between the insula and MFG, which weakens the effects of moral emotion on executive control, decreases moral behaviors (Zhong and Liljenquist, 2006; Lee *et al.*, 2015; Lobel *et al.*, 2015), and harshens moral judgment (Zhong *et al.*, 2010; Helzer and Pizarro, 2011). On the contrary, priming of cleaning increased the cognitive conflict between SFG, MFG and moral emotion related regions MPFC, which might increase the motivation of behaving morally to release these conflicts (Liljenquist *et al.*, 2010; Yang *et al.*, 2013).

Results in the current study also contribute to understanding the brain-body-world embodiment link, including body state regulation, sensorimotor coupling with environment, and social interaction (Thompson and Varela, 2001). It sheds light on studies about emotional processing in embodiment (Niedenthal, 2007) and how embodiment affects social cognition and behaviors (Winkielman *et al.*, 2015), such as cognitive dissonance after physical cleaning (Lee and Schwarz, 2010a), the relationship between social loneliness and body temperature (IJzerman *et al.*, 2012; Inagaki and

Eisenberger, 2013), and decision making in different physical environment (Kang *et al.*, 2011). Specifically, different neural networks of actual embodiment and priming of embodiment provide reference for how and when the embodiment occur, which would assist the measurement and replication of embodiment and priming effects in social psychology (Molden, 2014).

One limitation of this study would be that it is hard to exclude the influence of spontaneous fading of effects of unethical recalling on embodied moral purity metaphor, since participants' subjective ratings of guilt and shame were similarly reduced in both actual physical cleaning and priming of cleaning groups. Previous studies on emotion extinction have found that the prefrontal cortex are involved in the consciously cognitive emotion regulation, and then decrease the activation of emotion related regions (Ochsner and Gross, 2005; Sotres-Bayon *et al.*, 2006; Delgado *et al.*, 2008). In our study, both actual physical cleaning and priming of cleaning decreased the spontaneous activity in the prefrontal cortex. However, one was in the MPFC and the other was in the SFG/MFG, which implied it is less likely that they were induced by the similar mechanism such as emotion extinction. The following functional connectivity analyses further confirmed this assumption by showing that actual physical cleaning and priming groups recruit quite different brain networks that involved in different cognitive processes. In addition, actual physical cleaning has been found to increase positive feeling about future performance (Kaspar, 2013). In the current study, we also found that positive emotions were increased in both groups, and excitement was increased more in

actual physical cleaning group than that in priming group, which provided another evidence against the emotion extinction explanation. Taken together, it is unlikely that our results in both groups were simply due to similar mechanism such as emotion extinction.

Another limitation is that we retained some clusters in the FC analysis that did not survive from the multiple comparison correction (although very close to the threshold cluster size, see the functional connectivity analysis of method section and Table 2) because these regions have been consistently found in previous related moral purity studies. For example, being the location of the primary somatosensory cortex, the postcentral gyrus played an important role in evaluating cleaning products after doing an unethical deed (Schaefer et al., 2015; Denke et al., 2016), and processing embodied information such as metaphor and emotion (Saxbe et al., 2013; Schaefer et al., 2013).

In summary, this study revealed the neural mechanism underlying the embodied moral purity metaphor of actual physical cleaning and priming of cleaning. The results support the embodied theory of morality (Lakoff and Johnson, 1999; Winkielman *et al.*, 2015; Lee and Schwarz, in press), and found different neural networks for the actual physical cleaning and priming of cleaning. Future studies such as how physical cleaning affects subsequent decision making, and clinical research combining brain stimulation and neuroimaging techniques on obsessive compulsive disorder or psychopathic patients, would be needed to provide further empirical evidence for the links between the moral purity metaphor, brain, and

behaviors.

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Figure Legends

Figure 1. A) Experimental procedure. The fMRI scanning consisted of three 400-secs resting-state sessions. After the Baseline session, participants recalled and reported a personal unethical deed, and rated their emotions. Before the Before session, they were assigned to either cleaning or priming group, in which they cleaned their face with an antiseptic wipe (Cleaning) or just viewed the wipe picture (Priming) respectively. Then they finished the After session and rated emotions again out of the scanner. B) Comparison of the difference of emotion ratings between two groups showed that guilt and shame were significantly decreased in both groups without significant difference. In addition, the Cleaning group evoked significantly higher excitement than the Priming group did. (* $p<0.05$).

