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Cortical mechanism of communicative speech production

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Communicative speech requires conformity not only to linguistic rules but also to behavior that is appropriate for social interaction. The existence of a special brain mechanism for such behavioral aspects of communicative speech has been suggested by studies of social impairment in autism, and it may be related to communicative vocalization in animals. We used functional magnetic resonance imaging (fMRI) to measure cortical activation while normal subjects casually talked to an actor (communication task) or verbally described a situation (description task) while observing video clips of an action performed by a familiar or an unfamiliar actor in a typical daily situation. We assumed that the communication task differed from the description task in the involvement of behavioral aspects of communicative speech production, which may involve the processing of interaction-relevant biographical information. Significantly higher activation was observed during the communication task than during the description task in the medial prefrontal cortex (polar and dorsal parts), the bilateral anterior superior temporal sulci, and the left temporoparietal junction. The results suggest that these regions play a role in the behavioral aspects of communicative speech production, presumably in understanding of the context of the social interaction. The activation of the polar part of the medial prefrontal cortex during the communication task was greater when the actor was familiar than when the actor was unfamiliar, suggesting that this region is involved in communicative speech production with reference to biological information. The precuneus was activated during the communication task only with the familiar actor, suggesting that this region is related to access to biographical information per se.

Keywords: Social cognition; Social interaction; Communication; Speech act

Introduction

Speech in everyday verbal communication is a social behavior using language and is an act directed toward another person based on interpersonal knowledge (Austin, 1962; Flavell, 2000; Edwards, 2006). Although the brain mechanism for the linguistic aspects of speech processing has been intensively researched in cognitive neurolinguistics, little is known about the brain mechanism for the behavioral aspects of communicative speech production (Mar, 2004).

Recent studies of autism suggest that the behavioral aspects of communicative speech production are processed through a mechanism that is independent of linguistic mechanisms. Patients with Asperger syndrome, a type of autistic disorder, apparently have sufficient linguistic ability, but nevertheless show severe impairment in social verbal communication (Adams et al., 2002). Neuroimaging studies show that patients with autism have structural and functional abnormalities in the frontal and temporal cortices (Ohnishi et al., 2000; Castelli et al., 2002), but such abnormalities are outside the language-processing center (Saxe et al., 2004) and the speech production center (Kuriki et al., 1999; Wise et al., 1999; Kerns et al., 2004). The impairment of verbal communication in autism has often been interpreted in the framework of the theory of mind, or mentalization (Mundy and Markus, 1997; Frith and Frith, 1999), which is the ability to independently attribute mental states to oneself and to others (Premack and Woodruff, 1978; Baron-Cohen, 1995; Saxe, 2006). Accordingly, the behavioral aspect of communicative speech production is likely to be closely related to the process involved in the theory of mind; this is intuitively plausible because the maintenance of effective verbal communication requires a continuous monitoring of the intention, desire, and feelings of the target person. Recent neuroimaging studies suggest that the medial prefrontal cortex, superior temporal sulcus, and temporal pole form the neural system underlying the theory of mind or mentalization (Frith and Frith, 2003; Gallagher and Frith, 2003).

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We expected these regions to be at least partially associated with communicative speech production.

The distinction between linguistic and behavioral aspects of communicative speech production appears relevant to a discussion of language and its evolution (Hauser et al., 2002; Fitch et al., 2005; Pinker and Jackendoff, 2005). Although rich expressive and open-ended systems may be unique to the human language system (e.g., Chomsky, 1957), other species, such as primates, also have a complex set of vocalizations that are used to convey a wide variety of information, such as that concerning food quality, predators, and motivational state (Hauser, 1998). These vocalizations may share properties with the behavioral aspect of human verbal communication (Goldstein et al., 2003; Gil-da-Costa et al., 2004; Gifford et al., 2005). It has recently been suggested that the communicative vocalizations of macaques rely on the medial prefrontal cortex (Hadland et al., 2003). This region projects directly to the midbrain periaqueductal grey (PAG), which may play a major role in the control of communicative motivation in the monkey (Dujardin and Jurgens, 2005), suggesting the possible involvement of the medial prefrontal cortex in the behavioral aspect of communicative speech production in humans.

