

Mapping social target detection with functional magnetic resonance imaging

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The neural correlates of cognitive control and social processing functions, as well as the characteristic patterns of anomalous brain activation patterns in psychiatric conditions associated with impairment in these functions, have been well characterized. However, these domains have primarily been examined in isolation. The present study used event-related functional magnetic resonance imaging to map brain areas recruited during a target-detection task designed to evaluate responses to both non-social (i.e. shape) and social (i.e. face) target stimuli. Both shape and face targets activated a similar brain network, including the postcentral gyrus, the anterior and posterior cingulate gyri and the right midfrontal gyrus, whereas face targets additionally activated the thalamus, fusiform and temporooccipital cortex, lingual gyrus and paracingulate gyrus. Comparison of activations to social and non-social target events revealed that a small portion of the dorsal anterior cingulate gyrus (Brodmann's area 32) and the supracalcarine cortex were preferentially activated to face targets. These findings indicate that non-social and social stimuli embedded within a cognitive control task activate overlapping and distinct brain regions. Clinical cognitive neuroscience research of disorders characterized by cognitive dysfunction and impaired social processing would benefit from the use of tasks that evaluate the combined effects of deficits in these two domains.

Keywords: target detection; oddball; face processing; cingulate gyrus; fMRI; functional magnetic resonance imaging

INTRODUCTION

Neuroimaging research has identified a distributed network of brain regions recruited during cognitive control tasks and during social information processing tasks. However, the functional neural correlates of tasks that require joint cognitive control and social processing are largely unaddressed. For example, it is clear that the lateral prefrontal cortex mediates responses to tasks requiring inhibition and conflict monitoring (e.g. MacDonald *et al.*, 2000; Fan *et al.*, 2005) and the medial lateral fusiform gyrus responds to faces (e.g. Allison *et al.*, 1994; Kanwisher *et al.*, 1997). However, the functional neural effects of utilizing social stimuli, such as pictures of faces, in the context of a cognitive control task are not well understood (for examples, see Dichter and

Belger, 2007; Koshino *et al.*, 2008). In the present study, we implemented a novel modification of a classic target-detection oddball task that included both geometric shapes and faces as target stimuli to validate a task that is sensitive to the joint cognitive and social processing deficits that are present in a number of psychiatric conditions.

The term *cognitive control* is used to define the allocation of top-down resources for task-relevant processes, includes both behavioral control and performance monitoring components and is recruited under novel or complex conditions to optimize goal-directed behaviors (e.g. Davidson *et al.*, 2006). Cognitive control is mediated by a number of brain regions, including the lateral prefrontal cortex, the inferior frontal cortex (including the insula), the anterior cingulate cortex, the intraparietal sulcus and the striatum. The lateral prefrontal cortex is activated during cognitive set shifting and inhibitory control tasks (Elliott *et al.*, 1997; Konishi *et al.*, 1999; Rubia *et al.*, 2001), as well as working memory tasks (e.g. Blumenfeld and Ranganath, 2006; Murray and Ranganath, 2007). The inferior frontal cortex mediates response inhibition (Ramautar *et al.*, 2006), whereas parietal regions, both superior parietal cortex and temporal parietal junction, mediate visual and auditory spatial orienting and attention (Zimmer *et al.*, 2006). The functions of the anterior cingulate cortex in cognitive control are wide ranging and include error detection, response monitoring, evaluating and correcting behaviors (MacDonald *et al.*, 2000; Fan *et al.*, 2005) and integrating emotional and attentional

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processes (Fichtenholtz *et al.*, 2004; Dolcos *et al.*, 2007). Finally, the striatum, consisting of the caudate nucleus and the putamen, has been implicated in planning and the execution of self-generated novel actions (Shafritz *et al.*, 2005; Monchi *et al.*, 2006).

Social information processing, on the other hand, appears to be mediated by a network of ventral brain regions that include the amygdala, superior temporal sulcus, orbitofrontal cortex and the fusiform gyrus (for a review, see Pelphrey *et al.*, 2004). The amygdala is activated by facial expressions of emotion (fear in particular; Morris *et al.*, 1996). The superior temporal sulcus mediates perception of biological motion (for a review, see Allison *et al.*, 2000) and the interpretation of the intentions of goal-directed actions, including information from eye gaze shifts (e.g. Pelphrey *et al.*, 2003). The orbitofrontal cortex is involved in the self-monitoring of social-emotional exchange (Beer *et al.*, 2006). Finally, the medial lateral fusiform gyrus activates robustly in response to faces and has been proposed to a critical node of the 'social brain' (e.g. Allison *et al.*, 1994; Puce *et al.*, 1995; Kanwisher *et al.*, 1997).

