Expressing our internal states and understanding those of others

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Vitality form is a term that describes the style with which motor actions are performed (e.g., rude, gentle, etc.). They represent one characterizing element of conscious and unconscious bodily communication. Despite their importance in interpersonal behavior, vitality forms have been, until now, virtually neglected in neuroscience. Here, using the functional MRI (fMRI) technique, we investigated the neural correlates of vitality forms in three different tasks: action observation, imagination, and execution. Conjunction analysis showed that, in all three tasks, there is a common, consistent activation of the dorsocentral sector of the insula. In addition, a common activation of the parietofrontal network, typically active during arm movements production, planning, and observation, was also found. We conclude that the dorsocentral part of the insula is a key element of the system that modulates the cortical motor activity, allowing individuals to express their internal states through action vitality forms. Recent monkey anatomical data show that the dorsocentral sector of the insula is, indeed, connected with the cortical circuit involved in the control of arm movements.

vitality forms | insula | action style | mirror mechanism | fMRI

The observation of actions done by another individual allows the observer to understand (typically) what that individual is doing and in some instances, why that individual is doing it. Other than goal and motor intention, observing the expressive qualities of others' movements enables one to understand the internal psychological state of the agent on the basis of how the action is performed. This information carried by the kinematics of the observed actions has been defined by Stern as "vitality affects" or "vitality forms" (1–4).

This concept is of great interest, because it describes a primary feature of the psychological affective/communicative quality underlying the relation between the agent and the action recipient. According to Stern (1–4), the appraisal of vitality forms relies on five specific properties of the observed movements: time, space, force, trajectory, and direction. These movement aspects create a particular experience that reflects the affective/communicative state of the agent. The capacity to express and understand vitality forms represents a fundamental element of interpersonal relations and is at the basis of the sympathetic engagement in the early mother–child relationship (1–7).

Despite its psychological importance, little attention has been paid up to now to vitality forms in neuroscience. Recently, using functional MRI (fMRI), we showed that, when an individual pays attention to the action style rather than to its goal, there is a specific activation of the dorsocentral insula (8). It is unclear, however, the neural basis of the planning and production of vitality forms and the relationships between vitality form production and understanding.

In this study, we investigated the neurological bases of vitality forms in healthy participants using fMRI. Participants were required to execute, imagine, and observe arm action performed with two different vitality forms (gentle and rude). In the first task [observation (OBS)], the participants observed video clips showing the right arm of an actor performing actions toward another actor (e.g., passing a cup) with either a gentle or a rude vitality form (Fig. 1 *A1* and *B1* shows examples, *SI Methods*, and Fig. S1). In the second task [imagination (IMA)], participants had to imagine themselves performing the actions seen during the OBS task (Fig. 1 *A2* and *B2*), again with gentle or rude vitality forms (*SI Methods* and Fig. S2). In the third task [execution (EXE)], participants moved a packet of crackers located on a plane lying on their chest as if offering them to another person with a gentle or rude vitality form. Finally, in a control condition (Ctrl), the participants were requested to observe video clips showing the hand of an actor placing a small ball in a box (Fig. 1*C1*), imagine themselves performing the same action (Fig. 1*C2*), or finally, place a small ball inside one of two boxes placed inside the scanner and seen through digital visors (Fig. 1*C3*).

The main result of our study was the demonstration that the execution of actions performed with a vitality form relative to control actions determines a specific activation of the dorsocentral insula. The same region also became active during motor imagery and vitality forms observation. Note that recent anatomical evidence in monkeys shows that this sector of the insula is connected with the cortical circuit formed by the anterior intraparietal area (9), the frontal area F5 (10) and the prefrontal area F12r (11) (i.e., the circuit that controls hand/arm movements). We postulate that, during action execution, the insula may modulate this circuit, determining different vitality forms according to the internal state of the individual.

Significance

Vitality form is a term that describes the manner with which actions are performed. Despite their crucial importance in interpersonal communication, vitality forms have been almost completely neglected in neuroscience. Here, using a functional MRI technique, we investigated the neural correlates of vitality forms in three tasks: action observation, imagination, and execution. We found that, in all three tasks, there is a common specific activation of the dorsocentral sector of the insula in addition to the parietofrontal network that is typically active during arm movements production and observation. Thus, the dorsocentral part of the insula seems to represent a fundamental and previously unsuspected node that modulates the cortical motor circuits, allowing individuals to express their vitality forms and understand those of others.

