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Social gating of sensory information during ongoing communication

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ABSTRACT

Social context plays an important role in human communication. Depending on the nature of the source, the same communication signal might be processed in fundamentally different ways. However, the selective modulation (or "gating") of the flow of neural information during communication is not fully understood. Here, we use multivoxel pattern analysis (MVPA) and multivoxel connectivity analysis (MVCA), a novel technique that allows to analyse context-dependent changes of the strength interregional coupling between ensembles of voxels, to examine how the human brain differentially gates content-specific sensory information during ongoing perception of communication signals. In a simulated electronic communication experiment, participants received two alternative text messages during fMRI ("*happy*" or "*sad*") which they believed had been sent either by their real-life friend outside the scanner or by a computer. A region in the dorsal medial prefrontal cortex (dmPFC) selectively increased its functional coupling with sensory-content encoding regions in the visual cortex when a text message was perceived as being sent by the participant's friend, and decreased its functional coupling with these regions when a text message was perceived as being sent by the computer. Furthermore, the strength of neural encoding of content-specific information of text messages in the dmPFC was modulated by the social tie between the participant and her friend: the more of her spare time a participant reported to spend with her friend the stronger was the neural encoding. This suggests that the human brain selectively gates sensory information into the relevant network for processing the mental states of others, depending on the source of the communication signal.

Introduction

In modern society, humans are not only confronted with various communication signals sent by other humans, but also with a multitude of anonymous signals transmitted by electronic communication devices and the media. Despite their physical similarity, these communication signals might encode very different information, and might require very different processing, depending on the source. Suppose, for example, a person hearing a narrator in the radio and his best friend talking about a car accident that happened that morning. When listening to the radio, the listener is presumably primarily interest in the news. In contrast, when listening to his friend, the listener might try to understand how his friend felt when observing the accident. Thus, just as effective processing of signals from the physical world requires some form of sensory gating (e.g. Knight et al., 1999), effective processing of social signals might require some form of "social gating" that selectively relays information from socially relevant sources to higher stages of neural processing.

Recent advances in application of multivariate pattern-recognition algorithms in neuroimaging (Haynes and Rees, 2006; Kriegeskorte et al., 2006; Norman et al., 2006) have enabled researchers to investigate the processing of communication signals in the human brain at the level of content-specific neural representations. This research has shown that auditory and visual communication signals are parsed into content-related and source-related features early in the processing stream (Formisano et al., 2008; Ethofer et al., 2009; Fox et al., 2009). However, it is currently unknown how such content-specific sensory information is relayed to higher processing stages that enable social cognition.

A longer line of research has shown that when people interact with or make inferences about other people neural activity increases in a neural network (often referred to as "mentalizing network") that includes the medial prefrontal cortex (mPFC), precuneus and the temporo-parietal junction (TPJ) (Frith and Frith, 2003; Gallagher and Frith, 2003; Mitchell, 2009). This increase of neural activity has often been interpreted as reflecting activation of cognitive processes required during social cognition, such as directing attention towards mental

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states (Gallagher and Frith, 2003; Kampe et al., 2003) or projecting oneself into a different physical or mental world (Mitchell, 2009). Interestingly, a first study using multivoxel pattern analysis to investigate mPFC function provided evidence that the mPFC might not only support specific social cognitive processes, but might also encode content-specific information of communication signals at a supra-modal level (Peelen et al., 2006).

Here, we use a simulated communication experiment to examine how the human brain selectively gates sensory information of communication signals into neural networks that enable social cognition. Participants were made believe that they were receiving two alternative short text messages ("*happy*" or "*sad*") from their real-life friend outside the scanner, or from a computer. In order to separate sender-dependent modulation of the flow of neural information from any modulatory effects that might be due to different response requirements, participants were not required to respond to their friends. To map the selective gating of the flow of neural information in the receiver's brain, we first used multivoxel pattern analysis (MVPA, Haynes and Rees, 2006; Kriegeskorte et al., 2006; Norman et al., 2006) to identify brain regions where the sensory content of text messages was encoded independent of the perceived sender, and then searched for brain regions that changed their functional coupling with these sensory-content encoding regions in a sender-dependent manner. For the latter step we used multivoxel connectivity analysis (MVCA), a novel technique that allows to analyse context-dependent changes of the strength of interregional functional coupling between ensembles of voxels.