A small number of neuroimaging studies have demonstrated that reciprocal interactions occur between brain regions that mediate social-affective information and those that respond to cognitive control (Yamasaki *et al.*, 2002; Fichtenholtz *et al.*, 2004). However, relatively few have examined the brain regions recruited during tasks that involve cognitive control and social processing simultaneously. This omission is notable given that information processing in real-world settings requires processing of complex information and social data concurrently. One exception was a recent investigation that used a modified version of the Attention Networks Test (Fan *et al.*, 2002) to examine recruitment of brain areas mediating inhibition interference when stimuli contain arrows or faces (Dichter and Belger, 2007). This study found that brain responses to cognitive control stimuli were contingent on the social content of task items for individuals with autism but not a neurotypical control group; more broadly, this study highlighted that responses to cognitive control stimuli may be moderated by the presence of social information.

Clues regarding potential brain areas that may mediate cognitive control of social information stem from the rich event-related potential (ERP) literature documenting electrophysiological responses to infrequent stimuli and to images of faces. Infrequently presented stimuli reliably evoke the P3 ERP component, which reflects cognitive evaluation of stimulus significance, and is enhanced by low probability and task relevance (because the stimulus is either a designated target or a qualitative deviant) (Squires *et al.*, 1977; Picton, 1988). The P3 is strongest at central-parietal scalp locations and appears to be enhanced to target familiar faces relative to target shapes (Ninomiya *et al.*, 1998). Stimulus novelty, on the other hand, enhances P3 responses in central-frontal, rather than central-parietal, regions (Courchesne *et al.*, 1975).

Compared with other visual objects, faces typically elicit a larger ERP negative deflections at occipital-temporal recording sites ~170 ms after stimulus onset (i.e. the N170; Allison *et al.*, 1999). The N170 is believed to reflect perceptual processing of structural information from faces in specialized occipital-temporal brain areas (e.g. Haxby *et al.*, 2002). Visual oddball ERP studies using faces have revealed that subtracting the ERPs in response to frequent face stimuli from deviant face stimuli results in two classic oddball components: (i) the N2b component, maximally recorded at occipital sites around 230 ms and (ii) the P3b component, maximally recorded at parietal sites around 450 ms (Campanella *et al.*, 2004). In addition, there is also a negative shift around 280 ms in Electroencephalography (EEG) and Magnetoencephalography (MEG) recordings, a pattern that has been interpreted as a visual analogue of mismatch negativity (Susac *et al.*, 2003, 2004). The latency of this response suggests that it is elicited preattentively when one or more changes in previously repeating stimuli are detected (Näätänen, 1992).

Thus, in the present context, where infrequent images of faces were presented as target events, the ERP oddball and face processing literature suggests that brain activation to target faces may be greatest at central-parietal and central-frontal regions (due to their low probability and high novelty), as well as at occipital-temporal brain regions (which respond to faces preattentively) (see also, Eimer and Mazza, 2005).

The goal of the present study was to further characterize the neural correlates of cognitive control in a social information processing context with an oddball task that utilized non-face and face stimuli. Target-detection oddball tasks present a rare 'target' stimulus embedded within a stream of rare non-target (i.e. 'novel') stimuli and frequently occurring non-target events. Contrasting behavioral and functional magnetic resonance imaging (fMRI) blood oxygen level dependent (BOLD) responses to target and novel stimuli allows for the isolation of processes unique to events requiring a task-dependent shift in prepotent behavioral responses (MacDonald *et al.*, 2000; Botvinick *et al.*, 2001; Barber and Carter, 2005). Variants of this paradigm have been used to investigate brain regions activated to target stimuli in non-clinical contexts (e.g. Kirino *et al.*, 2000; Huettel *et al.*, 2004), as well as changes in activation patterns in psychiatric conditions (e.g. Shafritz *et al.*, 2008). Of note, however, most neuroimaging oddball studies have utilized simple geometric shapes as target events (for an exception, see Fichtenholtz *et al.*, 2004). Oddball studies that utilize both non-face and face stimuli as targets would be ideally suited to map the overlapping and distinct brain regions recruited by these two categories of target stimuli. We used images of faces, the quintessential social stimulus, because face perception has been called the 'lower-level subprocess of social cognition' (Brothers, 1990) and because face perception tasks have been widely used in studies of social perception and

social cognition (e.g. Allison *et al.*, 1994; Kanwisher *et al.*, 1997).

