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## Observing social interactions: The effect of gaze

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Our social abilities depend on specialized brain systems that allow us to perform crucial operations such as interpreting the actions of others. This functional magnetic resonance imaging (fMRI) study investigated whether human brain activity evoked by the observation of social interactions is modulated by gaze. During scanning participants observed social or individual actions performed by agents whose gaze could be either available or masked. Results demonstrated that the observation of social interactions evoked activity within a dorsal sector of the medial prefrontal cortex (MPFC), an area classically involved in social cognition. Importantly, activity within this area was modulated by whether the gaze of the agents performing the observed action was or was not available. The implications of these findings for a role played by the dorsal medial prefrontal cortex (dMPFC) in terms of inferential processes concerned with social interactions are considered.

Most of our actions occur within a social context and accordingly they are—factually and conceptually—dependent on the existence of other persons and their relevant actions. For example, such causal dependence can be found in the action of carrying a table together or singing a duet. These actions are necessarily social, for they involve taking into account at least another person as part of one’s reason for acting (Tuomela, 2000).

From a social neuroscience perspective, a key question is how the brain represents social interactions and whether there are neural structures in

some way devoted and specialized to subserve this function (Frith, 2007). It has been proposed that the dorsal medial prefrontal cortex (dMPFC) may be implicated in representing shared attention and goals, and more specifically in coding “triadic” relations between Me, You, and This, i.e., the subject, a second person, and an object (Saxe, 2006).

So far this prediction has only been tested in on-line tasks, at the level of forming a representation of joint attention with a partner (Bristow, Rees, & Frith, 2007; Williams, Waiter, Perra, Perrett, & Whiten, 2005). For instance, the

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dMPFC has been found to be active in a task whereby both a model and a participant attended to a visible moving target (Williams et al., 2005).

Here we sought to examine whether the neural response to social triadic interactions is modulated by gaze. Gaze direction is a potent social cue, which is indicative of other persons' goals (Allison, Puce, & McCarthy, 2000). In everyday life, it is intuitively apparent that gaze may provide an observer with an important cue in discriminating whether the two agents are acting on a shared goal or on individual purposes. Therefore, the main objective of the present study was to test for a significant interaction between the social context in which an action takes place and the availability of the actors' gaze. The type of observed action (SOCIAL versus INDIVIDUAL) and the presence/absence of gaze (GAZE versus NO-GAZE) constituted the two factors of the event-related factorial design implemented in the present fMRI study. Participants observed pictorial stimuli representing either two human actors involved in a social interaction (e.g., passing each other an object; SOCIAL) or two human actors performing individual goal-directed actions (INDIVIDUAL). Further, the gaze of the actors could be either present (GAZE) or masked (NO-GAZE). The factorial design allowed us to characterize brain activation due to the two main effects: the type of observed action, regardless of the presence of gaze cues; and the presence/absence of gaze, regardless of type of observed action. Furthermore, this design enabled us to investigate the effect of interactions between the two factors, which indicate the role of gaze in modulating the response to social interaction. We predicted that activity within the dMPFC (if any) should be differentially modulated depending on whether gaze cues were present or absent.