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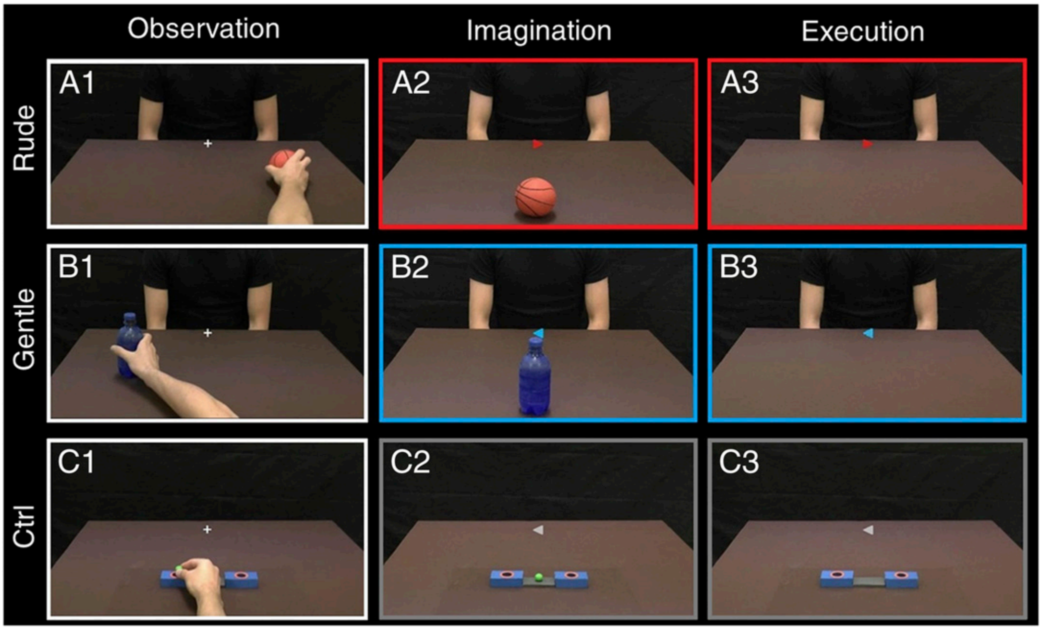

Fig. 1. Experimental task design. (*Left*) Observation. The participant observed the right hand of an actor moving an object in a (*A1*) rightward or (*B1*) leftward direction. Four objects were used. The observed action could be executed with a gentle or rude vitality form, and the request was to focus attention on the style of action. (*C1*) As a control, the participant observed a hand placing a small ball in the right or left hole of a box randomly. (*Center*) Imagination. The participant was required to imagine himself giving an object to another actor sitting in front of him with either a gentle or a rude vitality form. (*A2* and *B2*) In the central part of the screen, there was an arrow indicating the stile (blue, gentle; red, rude) and the direction of the imagined action. The contour of the screen (red or blue) reminded the participant of the requested action style. (*C2*) As a control, the participant had to imagine placing the ball in the box according to the direction of the arrow. (*Right*) Execution. The participant held a package of crackers and had to move it with (*A3*) rude (red) or (*B3*) gentle (blue) style toward the actor in front of him. As a control, the participant had to place the small ball in the box. All stimuli in OBS, IMA, and EXE tasks were viewed through digital visors (VisuaSTIM) with a 500,000px × 0.25-in^2 resolution and a horizontal eye field of 30°. The digital transmission of the signal to the scanner was through optic fiber. During the EXE task, the participant saw only the scene depicted and his hand was out of his field of vision.

Results

Cortical Activations During OBS, IMA, and EXE Tasks. The data showed that, during the OBS task, there was a bilateral activation of the occipital lobe, the dorsal premotor cortex, and the superior parietal lobule extending laterally into the rostral inferior parietal lobule. A similar activation pattern was observed during the IMA task but with a much less extended activation of the occipital areas. During the EXE task, activations were found in the same regions of the parietal and premotor cortices as in the other two tasks, and there was a strong activation of the left somatosensory and motor cortices ($P_{\mathrm{FWE}} < 0.05$ at voxel level) (*SI Methods* and Fig. S3).

The main aim of our study was to assess the activation of the insula during the three tasks (OBS, IMA, and EXE). The contrasts vitality forms relative to control are shown in Fig. 2. In all three tasks, there was a consistent activation of the dorsocentral sector of the insula ($P_{\mathrm{FWE}} < 0.05$ at cluster level). The effect was present in all contrasts, except for gentle vs. control in the right hemisphere.