In summary, we implemented a visual oddball paradigm that included runs with geometric shapes as targets and runs with faces as targets, as well as non-target novel stimuli. This design allows for three central contrasts: (i) responses to shape targets vs novels allowed for validation of brain areas recruited during non-social target detection, (ii) responses to face targets vs novels allowed for evaluation of brain areas recruited during social target detection, and (iii) contrasting (i) and (ii) reveals brain regions recruited uniquely to face and shape targets (relative to each other). We hypothesized that shape targets would recruit cognitive control brain regions, including the midfrontal gyrus, anterior cingulate cortex and posterior parietal regions (McCarthy *et al.*, 1997). We further hypothesized that face targets would recruit these same regions, possibly to a greater degree due to saliency differences of faces (Zink *et al.*, 2006), as well as portions of occipitotemporal cortex typically activated by faces (e.g. Allison *et al.*, 1994; Puce *et al.*, 1995; Kanwisher *et al.*, 1997; Grill-Spector *et al.*, 2004). Hypotheses concerning unique activations to face targets centered on the anterior cingulate gyrus because of evidence that this region is critical for integrating emotion and attentional functions, and that the degree of activation in subdivisions of the cingulate gyrus is contingent on overt attentional focus (Fichtenholtz *et al.*, 2004; Vogt, 2005). Finally, exploratory analyses evaluated the effects of reaction time and age on task-dependent regional brain activation patterns.

METHOD

Participants

Nineteen participants (18 male) consented to a protocol approved by the local Human Investigations Committees at both UNC-Chapel Hill and Duke University Medical Centers and were paid \$50 for completing the imaging portion of the study. All were righthanded and had normal or corrected-to-normal visions. Average (s.d.) age was 28.0 (7.9) (range = 19.3–47.5), and participants were screened against clinically significant psychiatric symptoms with the Symptom Checklist-90-Revised (Derogatis, 2000). All participants demonstrated Verbal IQ and Performance IQ ≥ 80 on the Weschler Abbreviated Scale of Intelligence (Weschler, 1999). Average (s.d.) IQ scores were full scale = 106.9 (19.2), verbal = 104.9 (19.2) and performance = 107.6 (18.4).

fMRI task

The fMRI session consisted of a visual target-detection task that included nine task runs. Each run contained 160 stimuli presented centrally. Stimuli were presented for 500 ms with an interstimulus interval (ISI) that was jittered between 1000 ms and 2500 ms. A fixation cross was presented during the ISI. There were four stimulus categories: squares, circles and triangle of various colors and sizes and pictures of faces with neutral expressions drawn from the highly

standardized Ekman and Friesen (1976) series. Pictures were cropped below the hairline and above the bottom of the chin. At the start of each imaging run, participants were instructed both verbally and via an instructional screen (e.g. 'Targets = ●') which stimulus category would be the 'target' category on that run. Each run included three conditions: (i) frequently occurring 'standard' stimuli that occurred on 90% of trials and that required a right-hand button press, (ii) infrequently occurring 'novel' stimuli that occurred on 5% of trials and that required the same button press as the standard stimuli and (iii) infrequently occurring 'target' stimuli that occurred on 5% of trials and that required an alternative button press. Infrequent events (i.e. target and novel stimuli) were separated by a minimum of 12 s to adequately observe the hemodynamic response for each event.

The stimuli designated target, novel and standard changed every run (Table 1). A forced-choice reaction time paradigm was used, whereby participants were instructed to respond via right-hand button box to every stimulus as quickly and accurately as possible by pressing one button for all non-target stimuli (including standards) and an alternate button for target stimuli. In this manner, motor activity related to making button presses was incorporated into the baseline task activation. Six of the nine runs included shape targets (two each of circles, squares and targets), and the other three included face targets. This design reflects the primary goals of the larger program of research from which these data derive, mainly to investigate frontostriatal brain activation patterns in psychiatric populations, and thus runs with shape targets were overrepresented. To equate the number of events of interest between face target and shape target categories, for the purposes of the present study, runs 1, 4 and 7 (all shape target runs) were not included in analyses; thus, the final analysis included three shape target runs and three face target runs.¹




























Immediately prior to the scanning session, participants were trained on the task. All stimuli were presented using CIGAL presentation software (Voyvodic, 1996) and displayed to participants in the scanner through magnet-compatible goggles (Resonance Technology, Inc., Northridge, CA). Accuracy and reaction time data were acquired for all responses.

Stimulus saliency

Because the goal of the present study was to assess differential regional brain activation in response to infrequent face vs shape targets, and because attentional resources dedicated to a given stimulus are contingent on the saliency of that stimulus (see Geng and Mangun, in press, for a review), the relative saliency of these two categories of target stimuli is of central relevance. Saliency maps of each individual stimuli were evaluated via the SaliencyToolbox (<http://www.saliencytoolbox.net>) of Walther and Koch (2006)

1 We note that results including runs 1, 4, 7 (i.e. an unbalanced design with twice as many shape targets as face targets) are nearly identical in all respects.

Table 1 Stimulus exemplars from the target detection oddball task

	Target	Novel	Standard
Run 1*			
Run 2			
Run 3			
Run 4*			
Run 5			
Run 6			
Run 7*			
Run 8			
Run 9			

All stimuli were presented against a gray background. Runs marked with asterisks were not included in analyses (see text for details).