Figure 2. A) Comparison of spontaneous activity between the After and Before sessions in the Cleaning group, showing that spontaneous activities of the right insula and medial prefrontal cortex (MPFC) decreased after actual physical cleaning. B) Comparison of spontaneous activity between the After and Before sessions in the Priming group, in which spontaneous activities of the right superior frontal gyrus (SFG) and middle frontal gyrus (MFG) changed significantly after priming of cleaning (mapping on the cortical surface with BrainNet Viewer (Xia *et al.*, 2013)) (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$). The statistical threshold was set to voxel wise $p < 0.05$ and cluster wise $p < 0.05$ **(3dClustSim)**.

Figure 3. Regions showed significant changes of functional connectivity (FC) with the right Insula and MPFC between the After and Before sessions in the Cleaning group. The FC between the right insula and right MFG was significantly decreased in the After session than in the Before session, whereas the FC between the right insula and precuneus, MPFC and MCC were increased in the After session than in the Before session. (** $p < 0.01$, * $p < 0.05$). Voxel wise $p < 0.05$ and cluster wise p < 0.05 **(3dClustSim)**.

Figure 4. Regions showed significant changes of functional connectivity (FC) with the right SFG and MFG between the After and Before sessions in the Priming group. The right SFG showed significantly decreased FC with the **right postcentral gyrus** in the After session than that in the Before session. The right MFG showed increased FC with the superior medial frontal gyrus**.** Priming of cleaning decreased the executive control between the SFG and **the right postcentral gyrus,** but increased the links between MFG and MPFC. (*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$). Voxel wise $p < 0.05$ and cluster wise p < 0.05 **(3dClustSim)**.

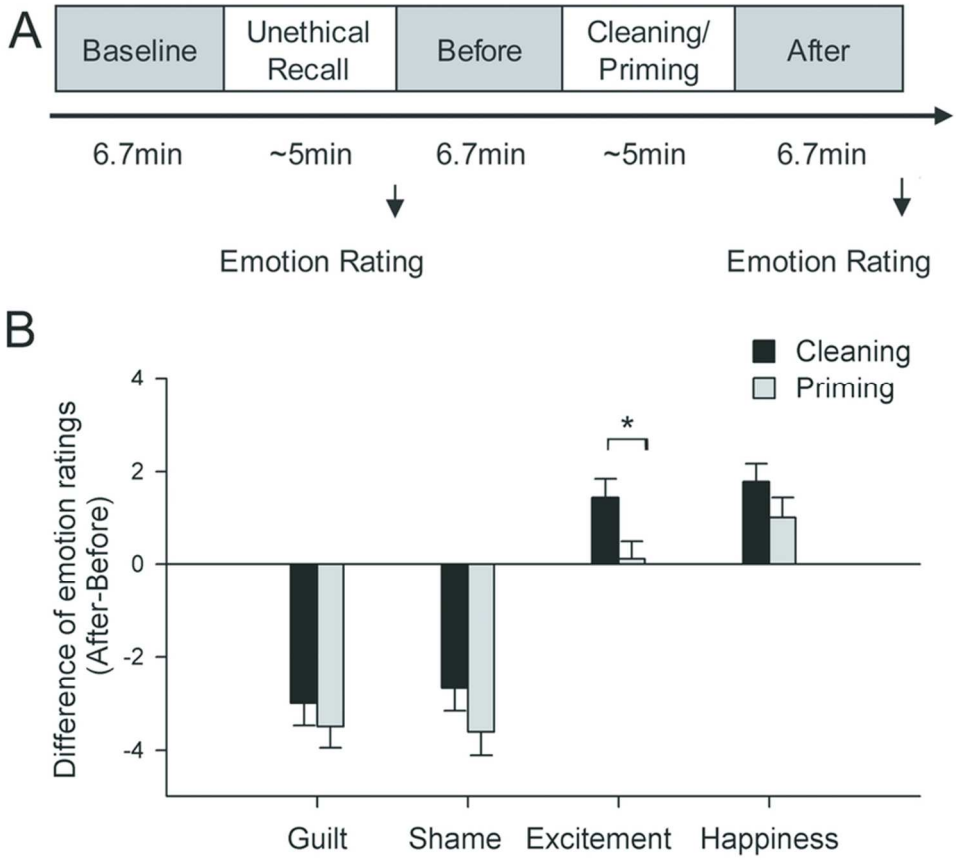

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Figure 1

75x66mm (300 x 300 DPI)