Conjunction Analysis of OBS, IMA, and EXE Tasks. Fig. 3 shows the results of the conjunction analysis ($P_{\mathrm{FWE}} < 0.05$ at cluster level) of the activations found in the three tasks (coordinates and

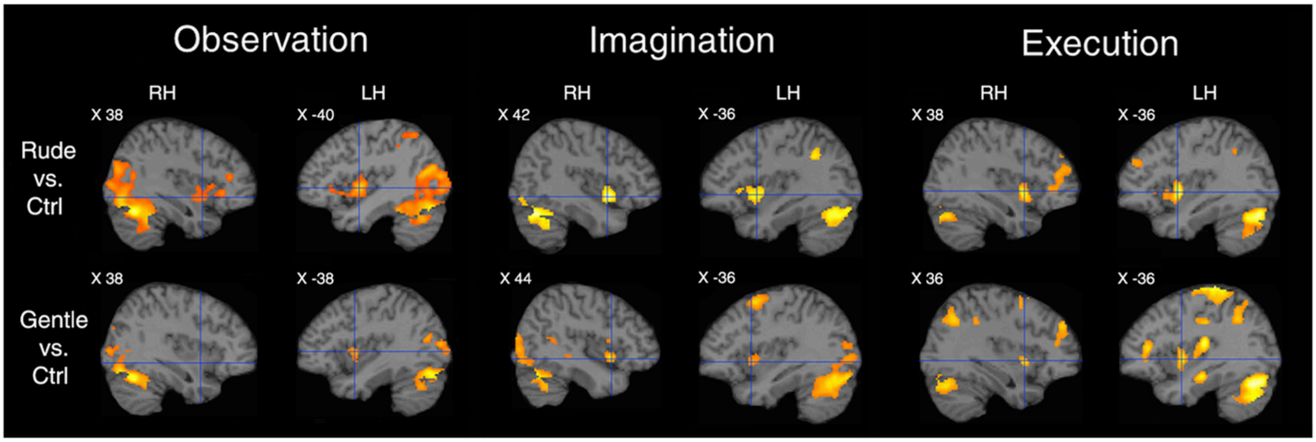

Fig. 2. Brain activations during vitality form processing. Parasagittal sections showing the insular activations in the two hemispheres during the contrasts rude vs. Ctrl and gentle vs. Ctrl in OBS, IMA, and EXE tasks. LH, left hemisphere; RH, right hemisphere.