(see Supplementary Figure 1 for exemplars), and then the average global saliency values of both categories of stimuli were compared. The average global saliency of the face stimuli was statistically less (mean = 26.3) than the average global saliency of the shape stimuli (mean = 38.8), $P < 0.026$. In other words, face stimuli had overall *lower* low-level saliency than the shape stimuli. Therefore, the shape stimuli actually had a relative advantage over face stimuli in terms of low-level attention.

Imaging methods

Scanning was performed on a General Electric Health Technologies, 3 Tesla Signa Excite HD scanner system with 50 mT/m gradients (General Electric, Waukesha, Wisconsin).

Head movement was restricted using foam cushions and Velcro straps. An eight-channel head coil was used for parallel imaging. Sixty-eight high-resolution images were acquired using a 3D fast SPGR pulse sequence [TR = 500 ms; TE = 20 ms; field of view (FOV) = 24 cm; image matrix = 256^2 ; voxel size = $0.9375 \times 0.9375 \times 1.9$ mm] and used for coregistration with the functional data. These structural images were aligned in the near-axial plane defined by the anterior and posterior commissures. Whole-brain functional images consisted of 34 slices using a BOLD-sensitive gradient-echo sequence with spiral-in k-space sampling and SENSE encoding to take advantage of the eight-channel coil, at TR of 1500 ms (TE = 27 ms; FOV = 25.6 cm; isotropic voxel size = 4 mm^3 ; SENSE factor = 2). Runs began with four discarded RF excitations to allow for steady-state equilibrium.

Imaging data analysis

Functional data were preprocessed using FSL version 4.0.2 [Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB), Oxford University, UK]. Timing files were converted to FSL-compatible format, and NIFTI image data files were generated. Preprocessing was applied in the following steps: (i) brain extraction for non-brain removal (Smith *et al.*, 2004), (ii) motion correction using MCFLIRT (Smith, 2002), (iii) spatial smoothing using a Gaussian kernel of Full-Width Half-Maximum (FWHM) 5 mm, (iv) mean-based intensity normalization of all volumes by the same factor and (v) high-pass filtering (Jenkinson *et al.*, 2002). Functional images of each participant were coregistered to structural images in native space, and structural images were normalized into a standard stereotaxic space (Montreal Neurological Institute) for intersubject comparison. The same transformation matrices used for structural to standard transformations were then used for functional to standard space transformations of coregistered functional images. All registrations were carried out using an intermodal registration tool (Jenkinson *et al.*, 2002; Smith *et al.*, 2004). Voxel-wise temporal autocorrelation was estimated and corrected using FMRIB's Improved Linear Model (Jenkinson and Smith, 2001).

Onset times of events were used to model a signal response containing a regressor for each response type, which was convolved with a double- γ function to model the hemodynamic response. Model fitting generated whole-brain images of parameter estimates and variances, representing average signal change from baseline (activation; positive regressor) and below baseline (deactivation; negative regressor). Group-wise activation and deactivation images were calculated by a mixed-effect higher level analysis using Bayesian estimation techniques, FMRIB Local Analysis of Mixed Effects (Woolrich *et al.*, 2001), with conservative cluster mean threshold of $Z > 2.3$ and a cluster-corrected significance threshold of $P < 0.05$ (FLAME 1 + 2; Beckmann *et al.*, 2003). The final fMRI analysis step consisted of

hemodynamic timecourse analyses of regions identified to differentiate conditions based on whole-brain analyses described above.

RESULTS

Behavioral performance

One-way repeated measures analysis of variance was conducted separately for accuracy (i.e. percent correct) and latency (i.e. reaction time) data for the four stimulus categories (i.e. shape targets, face targets, novels and standards), and significant effects were followed by paired *t*-tests, adjusted for multiple comparisons via step-down Bonferroni correction (Holm, 1979) (Figures 1 and 2). Analyses of accuracy data revealed a main effect of stimulus category [multivariate $F(3,16) = 15.61$, $P < 0.0001$], and paired *t*-tests indicated significant accuracy differences between all four stimulus categories (P 's range from 0.01 for standards vs novels to <0.0001 for standards vs shape targets). Of particular relevance in the present context is the considerably greater accuracy to face targets relative to shape targets, $P = 0.0002$.

Latency data within each condition adhered to a normal distribution as assessed by the Kolmogorov–Smirnov test (all z 's < 0.66), so no transformations were performed. Analyses of latency data revealed a main effect of stimulus category [multivariate $F(3, 14) = 98.96$, $P < 0.0001$].

