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Neural correlates of the relationship between discourse coherence and sensory monitoring in schizophrenia

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ABSTRACT

Unusual language use is a core feature of psychosis, but the nature and significance of this are not understood. In particular, thought disorder in schizophrenia (SZ) is characterized by markedly bizarre speech, but the cognitive components that contribute to this and the brain correlates of these components are unknown.

A number of studies have demonstrated language abnormalities in single word processing, but few have examined speech in SZ at the discourse level. This has been at least partly due to the difficulty in quantifying content of discourse. Recently, methods in computational linguistics have been found to be useful for detecting differences in semantic coherence during discourse between different clinical groups. We build on this work by demonstrating how these methods can be combined with funtional magnetic resonance imaging (fMRI) in order to tease apart factors that underlie free discourse and its deviations, and how they relate to brain activity.

Eleven volunteers with SZ and eleven controls participated in an interview during which they were asked to talk as much as they could about 'religious belief'. These same participants underwent fMRI during a word monitoring task, during which modality of monitoring was manipulated by varying the congruence of auditory and visual stimuli. Semantic coherence scores, measured from free discourse, were examined for their relationship to brain activations during fMRI.

In healthy controls, regions associated with executive function were related to coherence. In persons with SZ, coherence was mainly related to auditory and visual regions, depending on the modality of monitoring, but superior/middle temporal cortex related to coherence regardless of task. These findings are consistent with existing evidence for a role of superior temporal cortex in thought disorder, and demonstrate that computational measures of semantic content capture objective measures of coherence in speech that can be usefully related to underlying neurophysiological processes.

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1. Introduction

Disturbances in language are among the core features of schizophrenia (SZ). The speech of people with SZ is often characterized by features such as odd or unusual choice of words, inappropriate shifts of topic, unusual juxtaposition of associates or concepts, and other features that suggest poor organization of semantic content (Bleuler, 1950; Elvevåg & Goldberg, 1997; Harrow, Lanin-Kettering, Prosen, & Miller, 1983). While there have been numerous studies of language and semantic function at the single word level, there have been relatively few that have examined semantic organization at the discourse level in SZ. This is at least partly due to the difficulty of objectively quantifying semantic content at this level. Recent advances in computational methods augur significant progress in this area. These methods, which we refer to collectively as Computational Semantic Analysis (CSA), have been employed in a variety of applications, including grading written material (Kintsch, 2002), examining phenomena in psychology (Wolfe & Goldman, 2003), and extracting context-based information from large collections of texts such as PubMed (Vanteru, Shaik, & Yeasin, 2008). More recently, CSA methods have begun to be used in clinical applications in psychiatry and neurology. These investigations have demonstrated that CSA methods can distinguish among clinical populations (Cohen, Blatter, & Patel, 2008; Elvevåg, Foltz, Weinberger, and Goldberg, 2007; Roll et al., 2012) and detect changes in language use after treatment for depression (Arvidsson, Sikström, & Werbart, 2011). In the study of Elvevåg et al. (2007) CSA methods were shown to be sensitive to differences in language between individuals with SZ and a control group, and the CSA measures correlated with clinical measures of thought disorder, as rated by the Thought, Language and Communication (TLC) scale (Andreasen, 1986). Arvidsson et al. (2011) employed CSA methods to show that representations of self were significantly different between depressed young adults and a control group, but that this difference disappeared after treatment, and was maintained at an 18-month follow-up. However, speech is a complex process, and numerous cognitive components contribute to the expression of meaning. The cognitive components that contribute to CSA measures are not known, nor is it known whether these measures capture features that have a neurophysiological basis.

Multiple lines of evidence indicate that disturbances in both the executive and the semantic systems may underlie disordered speech in SZ (Barrera, McKenna, & Berrios, 2004; Chan et al., 2010; Giovannetti, Goldstein, Schullery, Barr, & Bilder, 2003; Kerns and Berenbaum, 2002; Kuperberg, 2010). Language abnormalities in SZ have been proposed to be associated with both an increased automatic spread of semantic associations and decreased executive control operations (Kiefer, Martens, Weisbrod, Hermle, & Spitzer, 2009; Kreher, Goff, & Kuperberg, 2009; Salisbury, 2008). One of the key executive functions of relevance in speech coherence is monitoring, a process in which speech that is being produced is compared against the intended output (Levelt, 1989). Deficits in monitoring of speech have been proposed to play a significant role in aberrant speech in SZ (Allen, Amaro, et al., 2007; McGuire et al., 1998). For example, it has been suggested that in people with SZ, deficits in monitoring can result in either associative or phonological chaining (glossomania), a phenomenon where meanings or sounds of the most recently uttered words influence what follows (for a review see Covington et al., 2005).

There is considerable evidence that at least up to the articulation phase, the processes and brain regions involved in monitoring self-generated and external speech are largely shared (Indefrey & Levelt, 2004; Levelt, 1999). Together, these considerations suggest that a monitoring task that involves linguistic stimuli is likely to tap into processes that can influence the content of speech. The logic behind this approach is that if brain activations during monitoring are positively related to coherence scores, it provides evidence for the role of monitoring in the coherence of free speech. Furthermore, monitoring is a composite process that depends on multiple functional components, such as attention, working memory, and sensory processing, among other things. A further goal of our approach is to examine the specificity of the regions that mediate the relationship between monitoring and speech coherence. The nature of these regions provides evidence for specific mechanisms that contribute to the effectiveness of monitoring.

The fMRI tasks in the current study involve monitoring linguistic representations in either the auditory or visual modality. Activations in these tasks are then examined to assess whether brain regions that mediate automatic processing, auditory monitoring, and visual monitoring are related to coherence of discourse as measured by CSA methods, in both individuals with SZ and healthy controls. There are two main hypotheses in this work. The first is that brain regions related to executive functions will be the primary regions that are correlated with CSA scores in the healthy control group. This would lend support to the idea that CSA methods capture underlying processes that contribute to speech coherence. The second hypothesis is that coherence of free speech in SZ is less related to these control regions, and instead reflects compensatory processes that primarily rely on sensory processing.

2. Materials and methods

The approach taken here is to employ fMRI during various tasks that make demands on different levels of automatic and controlled monitoring operations. Participants are scanned while performing three one-back matching tasks that are described in detail below and illustrated in Fig. 2. All stimuli are common words and are presented in both auditory and visual modalities simultaneously. The controlled processes have either homographs (HMG) or homophones (HMP) as stimuli and require monitoring either auditory or visual/orthographic properties while simultaneously ignoring the other modality. The resulting activation patterns are then regressed against CSA scores that were obtained from spontaneous speech samples outside the scanner.

The rationale for this approach is twofold. First, as reviewed above, contributions from specific operations can be