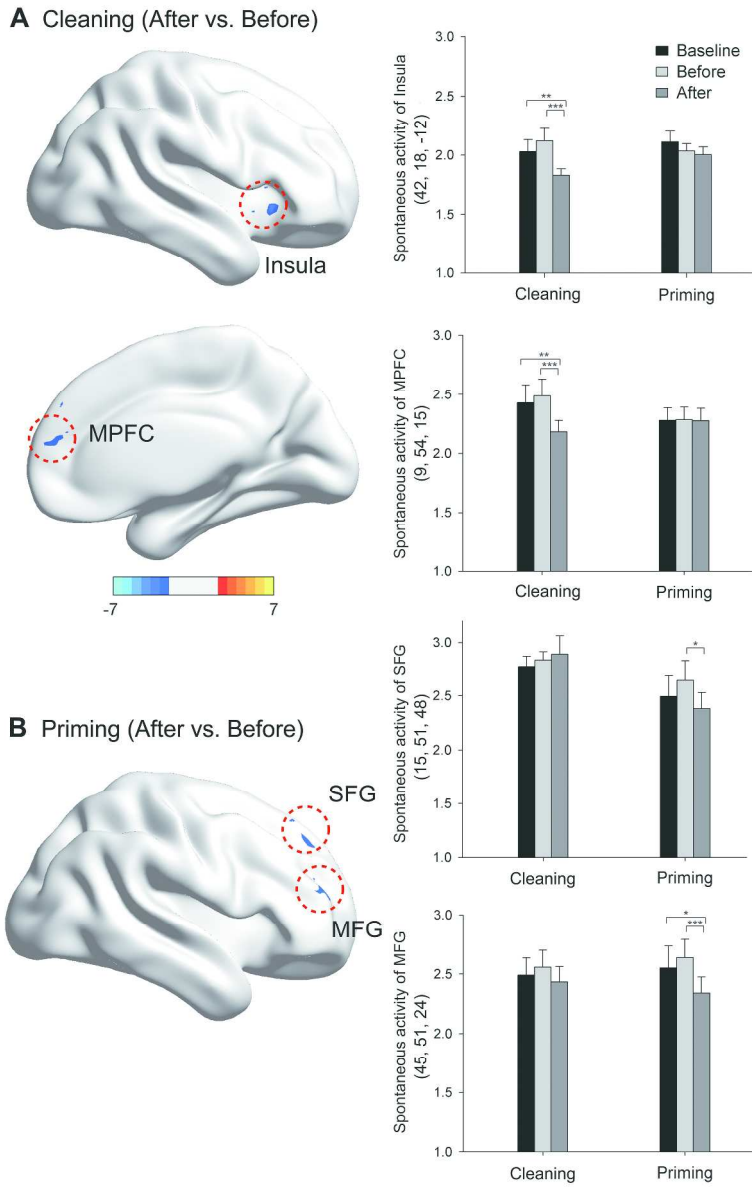

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Figure 2
134x213mm (600 x 600 DPI)