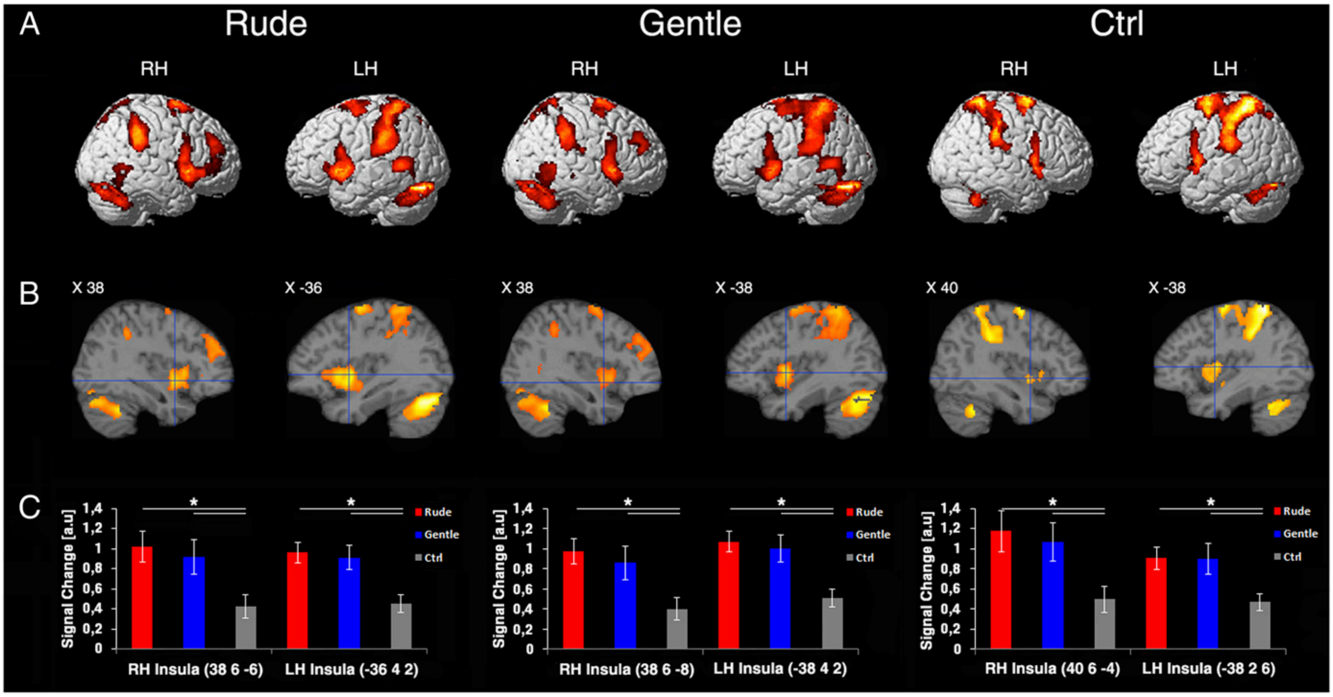

Fig. 3. Overlapping of areas active during the three different tasks (OBS, IMA, and EXE). (*A*) Lateral views of the right and left hemispheres. The activations in the three conditions (rude, gentle, and Ctrl) obtained with a conjunction analysis are rendered on a standard Montreal Neurological Institute brain template ($P_{\mathrm{FWE}} < 0.05$ at cluster level). (*B*) Parasagittal sections showing the insular activations in two hemispheres in three conditions. (*C*) Signal changes in six ROIs created on the central insula. All ROIs were defined centering the sphere (radius 10 mm) around the maxima of the functional maps resulting from conjunction analysis of OBS, IMA, and EXE tasks. The horizontal lines above the columns indicate the comparisons between the conditions. LH, left hemisphere; RH, right hemisphere. *Significant differences at $P < 0.05$ (Bonferroni corrected).

statistical values are in Table S1). As far as the cortical convexity is concerned (Fig. 3*A*), in both rude and gentle conditions, there was a bilateral signal increase near the posterior end of the middle temporal gyrus (possibly corresponding to hMT/V5+) (12), a bilateral activation of the posterior parietal cortex (larger in the left hemisphere than in the right hemisphere), and a bilateral activation of the dorsal premotor cortex. Signal increase was also present in the dorsal part of the cerebellum bilaterally. In the Ctrl condition, the activation pattern was similar to that observed for the vitality conditions, except for the lack of activation of visual area hMT/V5+.

Fig. 3*B* shows the results of conjunction analysis in the insula. The most interesting result concerned the dorsocentral insula, where the conjunction analysis revealed activation in all three tasks (OBS, IMA, and EXE). This finding implies that the same sector of insula is involved in planning and producing actions endowed with specific vitality forms as well as during vitality form recognition.

Fig. 3*C* illustrates the signal changes in six regions of interest (ROIs) created on the central insula (details in *Methods*). A significant difference was present among the three conditions for all ROIs (ROI 1: $F_{2,28} = 24.62$, $P < 0.05$; ROI 2: $F_{2,28} = 29.24$, $P < 0.05$; ROI 3: $F_{2,28} = 23.13$, $P < 0.05$; ROI 4: $F_{2,28} = 32.43$, $P < 0.05$; ROI 5: $F_{2,28} = 25.58$, $P < 0.05$; and ROI 6: $F_{2,28} = 23.55$, $P < 0.05$). Posthoc analysis revealed that, for all ROIs, rude and gentle conditions produced higher signal change relative to Ctrl [rude > Ctrl ($P < 0.05$); gentle > Ctrl ($P < 0.05$); Bonferroni corrected]. No difference was present between rude and gentle conditions ($P > 0.05$).

Discussion

The vitality forms are a psychological construct that deals with the style of actions and in particular, those directed toward others (1–7). In everyday life, people produce vitality forms in voluntary actions to communicate to others their internal state as well as automatically, even in the absence of another person, on the basis of their mood as a motor agent. However, despite their well-recognized importance in social life (1–7), very little attention has been paid to the neural bases of this behavior.

In a previous study (8), we examined the neural substrate of vitality form recognition. We asked participants to observe two consecutive actions with the instruction to decide whether the action goal was the same or different (what task) or whether their vitality form was the same or different (how task). The contrast in how vs. what tasks revealed a specific activation of the dorsocentral insula during vitality forms recognition. Planning and execution of action with specific vitality forms were not examined in that experiment.