## METHOD

### Participants

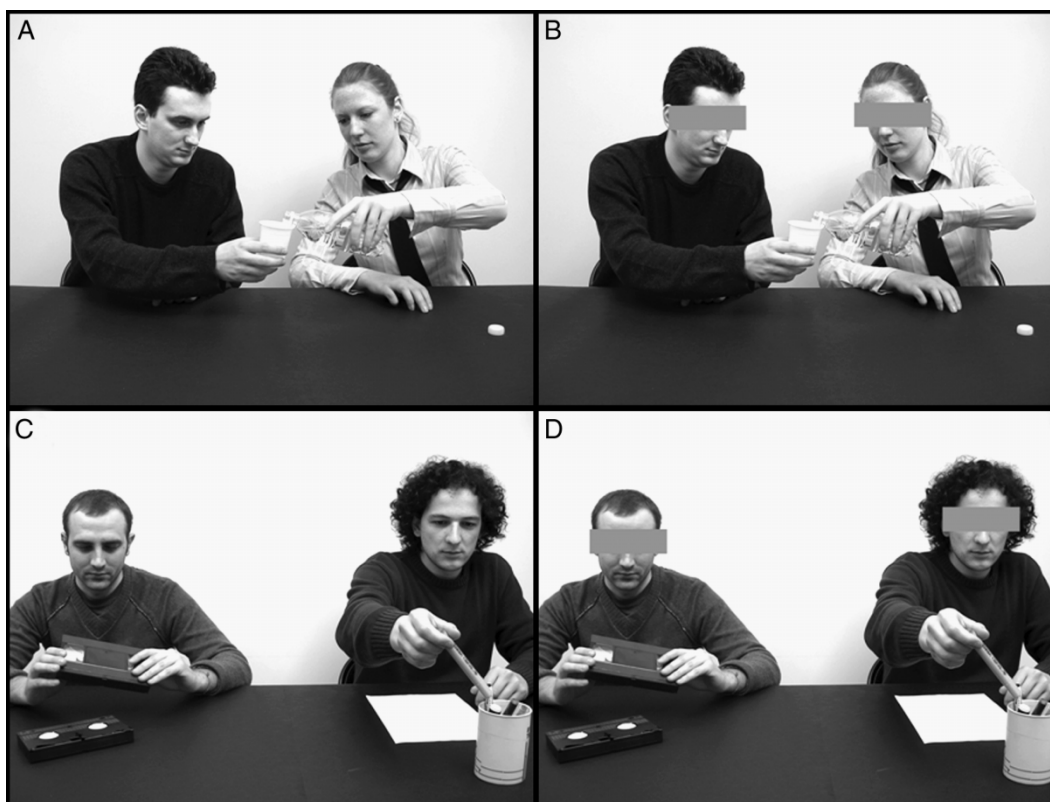
Seventeen paid volunteers (7 males and 10 females, mean age 26,  $SD = \pm 8.3$ ) were recruited for the present study. All participants were right-handed with no history of neurological problems. The study was approved by a local ethical committee. Informed consent was obtained from all of the participants before the testing session in accordance with the declaration of Helsinki.

### Experimental design and stimuli

We adopted a  $2 \times 2$  factorial event-related design (Rosen, Buckner, & Dale, 1998) in which the factors were "Type of observed action" (two levels: social or individual action) and "Gaze" (two levels: present or absent). During scanning, participants observed four different types of black and white digital photographs (2000 ms duration; bitmap format, resolution  $1024 \times 768$  pixels) corresponding to the four experimental conditions. In two conditions participants observed pictorial stimuli depicting two human actors during a social interaction (e.g., passing each other an object; social gaze condition, Figure 1A) or two human actors performing individual actions (individual gaze condition, Figure 1C). In the remaining conditions participants observed the same pictorial stimuli, but gaze-cues were masked by means of a grey rectangle (social no-gaze and individual no-gaze conditions; Figure 1B and 1D, respectively).

In order to avoid habituation, for both types of situations (e.g., social and individual) the actors could perform one of ten different actions. Six different pairs of actors were utilized. Three pairs (male-male, female-female, and male-female) acted for photographs representing social interactions whereas three different pairs (male-male, female-female, and male-female) acted for the individual actions photographs. This was done in order to avoid a possible attribution of social meaning to situations in which the actors performed individual actions. In other words, we were concerned that if the viewers observed the same pair acting in both conditions, then they would always attribute to the actors a social relation regardless of the type of observed condition. In addition, to avoid possible confounds concerned with the different number of agents present in the scene we opted to always present participants with pictorial stimuli depicting two human actors for both social and individual action.