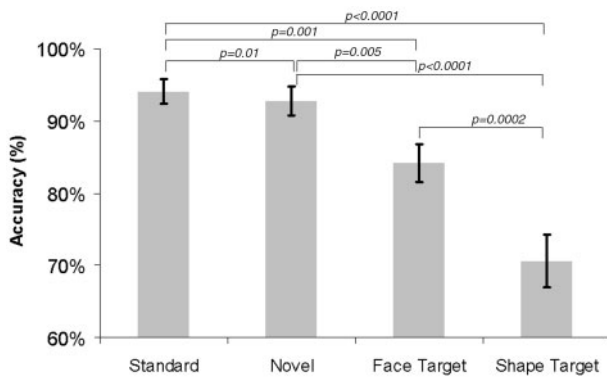


Fig. 1 Accuracy during the fMRI task. Error bars represent group s.e.m.

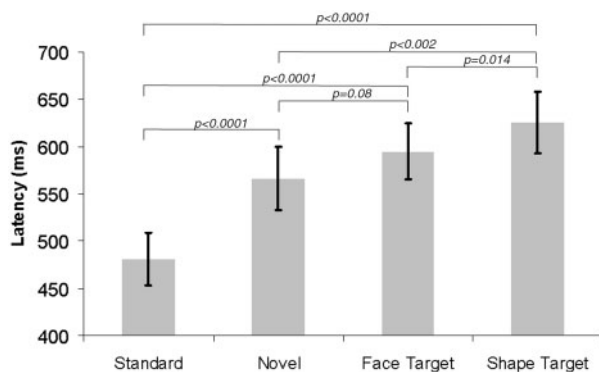


Fig. 2 Reaction time during the fMRI task. Error bars represent group s.e.m.

Follow-up paired *t*-tests, adjusted for multiple comparisons via step-down Bonferroni correction (Holm, 1979), indicated that all comparisons were significant except differential latency of responses to the novel stimuli and face targets. Once again, performance to face targets was improved relative to shape targets, $P = 0.014$.

Imaging data

Analyses of functional imaging data included only epochs corresponding to correct responses and included category-specific reaction times as covariates. Contrasts for FSL mixed-effect analysis included shape targets–novels, face targets–novels, and, of central interest (face targets–novels)–(shape targets–novels), as well as the converse of each contrast. Figure 3 illustrates results of target–novel contrasts for shape (top) and face (bottom) targets. Relative to non-target novel stimuli, both shape and face targets activated a similar network of brain regions, including the post-central gyrus, the anterior and posterior cingulate gyri and the right midfrontal gyrus. Face targets additionally activated the thalamus, fusiform and temporooccipital cortex, lingual gyrus and paracingulate gyrus. The inverse contrasts revealed no significant activations.

Figure 4 illustrates results of a direct comparison of (face targets–novels) and (shape targets–novels) contrasts. This figure reveals that a small portion of the dorsal anterior cingulate gyrus (Brodmann's area 32) and the supracalcarine cortex were preferentially activated to face targets. The inverse contrast revealed no significant activations. The figure also indicates average hemodynamic timecourses derived from dorsal anterior cingulate and supracalcarine cortex voxels identified by the whole-brain analysis to differentiate conditions. Both timecourses revealed activations to face targets, shape targets and novels in these two regions. However, face targets elicited relatively greater activation than shape targets. The difference between target conditions was significant 4.5 s after stimulus presentation in the dorsal anterior cingulate region, and at 1.5–6.0 s after stimulus presentation in the supracalcarine cortex. Table 2 indicates MNI coordinates of these activation contrasts.

Exploratory covariate analyses assessed relations between activation patterns and reaction time and age. No relations with reaction time were detected. Figure 5 illustrates that increasing age predicted pars opercularis activation to shape (in green) and face (in red) targets; additionally, increasing age predicted supplementary motor cortex activity to shape targets and paracingulate activity and left Heschl's gyrus activation to face targets.

DISCUSSION

The goal of the present study was to map brain regions differentially recruited during an oddball target-detection task when targets were pictures of faces with neutral expressions, relative to non-face targets. Behavioral results indicated that both target categories elicited less accuracy than

