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Getting on the same page: The neural basis for social coordination deficits in behavioral variant frontotemporal degeneration

Meghan L. Healey [a,b,*], Corey T. McMillan [a,d], Stephanie Golob [a], Nicola Spotorno [a], Katya Rascovsky [a], David J. Irwin [a,d], Robin Clark [c], Murray Grossman [a,b,*]

[a] University of Pennsylvania Perelman School of Medicine, Penn Department of Neurology and Frontotemporal Degeneration Center, Philadelphia, 19104 PA, USA
[b] University of Pennsylvania, Neuroscience Graduate Group, Philadelphia, 19104 PA, USA
[c] University of Pennsylvania, Department of Linguistics, Philadelphia, 19104 PA, USA
[d] University of Pennsylvania, Institute for Translational Medicine and Therapeutics, Philadelphia, 19104 PA, USA

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ABSTRACT

For social interactions to be successful, individuals must establish shared mental representations that allow them to reach a common understanding and "get on the same page". We refer to this process as social coordination. While examples of social coordination are ubiquitous in daily life, relatively little is known about the neuroanatomic basis of this complex behavior. This is particularly true in a language context, as previous studies have used overly complex paradigms to study this. Although traditional views of language processing and the recent interactive-alignment account of conversation focus on peri-Sylvian regions, our model of social coordination predicts prefrontal involvement. To test this hypothesis, we examine the neural basis of social coordination during conversational exchanges in non-aphasic patients with behavioral variant frontotemporal degeneration (bvFTD). bvFTD patients show impairments in executive function and social comportment due to disease in frontal and anterior temporal regions. To investigate social coordination in bvFTD, we developed a novel language-based task that assesses patients' ability to convey an object's description to a conversational partner. Experimental conditions manipulated the amount of information shared by the participant and the conversational partner, and the associated working memory demands. Our results indicate that, although patients did not have difficulty identifying the features of the objects, they did produce descriptions that included insufficient or inappropriate adjectives and thus struggled to communicate effectively. Impaired performance was related to gray matter atrophy particularly in medial prefrontal and orbitofrontal cortices. Our findings suggest an important role for non-language brain areas that belong to a large-scale neurocognitive network for social coordination.

1. Introduction

As humans, we navigate a complex world of social interactions, from negotiating with colleagues at work to gossiping with friends over coffee. For these interactions to be successful, individuals must establish shared mental representations to mediate common understanding. Behavioral game theory, rooted in principles of rational decision-making and strategy, refers to this process as social coordination (Clark, 2011). While examples of social coordination dominate our daily lives, surprisingly little is known about the neural mechanisms supporting this complex behavior. This is particularly true within the domain of language, which is the most common way in which we exchange information. In this study, we examine the neural basis for social coordination by studying semi-structured conversational exchanges in patients with behavioral variant of frontotemporal degeneration (bvFTD).

Traditional views of language suggest the core processing regions reside in left hemisphere peri-Sylvian cortex. Based primarily on studies of segmental language, this classic model fails to account for the complexities of real-world communication. Indeed, some recent models of language processing suggest prefrontal cortex and areas associated with cognitive control and social cognition are needed to supplement the core language processing regions (Cooke et al., 2006; Novais-Santos et al., 2007; Ferstl et al., 2008; Troiani et al., 2008; Hagoort, 2014).

* Corresponding author at: University of Pennsylvania, Perelman School of Medicine, Frontotemporal Degeneration Center, Department of Neurology, 3400 Spruce Street, 3 West Gates Building, Philadelphia, 19104 PA, USA.
E-mail addresses: mheal@mail.med.upenn.edu (M.L. Healey), mgrossma@upenn.edu (M. Grossman).

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We examine this possibility here and investigate the neural basis for social coordination during conversation by studying patients with behavioral variant frontotemporal degeneration (bvFTD). bvFTD is a rare neurodegenerative disease characterized by executive and social limitations due to progressive atrophy in frontal and temporal regions (Rascovsky et al., 2011). Patients with bvFTD demonstrate relatively preserved language, although higher-order narrative deficits have been reported (Ash et al., 2006; Cosentino et al., 2006; Farag et al., 2010). Because segmental language function is largely spared and patients are considered non-aphasic, these narrative deficits are often attributed to executive and social difficulties. A recent study using a single-word task also demonstrated impaired social coordination in bvFTD (McMillan et al., 2012). In this study, bvFTD patients differed from healthy controls in providing responses (e.g. a boy's name) that "others just like themselves" might provide. It remains unknown whether deficits in social coordination also contribute to difficulty with conversational discourse.