All stimuli were presented by means of a PC that ensured synchronization with the MR scanner using the software "E-prime" (Psychology Software Tools Inc., Pittsburgh, USA). An LCD computer-controlled projector was employed to present the stimuli on a screen positioned within the bore of the magnet, which was viewed by the participants through a mirror mounted on the



**Figure 1.** Sample stimuli utilized in the present study for the four experimental conditions. (A) “Social Gaze” condition. (B) “Social No-gaze” condition. (C) “Individual Gaze” condition. (D) “Individual No-gaze” condition. Examples of social actions were: “A” picks a fruit from tray and offers it to “B”, “A” pours water into “B’s” glass while “B” holds the glass, “A” grasps a book and passes it to “B”. Examples of individual actions were: “A” picks a pen from a penholder while “B” reaches and grasps a videotape, “A” reads a book while “B” eats an apple, “A” pours water into a glass while “B” puts a sheet of paper into an envelope.

head coil (visual angle  $15 \times 20$  degrees approximately).

### Activation paradigm

During the experiment participants laid supine in the scanner with the index and the middle finger of their right hand positioned on a two-button, MRI-compatible response keypad. They were requested to carefully observe all the presented pictures. Furthermore, in some trials a green dot rather than a pictorial stimulus was displayed (task trials). On this prompt participants were instructed to perform a task on the last presented picture by pressing, as fast as they could, one of the two buttons of the response keypad. They had to press the index finger button if the two actors were interacting or the middle finger button if the two actors were performing individual actions. Participants could only respond within 2000 ms from the green dot onset. By adopting this strategy not only we were able to ensure that

participants attended to the presented stimuli, but we were also able to dissociate motor-task-related activity from action-observation-related activity (please note that, as explained below, task trials were modeled as a separate event type). After a practice session (4 min; conducted during the anatomical scan) each participant underwent a single experimental functional run lasting approximately 26 min. Within the functional run 300 pictorial stimuli (75 for each condition) were intermixed with 150 null events consisting of a blank screen in which a small fixation cross was presented in the centre. In addition 36 task trials were randomly distributed along the run length. To increase statistical efficiency (Dale, 1999) the order of presentation of the stimuli was determined according to an optimized random sequence in which pictorial stimuli or null events appeared for 2000 ms followed by either 1200, 1400, 1600 or 1800 ms of blank screen. By adopting this strategy we ensured an optimal sampling of the evoked hemodynamic responses

(the changes in BOLD signal evoked by the experimental events).

## MRI data acquisition and analysis

Using a whole body 3T Siemens Magnetom Trio (Erlangen, Germany) scanner, functional images were obtained with a gradient echo-planar (EPI) T2\*-weighted sequence in order to measure blood oxygenation level-dependent (BOLD) contrast throughout the whole brain (42 contiguous axial slices, slice thickness 3 mm/0.45 mm gap, inplane resolution of  $64 \times 64$  voxels, FOV =  $192 \times 192$  mm, flip angle =  $90^\circ$ , TE = 32 ms, bandwidth = 1346 Hz/pixel). Five-hundred volumes were acquired continuously with a repetition time (TR) of 3 s in a single scanning run. In addition, at the beginning of the scanning session high-resolution T1-weighted images (anatomical scans) were also acquired for each participant (MP-RAGE, 160 axial slices, in-plane resolution  $256 \times 256$ , 1 mm isotropic voxels, TR = 1830 ms, TE = 4.43 ms, flip angle  $11^\circ$ , bandwidth = 130 Hz/pixel).

The initial two volumes were discarded and subsequent image volumes were pre-processed using SPM2 ([www.fil.ion.ucl.ac.uk/spm](http://www.fil.ion.ucl.ac.uk/spm)) by spatial realignment (Friston et al., 1995), and by normalization (Ashburner & Friston, 1999) to the standard space defined by the Montreal Neurological Institute template (Mazziotta, Toga, Evans, Fox, & Lancaster, 1995). Lastly, an 8 mm full-width at half-maximum isotropic Gaussian kernel was applied to spatially smooth all volumes. High-pass filtering was also applied to remove low-frequency drifts in signal.

