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Superior temporal sulcus and social cognition in dangerous drivers

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A B S T R A C T

Understanding the neural systems underpinning social cognition is a primary focus of contemporary social neuroscience. Using functional magnetic resonance imaging (fMRI), the present study asked if brain activity reflecting socio-cognitive processes differs between individuals according to their social behavior; namely, between a group of drivers with frequent traffic offenses and a group with none. Socio-cognitive processing was elicited by employing videos from a traffic awareness campaign, consisting of reckless and anti-social driving behavior ending in tragic consequences, and control videos with analogous driving themes but without such catastrophic endings. We investigated whether relative increases in brain function during the observation of these campaign stimuli compared with control videos differed between these two groups. To develop the results of our previous study we focused our analyses on superior temporal sulcus/gyrus (STS/STG). This revealed a bigger increase in brain activity within this region during the campaign stimuli in safe compared with dangerous drivers. Furthermore, by thematically coding drivers' verbal descriptions of the stimuli, we also demonstrate differences in STS reactivity according to drivers' scores on two indices of socio-cognitive processing: subjects' perceived consequences of actors' actions, and their affective evaluation of the clips. Our results demonstrate the influence of social behavior and socio-cognitive processing on STS reactivity to social stimuli, developing considerably our understanding of the role of this region in social cognition.

Introduction

Interacting successfully with others and generally conducting oneself appropriately within social contexts require a variety of cognitive capacities subsumed under social cognition. Such capacities include an understanding that others hold beliefs and desires independent of our own, the ability to infer others' mental states and emotional experiences (i.e. termed mentalizing and empathy, respectively), and an appreciation of the social consequences of our own and others' actions. Research within the social neuroscience domain has begun to elucidate the neural correlates of many of these cognitive faculties (for a review see Frith and Frith, 2010, 2012). One brain region implicated consistently in social cognition is the superior temporal sulcus (STS; e.g. Bzdok et al., 2012; Moor et al., 2012; Winston et al., 2002), within which brain activity appears to underlie the processing of social cues (e.g. Allison et al., 2000), mentalizing (e.g. Gallagher and Frith, 2003; Krämer et al., 2010; Peelen et al., 2010), and empathy (Müller et al., 2008; Pelphrey et al., 2005; Suda et al., 2011).

Importantly, neuroimaging studies have demonstrated individual differences in STS reactivity to social stimuli. Using blood oxygen level-dependent (BOLD) signal as an index of brain activity, Rauch et al. (2007) discuss a modulation of activity within, among other areas, STS in response to emotional facial expression stimuli according to individuals' coping styles. Likewise, Kaplan et al. (2007) report differential activation of a cortical network encompassing STS during the processing of faces belonging to presidential candidates according to the observers' political allegiance. In a similar vein, Goudriaan et al. (2010) report greater activation of a variety of cortical areas including STS in response to smoking-related images in heavy smokers relative to non-smoking controls. In a similar vein, greater activity within superior temporal gyrus (STG) has been observed in response to stimuli depicting risky or safe actions (Tamura et al., 2012). Such studies suggest that certain social behavioral tendencies – e.g. preferences, risk taking – influence directly STS activity reflecting socio-cognitive processes.

To achieve a comprehensive understanding of the neural mechanisms underlying social cognition, social neuroscience must also explore differences in the neural correlates of pro- and anti-social behavior. Indeed, a number of recent functional neuroimaging studies have focused specifically on antisocial behavior (for reviews see Loomans et al., 2010; Raine and Yang, 2006). This research reveals that antisocial behavior is associated with both atypical brain function and structure, particularly

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within the frontal and the temporal lobes (Blair, 2010; Buckholtz et al., 2008; Crowley et al., 2010; Weissman et al., 2008; Yang et al., 2008). This adds to other factors implicated in anti-social behavior, such as levels of hormones (e.g. cortisol [Freeman and Beer, 2010] and testosterone [Volman et al., 2011]), age (Ernst and Fudge, 2009), specific neurotransmitters and their receptors (e.g. Miczek et al., 2002), and a lack of empathy (Ellis, 1982). Additionally, substance abuse (e.g. alcohol, cannabis) and mental disorders are often involved (Kieling et al., 2011); the results of a recent study show that Attention Deficit Hyperactivity Disorder (ADHD) was associated with a higher number of traffic accidents, and antisocial personality disorder was associated with a greater number of traffic violations (Kieling et al., 2011).

Antisocial behavior often occurs in driving situations, presenting a potential danger to all drivers. For this reason, societies try to prevent antisocial driving behavior by means of public education campaigns. The main aim of these programs is to motivate drivers to avoid antisocial behavior that endangers themselves and others, often with the use of videos that aim to educate drivers on the potential consequences of reckless or irresponsible driving. These campaign videos provide important stimuli for social neuroscience research; by incorporating a wide variety of social cues (e.g. biological motion, social interactions, speech) and moral themes, these videos represent more accurately the complexity of real life social contexts. This allows research to move away from the study of single socio-cognitive functions by comparing two narrow categories of social stimuli (e.g. perception of faces vs. bodies). Importantly, Lahnakoski et al. (2012) demonstrated recently the role of STS during the processing of a wide variety of social cues, including biological motion, social interactions, and speech. As such, these campaign videos provide an opportunity to explore the involvement of STS in high-level socio-cognitive processes, and to investigate whether differences exist in STS reactivity to social stimuli between individuals differing in pro- or anti-social behavior.