The main result of this study has been the demonstration that the dorsocentral part of the insula is involved in not only the observation of vitality forms but also, their planning (motor imagery) and execution. A weak insular activation was also present during the apparently neutral Ctrl (Fig. 3*B*). The most likely explanation of this finding is that, even when there is no request to perform an action with a specific style, its execution automatically elicits a vitality form, suggesting that all motor actions are bound to a specific vitality form.

Our findings that the dorsocentral part of the insula plays an important role in vitality forms are in agreement with previous findings on the general functional organization of the insula in monkeys and humans.

Experiments in monkeys showed that electrical stimulation of the dorsocentral part of the insula determines body parts movements, with a rich representation of the movements of the upper limb. These movements are radically different from the complex motor behaviors obtained by the stimulation of the rostral insula.

In fact, the stimulation of the latter sector elicits complex positive ingestive behavior dorsally and negative ingestive behavior (e.g., disgust) ventrally (13).

A similar organization pattern has been reported by Kurth et al. (14) in humans. In a meta-analysis based on 1,768 functional neuroimaging experiments, Kurth et al. (14) described four distinct functional fields in the human insula: the sensorimotor, the socioemotional, the olfactory–gustatory, and the cognitive fields. The sensorimotor field corresponds to the insula sector involved in vitality form production and the analogous sensorimotor functional field of the monkey.

The finding that the dorsocentral insula is involved in both vitality form execution and recognition suggests that neurons of this sector of the insula might be endowed with the mirror mechanism transforming visual and possibly, auditory representations of the perceived vitality forms in their motor representations. This view is in line with the fMRI findings showing that the anterior sector of the insula is active during both expression and recognition of disgust in others (15, 16). A similar matching mechanism is likely involved in feeling pain and recognizing it in others (17). Thus, anterior and dorsocentral sectors of the insula, although underlying different functions, both seem to be endowed with the mirror mechanism.

An interesting question is how the dorsocentral insula may modulate the cortical circuits mostly responsible for voluntary movements. Is there an insulocortical circuit that may transmit vitality form information to the cortex? Anatomical data in the monkey support this possibility by showing that the dorsocentral sector of the insula has rich connections with areas AIP (9), F5 (10), and 12r (11) [that is, with the parietal and frontal areas that form the circuit involved in the organization of arm movements in the monkey (18, 19) as well as humans (20–22)] (Fig. 3*A*). In agreement with these findings, there are also results of intracortical electrical stimulation of the middle and posterior short gyri of the insula in humans. These stimulation data showed that these insular sectors determine evoked potential in the precentral gyrus and the superior and inferior parietal lobules (23), thus confirming the strict connections between these areas and the insula anatomically shown in the monkey.

It has been proposed that the general functional role of the insula is to integrate information coming from the external context with that encoding the internal state of the individual (24–26). The importance of the subcortical centers for affective self-regulation and emotional communication of other individuals has been stressed by Trevarthen and coworkers (27, 28). We propose that the dorsocentral sector of the insula plays a fundamental role in determining the overt expression of the internal state of the individuals and more specifically, that this sector sets the physical parameters of the performed movements through modulation of the cortical circuit controlling motor actions. The strong activation of the cerebellum during OBS, IMA, and EXE tasks suggests that this structure might play role in modulating the motor timing of the vitality forms.

As mentioned in the Introduction, vitality forms are a core element in social interactions (1–7). Behavioral studies show that children with autism are markedly impaired in vitality form recognition relative to children with typical development (29), thus implying that vitality form recognition deficit may play a role in determining the social impairments characterizing this disorder. These data indicating that the same sector of the insula is involved in both vitality form recognition and vitality form production suggest that children with autism might have deficits in executing actions with vitality forms appropriate to their internal state. If this hypothesis is correct, this deficit may play an important role in the genesis of early communication deficits in children with autism, with subsequent cascading effects in the development of their social abilities.

Methods

Participants. The experiment was carried out on 15 healthy right-handed volunteers (six females: mean age = 23.1 y, SD age = 2.1 y and nine males: mean age = 26 y, SD age = 3.9 y). All participants had normal or corrected-to-normal visual acuity. None reported a history of psychiatric or neurological disorders or current use of any psychoactive medications. They gave their written informed consent to the experimental procedure, which was approved by the Local Ethics Committee of Parma.