A random effects analysis was conducted on the data. The four different types of pictorial stimuli corresponding to the four experimental conditions were modeled as four separate event types. Motor responses provided by participants on the task trials were treated as a single fifth event type and were thus modeled separately. Regressors were defined based on the timing of presentation of each experimental condition, and these functions were convolved with a canonical, synthetic HRF (hemodynamic response function) in order to produce the individual models. For each participant, all regressors were incorporated into a General Linear Model (GLM) together

with six regressors of no interest comprising the estimated head motion calculated during the realignment stage of preprocessing. This was done in order to model residual effects due to head motion. Individual models were separately estimated and contrasts were defined in order to pick out the main effects of each experimental condition. These contrasts were then entered into a second-level analysis in which participants served as a random effect in a within-subjects ANOVA allowing for non-sphericity. The main effects (i.e., main effect of “type of observed action”, main effect of “gaze”) and the interactions between conditions were then specified by appropriately weighted linear contrasts. The alpha level for these second-level contrasts was set at  $p < .001$  (uncorrected); the extent threshold was of at least 10 contiguous voxels. The resulting SPM/*t*/ maps reflected areas in which variance related to the experimental manipulation was captured by the canonical HRF.

## Localization

Anatomical details of significant signal changes were obtained by superimposing the SPM/*t*/ maps on the T1 canonical MNI (Montreal Neurological Institute) template image. Results were also checked against structural images of each participant. We used two atlases as a general neuroanatomical reference (Duvernoi & Bourgouin, 1999; Mai, Assheuer, & Paxinos, 2004). Further, the SPM Anatomy Toolbox (Eickhoff et al., 2005) based on three-dimensional probabilistic cytoarchitectonic maps was used to determine the cytoarchitectonic probability (when available; see Table 1) of the peak activity voxels.

## RESULTS

First we tested the sensitivity of our design by verifying that right-hand finger movements performed by participants in the task trials evoked the expected hemodynamic responses within the motor system. We did so by conducting a second-order random-effects analysis (one sample *t*-test;  $p < .01$  FWE corrected) on those contrast images produced at first level to model brain activity time-locked to participants' motor responses (i.e.,

TABLE 1

Results for the main effect of type of observed action, the main effect of gaze and for the interaction type of observed action by gaze,  $p < .001$  uncorrected. Positive coordinates values on the x axis indicate right lateralization, negative values indicate left lateralization

Region	Probabilistic cytoarchitecture	T	Z	MNI coordinates (mm)		
				x	y	z
<i>Main effect of type of observed action</i>						
<i>Frontal cortex</i>						
Superior medial frontal gyrus (dMPFC)		4.58	4.15	12	42	56
Inferior frontal gyrus (pars triangularis)	area 45 (30%)	4.72	4.26	47	37	8
Superior medial frontal gyrus (dMPFC)		5.04	4.49	-18	34	56
Inferior frontal gyrus (pars triangularis)	area 45 (70%)	3.7	3.46	-46	34	14
	area 44 (10%)					
Inferior frontal gyrus (pars orbitalis)	area 45 (10%)	4.90	4.39	-50	34	-4
Inferior frontal gyrus (pars triangularis)	area 45 (70%)	4.13	3.80	-54	20	28
	area 44 (40%)					
<i>Parietal cortex</i>						
<i>Precuneus</i>						
Precuneus		3.57	3.34	-2	-56	36
Angular gyrus	hIP1 (10%)	4.51	4.10	-42	-60	36
Angular gyrus	hIP1 (10%)	4.65	4.20	40	-62	38
<i>Visual cortex</i>						
Middle occipital gyrus	area 18 (70%)	10.1	7.36	-28	-102	2
	area 17 (20%)					
Middle occipital gyrus	area 18 (70%)	8.29	6.50	28	-101	0
	area 17 (50%)					
<i>Main effect of gaze</i>						
<i>Frontal cortex</i>						
Inferior frontal gyrus (pars triangularis)	area 45 (60%)	3.87	3.59	50	26	12
<i>Temporal cortex</i>						
Posterior superior temporal sulcus		3.55	3.33	56	-56	16
<i>Visual cortex</i>						
Cuneus	area 18 (70%)	3.46	3.26	4	-86	24
	area 17 (10%)					
<i>Subcortical structures</i>						
Amygdala	amyg. LB (40%)	3.79	3.53	24	-2	-18
	amyg. SF (40%)					
<i>Interaction</i>						
<i>Frontal cortex</i>						
Superior medial frontal gyrus (dMPFC)		3.39	3.19	-4	32	61

button press during task trials). As expected, differential significant activity was particularly robust in the left primary motor cortex ( $x = -34$ ,  $y = -24$ ,  $z = 54$ ;  $Z$ -score = infinite) and in the supplementary motor area ( $x = 2$ ,  $y = 0$ ,  $z = 54$ ;  $Z$ -score = infinite).