Materials and methods

Participants

Twenty female participants with no record of neurological or psychiatric disorders were recruited from the Universität zu Lübeck. Participants were asked to bring one of their female friends as communication partner ("sender") to the imaging session. All participants gave written consent before participation and the study was approved by the local Ethics committee (Universität zu Lübeck, Lübeck). Data sets of two participants were later excluded because when explicitly asked after the experiment (see below) they reported doubts that the text messages they had received during imaging had actually been sent by their friend. The final data set consisted of data from 18 participants (age range 19–28 years, mean 22.1 years, 16 right-handed, 2 left-handed). Participants had first met their friend at school ($N = 3$), university ($N = 9$), leisure activities ($N = 2$) or on other occasions ($N = 4$). At the time of the study, participants had known their friend for an average of 3.4 years (range 6 months to 15 years). To ensure that participants were a representative sample of the population with regard to interpersonal traits all participants were asked to complete a German 16-item version of the *Interpersonal Reactivity Index* (IRI, Davis, 1983), the *Saarbrücker Persönlichkeitsfragebogen* (SPF, http://bildungswissenschaften.uni-saarland.de/personal/paulus/homepage/files/SPF-IRI-_V6.1.pdf). Participants' scores deviated less than one standard deviation (SD) from the norm of their German age reference group (Normentabellen des SPF, http://bildungswissenschaften.uni-saarland.de/personal/paulus/empathy/Normen.pdf, November 21, 2011) on all four subscales (empathic concern, mean = 3.5, SD = 0.6, norm 3.6; fantasy, mean = 3.5, SD = 0.8, norm 3.6; perspective taking, mean = 3.5, SD = 0.6, norm 3.7; personal distress, mean = 2.5, SD = 0.8, norm 2.8).

Cover story

Participants and their friends were told a cover story in order to create an experimental situation in which participants believed they were receiving short text messages sent by either their friend or a computer. Upon arrival in the lab, participants and their friends were informed that the goal of the study was to investigate the neural mechanisms of short text message communication. They were told that the task of the participant's friend (the "sender") would be to judge the affective state (*happy* or *sad*) of a number of persons, based on photographs of their faces, and to convey each of her decisions by a text message to the participant inside the scanner (the "receiver"). They were then shown the first two trials of a fake experimental set-up in which photographs appeared on a computer screen and, after the "sender" had entered her decision on a keyboard, the corresponding German text message ("*glücklich*" [happy] or "*traurig*" [sad]) appeared on a second screen. They were further told that, on a random basis, photographs would not be evaluated by the participant's friend but by a computer equipped with software for automatic analysis of facial expressions, which would then return the corresponding message to the participant. Finally, participants were told that in some runs the colour of the letters would indicate who had sent the message (i.e. green letters, *friend*; blue letters, *computer*; counterbalanced across participants) while in other runs all messages would be printed in grey letters. The latter runs were part of a different study and data of these runs were not analysed in the current study. The cover story was chosen to ensure that text messages perceived as being sent by the participant's friend and text messages perceived as being sent by the computer were highly similar with regard to (i) visual features, (ii) object of reference (an unknown third person), (iii) content (the third person's affective state, *happy* or *sad*) and (iv) response requirements (participants were not required to respond to the putative sender). Please note that this cover story was intended to allow the identification of visual areas that encode content-specific sensory information during text-message communication, and not to induce widespread empathic responses in the receiver's brain that are typically observed when participants observe an intimate's affective state (e.g. Anders et al., 2011). To ensure that participants attended to the text messages they were asked to indicate by button press after each message who they believed had sent that message. In fact, text messages were presented in a predefined order and the participant's friend was asked to perform an unrelated behavioural experiment while waiting for the participant. To maintain the illusion of the cover story, an error message instead of a text message appeared in a dummy trial after the first third of runs had been completed, and the experimenter suggested to the participant that her friend might have had hit an invalid key on the keyboard and that there would be a short delay because this had to be fixed.

Experimental procedure

Functional image acquisition was divided into sixteen runs. During each run, eight coloured text messages, balanced across the four sender-content combinations (*friend-happy*, *friend-sad*, *computer-happy*, *computer-sad*) (odd runs, 1-3-5-7-9-11-13-15), or twelve grey text messages, balanced across the two contents (*happy* and *sad*) (even runs, 2-4-6-8-10-12-14-16), were presented for 1000 ms each in randomized order. After a delay (2 s or 3.5 s) a response mapping screen appeared for 300 ms (two arrow heads, one pointing to the left and one pointing to the right, one labelled with the friend's first name and the other labelled with "PC"), indicating the participant to convey her response by a response button in her left or right hand, respectively (Fig. 1). Two alternative response mapping screens were used, one with the left and the other with the right arrow head labelled with the participant's first name. Response mapping screens were balanced across the four sender-content combinations and presented in randomized order for each sender-content combination. This way, the participant's decision and subsequent motor response were decoupled. Each trial terminated with a variable inter-trial interval (8.7 to 13.2 s, varying in steps of 1.5 s). Text messages and response mapping screens were presented through MRI-compatible video goggles (VisuaStim, Resonance Technology, Northridge CA, USA) and stimulus presentation and response logging was controlled with Cogent (Wellcome Laboratory of