We used functional magnetic resonance imaging (fMRI) to investigate the cortical mechanism of the behavioral aspect of communicative speech production. We measured brain activation while normal volunteers casually talked to an actor in a video (communication task) or explicitly described the actor's situation (description task). The experimental paradigm was designed to isolate the behavioral aspect of communicative speech production from linguistics and articulatory motor processing. In addition, we assumed that processes related to the comprehension of a situation, including the observation of action and comprehension of the intention, desire, and feelings of the target person, were included in the description task, thereby controlling the basic processes that are related to the theory of mind, or mentalization (Saxe, 2006), between the communication and description tasks.

We also investigated the cortical mechanisms that reflect biographical information in communicative speech; during communication, people usually make reference to the personality traits of the target person and to events related to that person. Therefore, to examine the effect of familiarity on cortical activation during communicative speech production, we used two conditions for each task: familiarity or unfamiliarity of the target person to the subject.

Materials and methods

Subjects

The participants were 29 healthy right-handed volunteers, aged 18–24 years (13 were female). All of the subjects were native Japanese speakers with normal vision and no history of neurological illness. Handedness was evaluated using the Edinburgh Handedness Inventory (Oldfield, 1971). Written informed consent was obtained from each subject prior to participation in the study.

Stimuli and tasks

The visual stimulus was a short, 3-s video clip of a daily action in which an actor was using a tool or handling an object. The actor glanced at the camera in the last part (at nearly 2.5 s) of the video clip, as if glancing at the viewer (action video clip; Fig. 1), probably thereby naturally facilitating speech communication. In one set of 24 video clips, the actor was a close friend of the subject, and in another set of 24 the actor was unfamiliar to the subject. The same 24 actions were performed by each actor. A different tool or object was used in each action. The familiar and unfamiliar actors shown to each subject were of the same sex and of a similar age. In another set of 24 clips, a picture of a tool or object that had appeared in the action video clips was overlaid on a moving mosaic (control clips).

During the presentation of the action video clips, each subject performed the communication or description task. In the communication task, each subject casually talked to the actor, as if the actor was able to respond. In the description task, each subject verbally described the action or situation of the actor. The subjects performed both the communication and the description tasks for each action video clip in separate trials. During the presentation of the control videos, the subjects performed a control task in which they named the tool or object three times to adjust for differences in the duration of speech among tasks. In each trial, the video clips were presented for 3 s, followed by a 2-s inter-trial interval. Each subject pressed a button with the right index finger when they started to speak to record the time of speech onset, which was regarded as an index of task difficulty. Each subject was asked to speak quietly to avoid head motion.

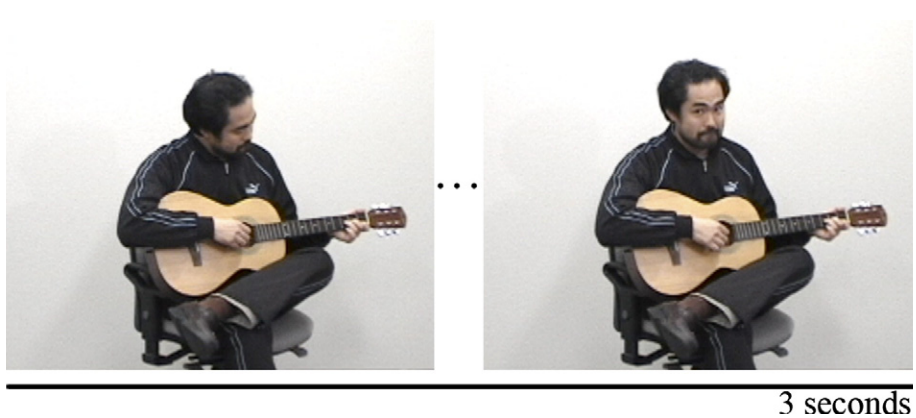

Fig. 1. An example of the stimulus: snapshots from the video clips over the time course of the stimulus (for 3 s). The actor was using a tool or handling an object (left) and then glanced at the camera naturally, as if glancing at the subject, in the last part of the stimulus (at nearly 2.5 s) (right).