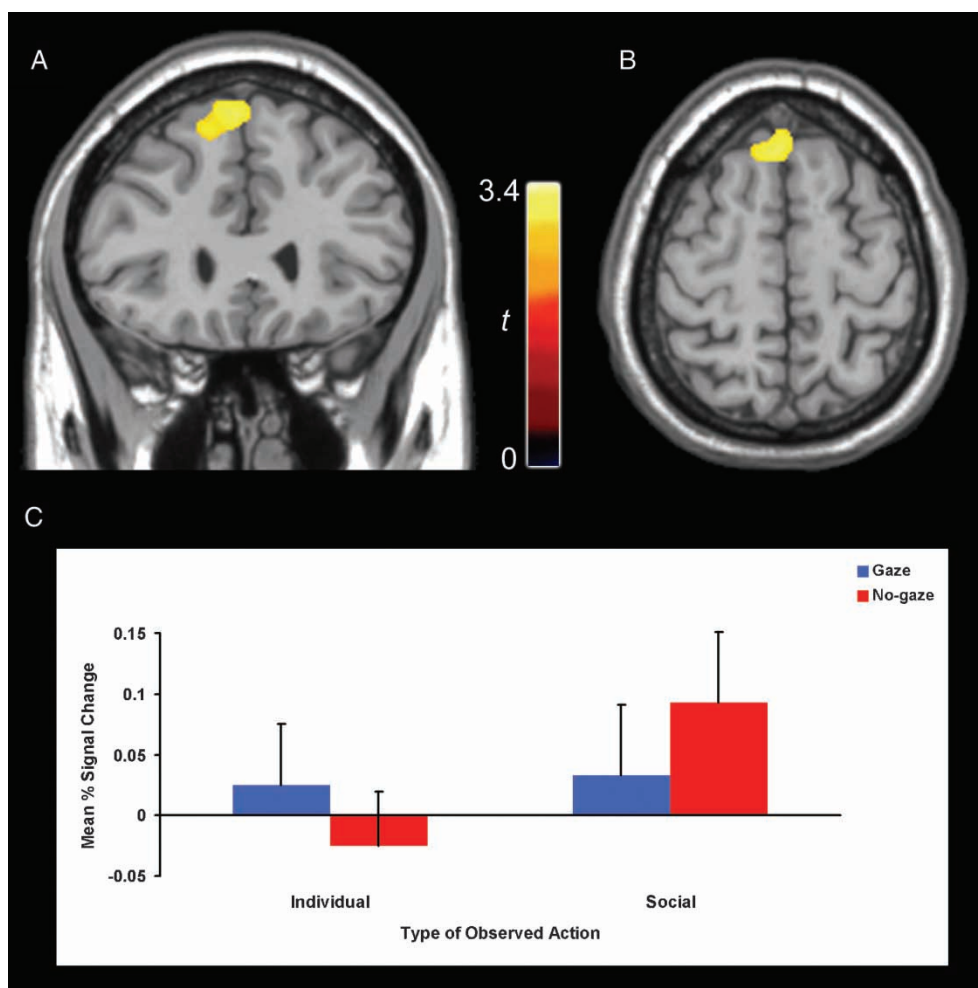
### Main effect of type of observed action

Results from the factorial analysis revealed a significant main effect of type of observed action

[(Social Gaze + Social No-gaze) - (Individual gaze + Individual No-gaze)] for the dMPFC, the pars triangularis of the inferior frontal gyrus bilaterally (IFG), the precuneus, and the angular gyrus bilaterally (Table 1).