Here, we investigate social coordination using a novel, language-based task that involves describing a single object to a conversational partner. Much of the previous work examining perspective-taking during language use has employed complex narratives, many illustrating false beliefs or social faux pas. These studies consistently demonstrate a deficit in bvFTD (Gregory et al., 2002; Kipps and Hodges, 2006; Lough et al., 2006; Torralva et al., 2007, 2009; Fernandez-Duque et al., 2009; Kipps et al., 2009; Freedman et al., 2013). These narrative-based measures, however, require patients to track complex activities that involve multiple actors and extend over time. Since executive and working memory limitations have been documented in bvFTD (Kramer et al., 2003; Libon et al., 2007), the results of these demanding studies are controversial and potentially confounded (Henry et al., 2014). For instance, some studies have suggested that the results of these traditional, story-based theory of mind tasks may reflect deficits related to task demands and executive functioning, rather than mentalizing or social cognition per se (Fernandez-Duque et al., 2009; Le Bouc et al., 2012). Such a relationship between executive function and theory of mind in bvFTD remains a source of contention, however, with a number of studies reporting that the two deficits are dissociable and independent. For example, Torralva et al. (2007) report a deficit in theory of mind in bvFTD patients that is consistent across the Reading the Mind in the Eyes and faux pas tasks but independent of a general deficit in decision making. Similarly, Freedman et al. (2013) found significant deficits in second-order false belief performance that persisted when controlling for deficits in executive function. In the latter study, the authors also demonstrated that the patient deficit was specific: no deficits in visual perspective-taking were observed.

Beyond the potential confounds related to executive function, the existing theory of mind tasks are also limited in their ecological validity. These comprehension-based tasks only ask patients to be passive observers; they do not require subjects to play an active role in the experimental situation and *use* their understanding of a conversational partner's perspective.

To our knowledge, this study is the first to examine social coordination in a natural, semi-structured discourse context. Furthermore, we manipulate two aspects of coordination. The first is perspective-taking, or the ability to adopt another's point of view. We examine perspective-taking by assessing the patient's sensitivity to the amount of information available to the conversational partner. Second, we examine the resource demands associated with tracking the multiple elements of a conversation. We independently examine the effect of resource demands by manipulating the number of objects sharing perceptual features and competing with the target object to be described by the patient.

Previous work in bvFTD has related both narrative (Ash et al., 2006; Farag et al., 2010) and social (Eslinger et al., 2007; Kipps et al., 2009; Mendez and Shapira, 2009; Grossman et al., 2010; Couto et al., 2013) deficits to prefrontal disease. fMRI studies of non-verbal coordination in healthy adults also implicate prefrontal regions (Kuo et al., 2009; Yoshida et al., 2010). Accordingly, our model of coordination predicts essential roles of medial prefrontal (mPFC), dorsolateral prefrontal (dlPFC), and orbitofrontal cortices (OFC), areas associated with mentalizing/perspective-taking, working memory, and decision-making, respectively (Amodio and Frith, 2006; Wallis, 2007; Badre, 2008). Therefore, in the context of the current experiment, we predict a priori that impaired behavioral performance on the social coordination task in bvFTD will be related to reduced gray matter density in these regions.

The interactive-alignment account provides an alternative, although not necessarily mutually exclusive, hypothesis (Pickering and Garrod, 2004). According to this perspective, effective interpersonal communication results from alignment at multiple levels of linguistic representation, including lexical selection and syntactic construction. Citing evidence that speakers and listeners both activate peri-Sylvian regions and show correlated brain activity during communication, Menenti et al. (2012) propose co-activation of the language network as a mechanism for conversational alignment. Relatedly, simulation theory suggests that social interactions are supported by mirror neuron activity in premotor areas (including Broca's area) (Gallese, 2007). The present investigation may help clarify the relative contributions of social processing dependent upon prefrontal regions (coordination) versus linguistic priming dependent upon peri-Sylvian language-specific regions (interactive-alignment) and simulation dependent upon premotor regions (mirror neurons) to communication.

2. Methods

2.1. Participants

Participants included twelve patients with bvFTD who were demographically-comparable with fourteen healthy seniors in terms of age, education, and gender. Demographic and clinical characteristics are summarized in Table 1. Patients with bvFTD were diagnosed by board-certified neurologists (M.G., D.J.I) using a consensus procedure and published criteria (Rascovsky et al., 2011). Alternative causes of cognitive difficulty due to other neurodegenerative conditions such as Alzheimer's disease, hydrocephalus, stroke or head trauma were excluded by clinical exam, neuroimaging, CSF, and blood tests. As summarized in Table 1, severity of overall cognitive impairment was assessed in patients using the Mini-Mental State Examination. On average, patients were not in the demented range (mean MMSE=25.75, SD=3.47), and individual scores all fell in the range of minimal to mild impairment (range: 18–29). To test specificity and ensure that any observed deficits in social coordination were not the result of linguistic deficits, patients with bvFTD also completed a short battery of language tests. These tests included an abbreviated version of the Boston Naming Test (Kaplan et al., 1983), a test of lexical retrieval in which participants name 30 black and white line drawings of objects that are graded in difficulty; the language section of the Philadelphia Brief Assessment of Cognition (PBAC), which yields a composite measure based on a broad spectrum of language skills including lexical retrieval, semantic knowledge, conversational fluency, reading, writing, and repetition (Avants et al., 2014; Libon et al., 2011); and the Pyramid and Palm Trees test (Howard and Patterson, 1992), a test of semantic access in which participants must identify the word or picture that is associated with the presented target. Finally, patient caregivers were