In a previous functional magnetic resonance imaging (fMRI) study we employed videos from one such campaign to explore the neural correlates of social cognition. By contrasting campaign video clips, depicting anti-social driving behavior ending with tragic consequences, with control videos presenting less socially unacceptable driving behavior, we revealed greater STS activity in response to the campaign videos. Importantly, the region of STS exhibiting this preference for the campaign stimuli lay in close proximity to the foci reported by some of the aforementioned studies (Dziobek et al., 2011; Schultz et al., 2005). Moreover, this difference in STS reactivity was particularly pronounced in individuals demonstrating high empathic ability (Zelinková et al., submitted for publication). In the present study we set out to extend these initial findings by investigating whether or not greater STS activation during campaign videos differs between individuals according to their tendency for pro- or anti-social behavior. To do so, we use driving as an index of social behavior, assuming that more pro-social individuals will drive in a manner that is safe and consistent with road regulations, whereas anti-social individuals will drive more dangerously without consideration for others. Specifically, we compared STS reactivity to the complex social stimuli between our previous sample of safe, pro-social drivers and a group of drivers involved regularly in road traffic accidents or the violation of traffic regulations. Such an investigation should help us to understand whether or not STS is associated with an individuals' tendency for a specific form of antisocial behavior. This second aim was to investigate whether greater STS reactivity to the campaign compared with the control videos reflects the degree to which the observer engages in socio-cognitive processing. To this end, we divided our entire sample of drivers into two groups according to their verbal descriptions of the stimuli – under the assumption that subjects would discuss those aspects that are most important and salient to them – and compared relative increases in brain activity within STS between these groups.

We hypothesized that driving behavior would be related to the degree of STS reactivity to campaign videos – as indexed by BOLD signal – with safer, more pro-social drivers engaging this brain region more than dangerous, anti-social drivers. Furthermore, we predicted that relative increases in BOLD STS activity during the campaign relative to the control videos would be greater in individuals who engage in more socio-cognitive processing, such as empathizing and mentalizing.

Materials and methods

Subjects

Functional MRI data were acquired from two different groups of healthy right-handed male volunteer drivers. The first group consisted of 19 drivers who reported at least one incidence of traffic offense (e.g. driving under the influence of alcohol or drugs, high-speed driving) or involvement in road-traffic accident. The mean age of this dangerous driver (DD) group was 24.4 years (SD = 3.3 years; range = 19–30 years; median = 24 years). The second group included 25 control subjects with no recorded traffic offenses and who reported no traffic accidents, including but not exclusive to the sample of drivers comprising our previous study. The mean age of this safe driver (SD) group was 23.1 (SD = 3.0 years; range = 20–9 years; median = 22 years).

All participants had normal or corrected-to-normal vision. Czech or Slovak was the first language for all subjects. Written informed consent was obtained from each subject prior to the experiment, and the study received the approval of the St. Anne's Hospital Ethics Committee.

Task

During the scanning procedure, all subjects viewed a series of twelve 30-second video clips representing various types of driving situations. Six clips were taken from a national traffic awareness campaign (campaign videos [CV]), each involving a catastrophic and tragic ending by showing various potential consequences of traffic accidents (e.g. resuscitation, death). These video clips, broadcasted widely between 2008 and 2010, were prepared by a professional agency in cooperation with the Ministry of Transport. This Czech road safety campaign – "If you don't think, you will pay!" – was targeted especially at young drivers and the most common causes of traffic accidents, such as alcohol or drug influence, and aggressive or reckless driving. These CV stimuli were presented pseudo-randomly (see below) with 6 control videos (neutral videos [NV]). These NV stimuli, created in our lab by extracting sequences from typical car advertisements involving various traffic situations, followed analogous driving themes but consisted of less anti-social driving behavior and without dramatic endings. The NV stimuli contained no advertisement logos or slogans. All CV and NV clips contained sound, presented binaurally via MRI-compatible headphones. All clips contained an equivalent number of words and lasted identical durations.

No more than two instances of the same stimulus category (CV or NV) succeeded one another. A 26-second pause was inserted between the presented videos, in which a central yellow cross was presented against a black background. Visual stimuli were shown via a back-projection screen onto an overhead mirror. All stimuli subtended 16° visual angle. The subjects were instructed to remain still while in the scanner and to watch the presented video clips. Subjects were informed that some clips would have dramatic endings.

Data acquisition

Imaging was performed on a 1.5 T Siemens Symphony scanner equipped with Numaris 4 System (MRease). The functional scans were obtained using a gradient echo, echoplanar imaging sequence: TR = 3000 ms, TE = 40 ms, FOV = 220 mm, flip angle = 90°, matrix size 64 × 64, in-plane resolution = 3.44 mm × 3.44 mm, slice thickness = 3.5 mm, and 32 transverse slices per scan. Functional scans consisted of 220 volumes covering most of the brain, excluding the vertex. Following functional measurements, high-resolution anatomical T1-weighted images were acquired using a 3D sequence that served as a matrix for the functional imaging (160 sagittal slices, resolution