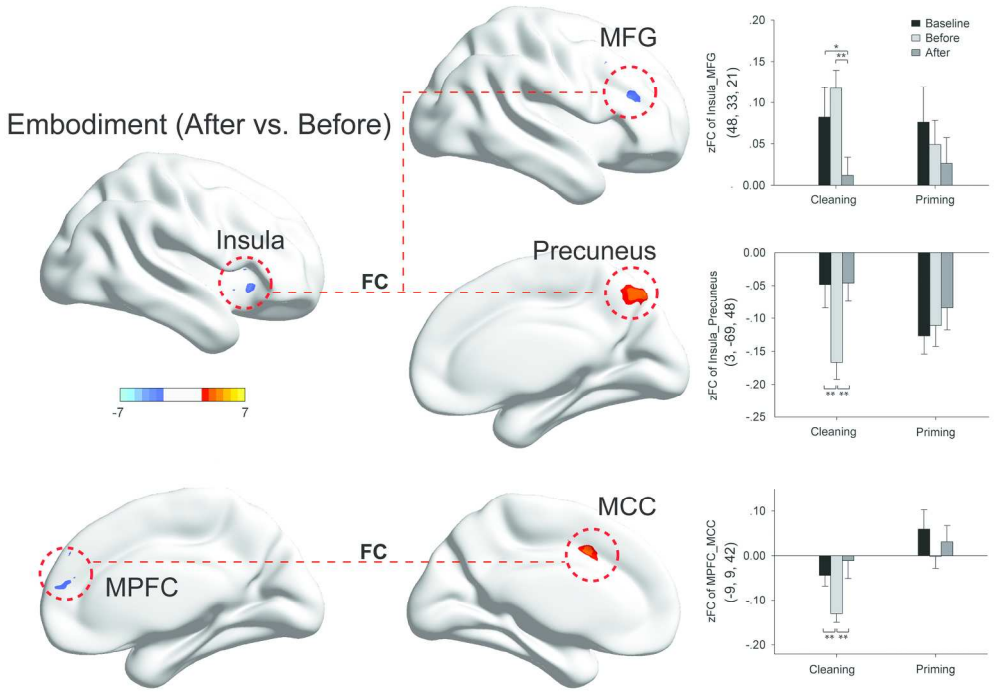

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Figure 3

97x70mm (600 x 600 DPI)

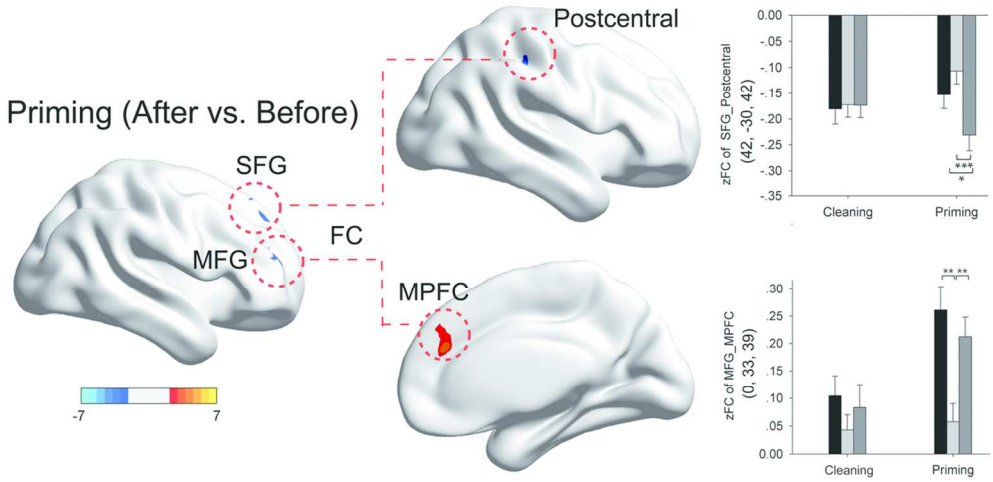

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Figure 4

55x27mm (600 x 600 DPI)

Table 1. Regions showed significant differences in spontaneous activity between the After and Before sessions in two groups separately, and regions showed significant differences in spontaneous activity between two groups in the Before session (with spontaneous activity in the Baseline session as covariates) and After session (with spontaneous activity in the Before session as covariates)

Brian Regions	BA	Peak MNI coordinates				
		x	y	z	*t*(peak)	Cluster Size
Cleaning (After vs. Before)						
Right Insula	13/47	42	18	-12	-4.02***	128
Right Medial Frontal Gyrus	10	9	54	15	-3.54**	97
Priming (After vs. Before)						
Right Middle Frontal Gyrus	46	45	51	24	-5.32***	101
Right Superior Frontal Gyrus	8/9	15	51	48	-3.66**	88
After (Cleaning vs. Priming)						
Supplementary Motor Area	6	0	3	45	-3.69***	203
Right Inferior Frontal Gyrus	44	51	3	24	-4.75***	123
Left Cuneus	18/31	-6	-81	18	-3.90***	82

Note: BA, Brodmann Area. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. (3dClustSim corrected $p<0.05$).

Table 2. Regions that showed significant differences in the functional connectivity (FC) with seed regions between the After and Before sessions in two groups separately.

Brian Regions (After vs. Before)	BA	Peak MNI coordinates				
		x	y	z	*t*(peak)	Cluster Size
Cleaning: Right insula						
Right Precuneus	7	3	-69	48	4.36***	168
Left Superior Parietal Lobule	7/40	-30	-54	63	3.18**	92
Right Middle Frontal Gyrus	45/46	48	33	21	-4.47***	87
Cleaning: Right MPFC						
Left Middle Cingulate Gyrus	32	-9	9	42	3.91**	89
Priming: Right SFG						
Left Lingual Gyrus	18	-12	-75	-9	4.46***	109
Right Postcentral Gyrus	2	42	-30	42	-4.22***	94
Priming: Right MFG						
Superior Medial Frontal Gyrus	9/32	0	33	39	3.70**	87

Note: BA, Brodmann Area. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. (3dClustSim corrected $p<0.05$).