Paradigm and Task. The experiment was composed of six functional runs (two runs for Ctrl and four runs for vitality conditions: rude and gentle). To avoid possible biases elicited by the vitality conditions on Ctrl, we decided to present Ctrl before the vitality conditions. This decision was motivated by the concern that instruction to pay attention on the vitality form may also bias Ctrl.

In the first run, we presented participants with video clips in two different tasks: OBS and IMA (Ctrl). The two tasks were presented in independent mini-blocks (OBS block and IMA block) in a sequential order. The OBS task started with the instruction to observe and required the participants to pay attention to the action (Fig. 1*C1*). The IMA task started with the instruction to imagine and required the participants to imagine themselves performing the action (Fig. 1*C2*). During the IMA task, in the central part of the screen, a cue indicated the direction (left side or right side) toward which they were requested to imagine the performance of the action. In 10% of the trials in both tasks, participants had to provide an explicit response on a response box placed inside the scanner concerning the color of the small ball observed in the video clip.

In the second run, we presented a static image of two boxes (Fig. 1*C3*) and asked participants to place a small ball in the box (EXE task). In the central part of the screen, a cue indicated to which box to perform the action (left box or right box).

In the third and fourth runs, we presented participants with video clips in two different tasks: vitality form OBS (VF-OBS) and vitality form IMA (VF-IMA). For each run, the two tasks were presented in independent blocks in sequential order. The VF-OBS task started with the instruction to observe and subsequent presentation of the video clip (Fig. 1 *A1* and *B1*). During this task, participants had to pay attention to the style of the action (vitality form). The VF-IMA task started with the instruction to imagine and required the participants to imagine themselves performing the action in a gentle or rude way (Fig. 1 *A2* and *B2*). During the VF-IMA task, the color of the edge screen indicated the action style in which to imagine the performance of the action (red, rude; blue, gentle). Finally, in the central part of the screen, a cue indicated the direction toward which to imagine the performance of the action (left side or right side). In 10% of the trials, in both tasks, participants had to indicate whether VF-OBS and VF-IMA were rude or gentle (*SI Methods* and Fig. S2).

In the fifth and sixth runs, we presented a static image of an actor seated opposite the observer and asked participants to move a packet of crackers toward the opposite actor in a rude or gentle way by simply rotating the wrist (Fig. 1 *A3* and *B3*). A cue indicated the direction (left side or right side) in which to perform the action, whereas the color of the edge screen indicated the style to use during the execution of action (red, rude; blue, gentle). In each video, a fixation cross was introduced to control for restrained eye movements.

fMRI Data Acquisition and Analysis. Anatomical T1-weighted and functional T2*-weighted magnetic resonance images were acquired with a 3-T General Electrics Scanner (details in *SI Methods*). After standard preprocessing steps, a series of within-subject, whole-brain general linear models was conducted using SPM8 (The Wellcome Department of Imaging Neuroscience) to examine effects of conditions (rude, gentle, and Ctrl) in the three different tasks (OBS, IMA, and EXE) (details in *SI Methods*). On the basis of the functional maps (group analysis) resulting from the overlapping of the OBS, IMA, and EXE tasks obtained for rude, gentle, and Ctrl conditions (Fig. 3*C*), six regions of interest (ROIs) were created. Using MarsBaR ROI Toolbox for SPM (release 0.42), all ROIs were defined on the central insula, centering the sphere (radius 10 mm) around the maxima (rude, right hemisphere ROI 1: $x = 38$, $y = 6$, and $z = -6$; left hemisphere ROI 2: $x = -36$, $y = 4$, and $z = 2$; gentle, right hemisphere ROI 3: $x = 38$, $y = 6$, and $z = -8$; left hemisphere ROI 4: $x = -38$, $y = 4$, and $z = 2$; Ctrl, right hemisphere ROI 5: $x = 40$, $y = 6$, and $z = -4$; left hemisphere ROI 6: $x = -38$, $y = 2$, and $z = 6$). Signal change for each subject was extracted using REX Toolbox. In the ROIs, signal change values associated with rude, gentle, and Ctrl were calculated for all three task (OBS, IMA, and EXE) for each subject on the basis of contrast images (second-level analysis) (*SI Methods, Statistical Analysis*). Finally, the signal change values were averaged among tasks, and a general linear model analysis was carried out on the time course in the ROIs.

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