### Main effect of gaze

For the main effect of gaze [(Social Gaze + Individual Gaze) - (Social No-gaze + Individual No-gaze)] differences in brain activity were found



**Figure 2.** dMPFC activation emerged from the interaction [(Individual Gaze + Social No-gaze) – (Individual No-gaze + Social Gaze)]. Activation map superimposed on the canonical brain of the MNI series shows significant differential activity ( $p < .001$ , uncorrected) in coronal (A) and transverse (B) sections. (C) Mean percent signal change for the dMPFC cluster is shown. Bars represent standard errors.

in the right hemisphere for the IFG (pars triangularis), the amygdala, and the posterior superior temporal sulcus (pSTS; Table 1).

### Interaction type of observed action by gaze

Results from the interaction [(Individual Gaze + Social No-gaze) – (Individual No-gaze + Social Gaze)] revealed activity in the dMPFC (Figure 2A and 2B; see also Table 1). As shown in Figure 2C the activation within the dMPFC appears to be driven by a significant effect occurring in the absence of gaze cues. Particularly, the level of dMPFC activity seemed to be substantially dependent on the type of observed action only when gaze cues were not available to

the observer. When the gaze was masked, the dMPFC activation was greater for the observation of social interactions than for the observation of individual actions. When gaze was available the differences between the two types of action were less evident. The reverse interaction was not significant.

## DISCUSSION

The factorial design allowed us to characterize brain activation concerned with the two main effects: type of observed action, regardless of the presence of gaze cues; and gaze, regardless of the type of observed action. Furthermore, this design enabled us to investigate the interaction between the two factors, which indicates the effect of gaze

in modulating response to the observation of social versus individual actions.

### Main effect of type of observed action

Contrasting the observation of two human actors interacting with the observation of two human actors performing individual goal-directed actions resulted in activation of a fronto-parietal network, including the dMPFC, the inferior frontal gyrus, the precuneus, and the angular gyrus. This pattern of activation largely resembles that previously reported by Iacoboni and colleagues (2004) in a study in which healthy subjects were requested to watch realistic movie clips depicting everyday social interactions. In their study, observing social interactions produced dorsomedial frontal and medial parietal BOLD fMRI signal increase compared to observation of the segment of the movie clip depicting a single individual engaged in everyday activities.

Whereas the study by Iacoboni and colleagues (2004) focused on social relationship between agents, it did not differentiate the specific nature of social interactions, including both triadic (agent, agent, object) and dyadic (agent, agent) interaction. In the present study, social interactions always involved an object. A further difference with respect to the present experiment is concerned with the number of agents: observation of a person acting alone (single agent) was contrasted with observation of the same person interacting with a partner (two agents). Here, by equating the number of agents, we controlled for the possibility that differential dMPFC activity would be simply related to the number of agents present in the scene.

In this respect, the robust bilateral activations found within a dorsal sector of the MPFC support the idea that this region is the neural substrate underlying the coding of social triadic relations (Saxe, 2006). Previous studies investigating joint attention found triadic-related activation in a more ventral sector of the MPFC (Bristow et al., 2007; Williams et al., 2005) corresponding to the anterior rostral MPFC (see Amodio & Frith, 2006). A possible interpretation for this ventral-to-dorsal displacement may lie in the level of personal involvement. Whereas previous studies investigated on-line triadic interaction with a partner (Bristow et al., 2006; Williams et al., 2005), in our study the participants were not personally involved, but simply observed a triadic

interaction between two agents (off-line triadic interaction). In this connection, Schilbach and colleagues (2006; see also Decety & Sommerville, 2003) recently showed modulation of prefrontal activity that was associated with personal involvement in dyadic interaction. Being oneself engaged in a social interaction revealed ventral displacement of activation compared to observation of dyadic interaction between two agents. This seems to suggest a modulation of MPFC activity as a function of personal involvement in dyadic interactions. The fact that we found activations confined to the most dorsal sector may signify that a similar modulation of MPFC activity occurs depending on the level of personal involvement experienced in triadic interaction.