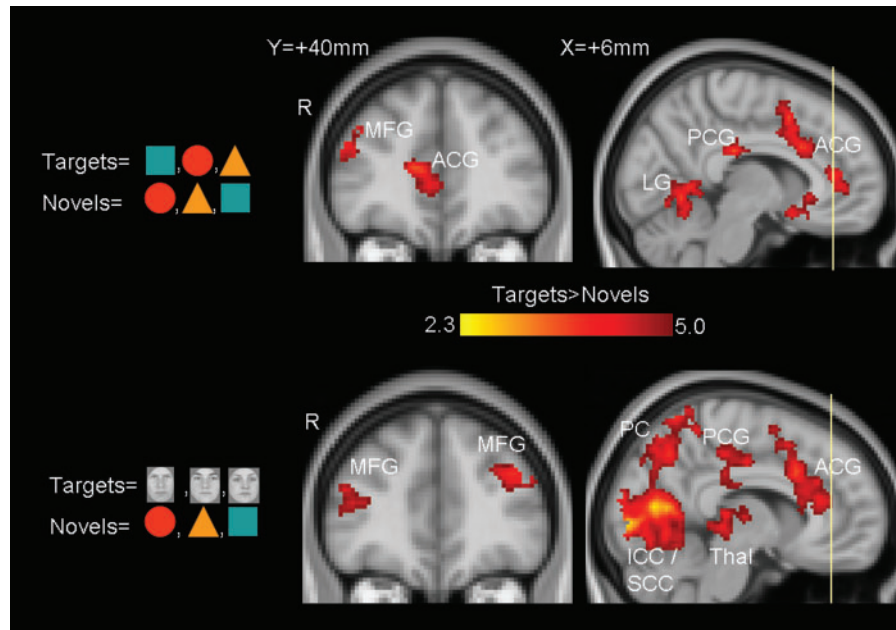


Fig. 3 Target–novel contrast activations for shape targets (top) and face targets (bottom). ACG, anterior cingulate gyrus; PCC, postcingulate gyrus; MFG, midfrontal gyrus; LG, lingual gyrus; Thal, thalamus; ICC, intracalcarine sulcus; SCC, supracalcarine cortex.

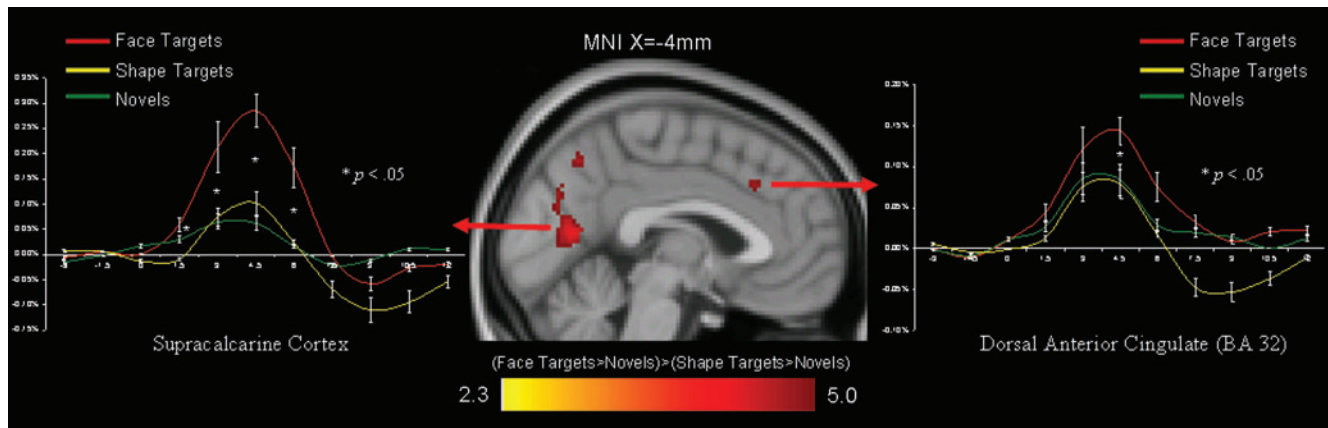


Fig. 4 Results of the (face targets > novels) > (shape targets > novels) contrast, and average hemodynamic timecourses from active clusters. On the plots, the *x*-axes are time and the *y*-axes percent signal change.

standard or novel stimuli, validating that these conditions required greater cognitive control. Additionally, face targets elicited quicker and more accurate responses than shape targets.

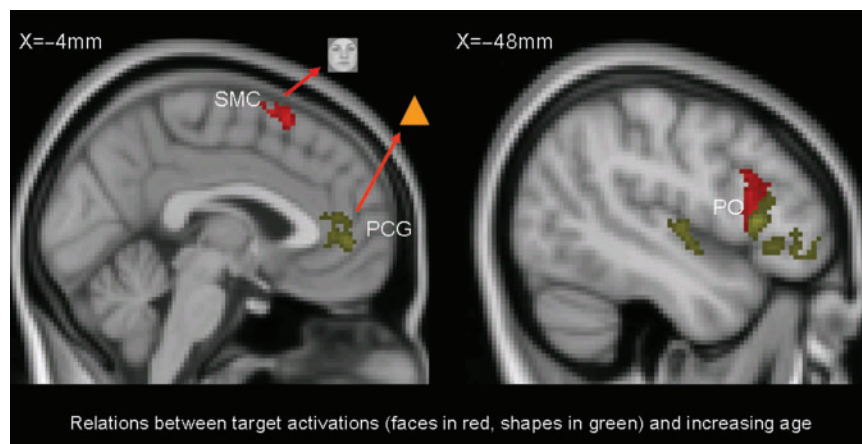
Confirming numerous published accounts, functional brain imaging data revealed activation of postcentral gyrus, the anterior and posterior cingulate gyri and the right midfrontal gyrus to shape and face targets, relative to non-target novel events. Face targets additionally activated the thalamus, fusiform and temporooccipital cortex, lingual gyrus and paracingulate gyrus. Activation of fusiform and temporooccipital cortex was not surprising, given the rich history of research documenting activation in these regions to faces and face-like stimuli (e.g. Allison *et al.*, 1994; Puce *et al.*, 1995; Kanwisher *et al.*, 1997; Grill-Spector

et al., 2004), although the present study was clearly not designed to assess responding in the functionally defined fusiform ‘face area’.

