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Spontaneous mentalizing during an interactive real world task: An fMRI study

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Abstract

There are moments in everyday life when we need to consider the thoughts and intentions of other individuals in order to act in a socially appropriate manner. Most of this mentalizing occurs spontaneously as we go about our business in the complexity of the real world. As such, studying the neural basis of spontaneous mentalizing has been virtually impossible. Here we devised a means to achieve this by employing a unique combination of functional magnetic resonance imaging (fMRI), a detailed and interactive virtual reality simulation of a bustling familiar city, and a retrospective verbal report protocol. We were able to provide insights into the content of spontaneous mentalizing events and identify the brain regions that underlie them. We found increased activity in a number of regions, namely the right posterior superior temporal sulcus, the medial prefrontal cortex and the right temporal pole associated with spontaneous mentalizing. Furthermore, we observed the right posterior superior temporal sulcus to be consistently active during several different subtypes of mentalizing events. By contrast, medial prefrontal cortex seemed to be particularly involved in thinking about agents that were visible in the environment. Our findings show that it is possible to investigate the neural basis of mentalizing in a manner closer to its true context, the real world, opening up intriguing possibilities for making comparisons with those who have mentalizing problems.

Keywords: Theory of mind; Mentalizing; Neuroimaging; Verbal report; Thought; fMRI; Virtual reality; Superior temporal sulcus; Medial prefrontal cortex

1. Introduction

Our survival depends on considering the actions and intentions of others. Being able to predict what they might do or expect of us can help direct our own behaviour appropriately. This ability to attribute mental states to others is known as having ‘theory of mind’ (ToM) (Premack & Woodruff, 1978) or ‘mentalizing’ (Frith, Morton, & Leslie, 1991). It has been specifically linked with a number of brain regions, in particular the posterior superior temporal sulcus (pSTS), the temporo-parietal junction, the medial prefrontal cortex (mPFC) and the temporal poles (Frith & Frith, 2003; Gallagher & Frith, 2003). Evidence for their involvement in ToM has been provided by neuroimaging and neuropsychological studies in which subjects must make inferences about the mental state or intentions of other individuals.

These individuals, or agents, have been presented through a variety of methods including stories (Fletcher et al., 1995; Rowe, Bullock, Polkey, & Morris, 2001; Saxe & Kanwisher, 2003), static cartoons (Brunet, Sarfati, Hardy-Bayle, & Decety, 2000; Gallagher et al., 2000), animations of interacting shapes (Castelli, Happe, Frith, & Frith, 2000; Schultz, Friston, O’Doherty, Wolpert, & Frith, 2005) and movies of people or simulated characters making intentional actions (Grezes, Frith, & Passingham, 2004; Pelphrey, Singerman, Allison, & McCarthy, 2003; Pelphrey, Viola, & McCarthy, 2004). Converging evidence for the involvement of these brain regions has come from a different approach, using interactive tasks to tease out components of our mentalizing capacity during cooperative or competitive games (Gallagher, Jack, Roepstorff, & Frith, 2002; McCabe, Houser, Ryan, Smith, & Trouard, 2001; Ramnani & Miall, 2004; Rilling et al., 2002; Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004; Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003; Stuss, Gallup, & Alexander, 2001). While these studies have given insight into the brain regions underlying mentalizing, they often involve simplified repetitive tasks that do not speak

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directly to the experience of spontaneously mentalizing in everyday life. We are all confronted by other individuals on a daily basis, but not all our time is consumed with considering their mental states. At particular moments their actions might give us reason to consider their mental states or we might in turn think about how our own behaviour might affect their future choice of actions.

Examining the brain regions associated with spontaneous mentalizing during our everyday experiences represents a huge challenge. Not only must we capture the richness of external world, but subjects must be free to interact with it as they wish. One means of creating interactive experiences is to use virtual reality (VR). While VR has been used successfully in combination with neuroimaging to examine the neural correlates of large-scale navigation (Aguirre, Detre, Alsop, & D'Esposito, 1996; Gron, Wunderlich, Spitzer, Tomczak, & Riepe, 2000; Hartley, Maguire, Spiers, & Burgess, 2003; Maguire et al., 1998), the VR environments employed have been simplistic, unfamiliar and uninhabited, making them unsuitable for studying ToM. Furthermore, standard behavioural measures are insufficient for identifying when subjects engage in mentalizing or other thought processes during ongoing real world experiences.

We set out to overcome these limitations by combining functional neuroimaging with an accurate interactive virtual simulation of a bustling central London (UK), comprising people and traffic. We also employed a novel means of 'reading' participants' thoughts while they moved around the city. To determine when subjects were engaged in different thought processes, immediately post-scan and without prior warning, subjects watched a video replay of their performance and were interviewed using a verbal report protocol that was carefully developed from pilot studies (Ericsson & Simon, 1980). Simply put, this involved getting subjects to review their performance and report on what they had been thinking while they had been doing the task in the scanner. The transcribed thoughts of the subjects could then be used to model every second of the functional magnetic resonance imaging (fMRI) time series. Analysing the brain activity during the moments when subjects reported engaging in spontaneous mentalizing, we were able to reveal the neural correlates underlying these events.

2. Methods

2.1. Subjects

Twenty healthy right-handed male licensed London taxi drivers participated in the experiment (mean age 49.8 years, S.D. 8.5 years, range: 27–59 years). Licensed taxi drivers were chosen in order to ensure a consistent pattern of movement around the city as a platform for our analyses. All subjects were naïve to the stimuli used in the experiment and gave informed written consent in accordance with the local research ethics committee.

2.2. The virtual environment

The video game 'The Getaway' (©Sony Computer Entertainment Europe 2002) run on a Sony Playstation2 (©Sony Computer Games Inc.) was used to present subjects with a ground-level first person perspective view of a simulation of central London, UK (see Fig. 1). The game designers decided to truly recreate the city and a large team of photographers walked the streets of central London for 2 years recording many streets, shops, other details. Over 110 km (70 miles) of driveable roads have been accurately recreated from Ordinance Survey map data, covering 50 km^2 (20 $miles^2$) of the city centre. Breaking all speed limits and ignoring all red traffic lights, it takes 15 min to travel between the furthest points east to west. The one-way systems, working traffic lights, the busy London traffic, and an abundance of Londoners going about their business are all included. The simulated drivers and pedestrians followed the traffic regulations, and reacted to the subjects' movements appropriately, e.g. avoiding being run over and giving way at junctions. The 'Free Roaming' mode of the game was used, permitting free navigation with the normal game scenarios suspended. Subjects moved through the environment with a normal ground-level first person perspective, in a London taxi cab, controlled using a modified MRI-compatible game controller, consisting of two joysticks providing analogue control of acceleration, braking and steering left and right. To avoid constant collisions with other vehicles in the environment, Action Replay Max software (©Datel Design and Development Ltd. 2003) provided a 'cheat' modification to the game, permitting subjects to drive through other vehicles if necessary. Subjects were instructed to drive 'legally' as they would in actual London. All of the taxi drivers confirmed that the game was very reminiscent of their experience of driving in central London.

2.3. Pre-scan training and familiarization

Two weeks prior to scanning subjects were given 2 h of practice with the game controls by asking them to navigate to various locations in areas of envi-

Fig. 1. Example views from within the virtual simulation of London: 'The Getaway' ©Sony Entertainment Europe 2002. These images are reproduced with the kind permission of Sony Computer Entertainment Europe. (a) Piccadilly Circus and (b) Trafalgar Square. The rear view of a London black taxi cab in the lower middle of each image was the vehicle that the subjects drove during the experiment.