### Main effect of gaze

For the main effect of gaze, differential activity was found within the right hemisphere for the IFG, the amygdala, and the pSTS region (see Table 1). The STS region and the amygdala play an important role for the interpretation of actions and social intentions through the analysis of biological-motion cues (e.g., Bonda, Petrides, Ostry, & Evans, 1996). In particular, differential activation of the amygdala in response to gaze direction is consistent with neuroimaging (Kawashima et al., 1999) and human lesion studies (Adolphs, Tranel, & Damasio, 1998), suggesting that this region plays a role in monitoring other people's gaze. With respect to the pSTS activation, several studies implicated this area in visual analysis and interpretation of gaze cues (see Pelphrey & Morris, 2006, for a review). More specifically, pSTS activity has been shown to be sensitive to the context in which the gaze shift is perceived (Pelphrey, Morris, & McCarthy, 2004; Pelphrey, Singerman, Allison, & McCarthy, 2003). In line with the present results, contextual influences on the activity of pSTS have been observed under conditions of passive viewing.

A lateralized pattern of activation for the IFG has been found by Iacoboni et al. (2005). They reported increased right IFG activity in response to the observation of actions embedded in a context compared to the observations of actions without a context. Furthermore, right IFG activations have been previously revealed during action-observation tasks in which gaze direction (away or towards an object) was manipulated (Pierro et al., 2006). These findings have been



interpreted as evidence that the right IFG plays a role in understanding the intentions of others. The fact that we found increased right IFG and pSTS activation for the gaze conditions may indicate that, in the presence of gaze cues, participants gain an immediate access to the intentions of the observed agents.

### Interaction type of observed action by gaze

As for the main effect of type of observed action, the interaction revealed activation within the dMPFC, suggesting that gaze plays a pivotal role in modulating activity within this region. Crucially, increased activity within the dMPFC was observed for the observation of social interactions chiefly in the absence of gaze cues. An explanation for this effect may be found in the pivotal role played by gaze cues in representing social interactions.

Evidence from developmental science demonstrates that sensitivity to triadic eye-gaze cues emerges well before the infant is capable of engaging in social and communicative interactions. By three month of age, infants use gaze cues in order to discriminate between various triadic relations (Striano & Stahl, 2005). As the present results confirm, gaze-cues still have a special salience for adults. In the presence of two agents, gaze direction may provide an immediate cue to discriminate whether they are interacting on a common goal or acting independently for the pursuit of an individual goal. When gaze cues are not available, additional inferential processing might become necessary to discriminate between social interactions and individual actions. Therefore, differential activity within the dMPFC could be interpreted in terms of the inferential processing necessary to extract the social relation embedded in the actions performed by the two agents. This interpretation finds support in a number of studies suggesting the role of dMPFC in social-related inferential processes (Castelli, Happé, Frith, & Frith, 2000; Gallagher, Jack, Roepstorff, & Frith, 2002; Mitchell, Macrae, & Banaji, 2005; Saxe & Kanwisher, 2003; Walter et al., 2004). The present results add to these findings, suggesting that under appropriate testing conditions, the dorsal sector of the MPFC may specifically contribute to the inference of the social meaning of an action when such meaning cannot be “watched” in the agents’ gaze.

## CONCLUSIONS

Understanding the relations between others is a crucial unique component of human social cognition that we can easily recognize in a variety of everyday life situations. Predicting the behavior of others as well as planning one’s own action in a social context presupposes this ability. Discriminating whether they act on their own or are engaged in interaction may be regarded as a basic, first step in representing social relations. In our experiment participants were requested to observe social or individual actions performed by two agents whose gaze could be either available or masked. We showed that activation within the dorsal sector of MPFC, an area classically involved in social cognition processes, was greater during the observation of social interactions as compared to individual actions. Whereas previous understanding of the role played by the MPFC in coding social interaction has been confined to on-line interaction, here we demonstrate that the most dorsal sector of this region participates in the observation of social interaction between agents. Crucially, activity within the dMPFC seems to be substantially dependent on the social content of an observed action only when gaze cues are not available to the observer. We suspect that such a result has to be ascribed to the greater level of inferential processing dictated by the unavailability of access to one of the most important social cues, i.e., gaze direction.

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