The central contrast of interest, face targets vs shape targets (both corrected for novel stimuli), revealed that dorsal anterior cingulate gyrus (Brodmann’s area 32) and supracalcarine cortex were preferentially activated to face targets. Once again, preferential activation to face targets of supracalcarine cortex, a region not typically associated with target detection *per se* but part of the face processing network, is not surprising. However, preferential activation of dorsal anterior cingulate, a region that is typically implicated in standard oddball tasks, suggests that this region may play a critical role in processing cognitive control stimuli that contain social information. Mayberg (1997) has

Table 2 Regions of activation for experimental contrasts

Region	Cluster size (voxel)	Montreal Neurologic Institute coordinates (mm)			<i>p</i>	<i>Z</i> _{max}
		<i>X</i>	<i>Y</i>	<i>Z</i>		
Shape Targets > Novels						
Left post-central gyrus	3418	−38	−30	62	1.34e-09	4.74
Right post-central gyrus	1764	48	−30	60	1.03e-05	4.66
Lingual gyrus	1125	4	−56	2	0.000677	4.01
Anterior cingulate gyrus	899	2	8	48	0.00356	3.98
Posterior cingulate gyrus	702	6	−26	26	0.0169	3.53
Paracingulate gyrus	653	12	40	12	0.0254	1.65
Right midfrontal gyrus	253	46	38	20	0.0376	1.61
Face Targets > Novels						
Intracalcarine cortex/supracalcarine cortex	6517	2	−68	14	3.03e-23	6.22
Left post-central gyrus	5682	−38	−30	64	7.36e-11	5.94
Right post-central gyrus	2382	42	−34	60	5.38e-09	4.71
Anterior cingulate gyrus	1121	6	16	32	3.52e-06	4.32
Right fusiform cortex	1019	29	32	33	4.13e-05	4.01
Left insular cortex	634	−36	−4	10	7.62e-05	3.62
Left temporooccipital cortex	469	−56	−50	10	0.00631	4.63
Posterior cingulate gyrus	458	2	−30	22	0.00732	3.94
Right insular cortex	352	38	14	−8	0.0326	3.87
(Face Targets > Novels) > (Shape Targets > Novels)						
Intracalcarine cortex/supracalcarine cortex	1093	−16	−66	8	2.98e-07	4.11
Right fusiform cortex	719	36	−62	−10	7.98e-05	3.98
Left fusiform cortex	653	−34	−60	−10	0.000714	3.51
Dorsal anterior cingulate	63	−2	26	36	0.0361	1.75
Precuneus	59	0	−62	48	0.0492	1.41

**Fig. 5** Exploratory covariate analyses of the effects of participant age on responses to shape targets (in green) and face targets (in red). SMC, supplementary motor cortex; PCG, paracingulate gyrus; PO, pars opercularis.

hypothesized that the dorsal portion of the anterior cingulate serves to integrate vegetative–somatic functions and attentional controls. Others have also postulated that the cingulate cortex integrates the emotional or motivational relevance of stimuli with attentional functions, due to its connections between the limbic system and sensory areas (Mesulam, 1981). Finally, Papez (1995) called the anterior cingulate the ‘seat of dynamic vigilance’, where emotional and executive processing are integrated. The present findings are consistent with these conceptualizations of the functions

of the dorsal anterior cingulate and suggest that social information embedded with an executive attention task recruits this subdivision of the cingulate gyrus.

The anterior cingulate is composed of a number of subdivisions. One classical functional dissociation of the cingulate is into dorsal ‘cognitive’ and ventral ‘affective’ subdivisions (see Bush *et al.*, 2000 for a review). The dorsal anterior cingulate is part of a distributed attentional network that maintains strong reciprocal interconnections with lateral prefrontal, parietal and motor areas, and is

implicated in modulation of attention by influencing sensory and response selection, conflict monitoring and error detection (e.g. Bush *et al.*, 1999; Carter *et al.*, 1999). In contrast, the affective subdivision is connected to limbic regions, and is primarily involved in assessing motivational information and the regulation of emotional responses (e.g. Devinsky *et al.*, 1995; Whalen *et al.*, 1998).

In the present context, this formulation raises the question of why does the 'cognitive' dorsal anterior cingulate respond more strongly to social stimuli. In this regard, it is critical to note that more recent formulations of the functions of the dorsal anterior cingulate stress the evaluative, rather than regulative, role of this region (see, for example, Botvinick, 2007 for a review). This account highlights that the dorsal anterior cingulate detects events or internal states, indicating a need to strengthen top-down control rather than conflict *per se* (Badre and Wagner, 2004). It may be the case, then, that face stimuli presented in the context of a cognitive control task prompted relatively increased evaluation that resulted in increased dorsal anterior cingulate activity. Although the precise reasons for this are presently unclear, faces are known to prompt automatic attention (Gliga and Csibra, 2007), even when processed without awareness (e.g. Balconi and Lucchiari, 2005; Morris *et al.*, 2007). We, thus, conclude that augmented evaluation of face targets resulted in relatively increased dorsal anterior cingulate activity. Future research into disorders characterized by anomalous attention to faces should evaluate the impact of these conditions of this preferential dorsal anterior cingulate activity in response to face targets.

Exploratory covariate analyses revealed that increasing age predicted (i) pars opercularis activation to both types of targets, (ii) supplementary motor cortex activity to shape targets and (iii) paracingulate activity and left Heschl's gyrus activation to face targets. Relations between age and pars opercularis activation (BA 44) is particularly noteworthy. This region mediates both language and motor function, as well as observation and, in particular, imitation of action in others (Molnar-Szakacs *et al.*, 2005). This region is also known to show hypoactivation in autism during emotion imitation (Dapretto *et al.*, 2006). Though the present task involved cognitive control and not imitation, autism is characterized by functional brain deficits during both imitation (Dapretto *et al.*, 2006) and cognitive control (Shafritz *et al.*, 2008), and it may be that the developmental delay reflected by pars opercularis hypoactivation in autism is paralleled to some extent in typical development.

Our observed linkage between age and supplementary motor cortex activity to shape targets confirms findings of relations between development and the learning, planning and performance of motor tasks (Mall *et al.*, 2005), and relations between age and paracingulate activity to face targets may reflect an association between this area and perception of faces (Gobbini and Haxby, 2007), a process which is known to change during the course of development

(Mondloch *et al.*, 2006) and to be aberrant in neurodevelopmental disorders (Sasson *et al.*, 2007). Clearly, these exploratory findings require replication but suggest that target-detection tasks may be a rich resource for examining changes in neural functioning during development, and, by extension, in neurodevelopmental disorder. They also suggest that individual difference and/or developmental factors may moderate relations between regional brain activations and response to social and non-social target stimuli.

One alternative explanation for increased regional brain activation in response to face relative to shape targets is that brain activation differences resulted from stimulus features of the face stimuli other than their 'social-ness', such as their saliency. In this regard, our analyses of low-level attentional features indicated that shape stimuli demonstrated relatively greater global saliency, likely due to strict edges and the feature of color, which were present only in the shape stimuli, than face stimuli. However, future studies that parametrically match stimuli on relevant features will be required to isolate what specific components of face images preferentially recruit the anterior cingulate gyrus and the supracalcarine cortex in a target-detection context. In this regard, we note that the present study did not include non-face target events that differed in stimulus features from the novel and standard events (i.e. that were not geometric shapes themselves) or novel faces, two additional task conditions that will be utilized in future studies to establish the specificity of the present findings to the social nature of target events.

The ultimate goal of this line of research is to evaluate anomalous regional brain activation in psychiatric conditions characterized by cooccurring cognitive and social deficits. The functional neural underpinnings of deficits in cognitive or social tasks have been investigated separately in a number of disorders. For example, individuals with schizophrenia demonstrate hypoactivation in frontostriatal brain regions during tasks requiring sustained attention and cognitive control (Zink *et al.*, 2006). Additionally, schizophrenia is associated with functional and structural deficits in brain regions subserving face perception (e.g. Manoach *et al.*, 2000; Ardekani *et al.*, 2002; van Veen and Carter, 2002; Barch *et al.*, 2003). Similarly, affective disorders are characterized by anomalous processing of cognitive (see, for example, Onitsuka *et al.*, 2006 for a review) and social (see, for example, Walter *et al.*, 2007, p. for a review) information. Finally, autism spectrum disorders are associated with regional brain hypoactivation during executive (e.g. Gilbert *et al.*, 2008; Gomot *et al.*, 2008; Shafritz *et al.*, 2008) and social (e.g. Schultz *et al.*, 2000; Dapretto *et al.*, 2006) tasks. However, the challenges faced by individuals with various psychiatric disorders involve simultaneous cognitive and social demands. Therefore, the logical next step in clinical neuroscience studies of these neuropsychiatric conditions is the development of paradigms that simultaneously evaluate the effects of such

disorders on cognitive control and social processing in tandem.

SUPPLEMENTARY DATA

Supplementary Data are available at SCAN Online.

CONFLICT OF INTEREST

None declared.

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