Brain & Language 129 (2014) 58–64

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

The role of ventromedial prefrontal cortex in text comprehension inferences: Semantic coherence or socio-emotional perspective?

Debora I. Burin [a,*], Laura Acion [b], Jake Kurczek [c,e], Melissa C. Duff [d,e], Daniel Tranel [e], Ricardo E. Jorge [f,1]

[a] Facultad de Psicología, Universidad de Buenos Aires – CONICET, Instituto de Investigaciones, Lavalle 2353 (1052), Ciudad de Buenos Aires, Argentina
[b] Iowa Consortium for Substance Abuse Research and Evaluation & Department of Biostatistics –College of Public Health, University of Iowa, 100 MTP4, Room 102, Iowa City, IA 52242-5000, United States
[c] Neuroscience Graduate Program, University of Iowa, 357 Medical Research Center, Iowa City, IA 52242-1101, United States
[d] Department of Communication Sciences & Disorders, University of Iowa, Wendell Johnson Speech and Hearing Center, Iowa City, IA 52242, United States
[e] Departments of Neurology and Psychology, University of Iowa, Iowa City, IA 52242, United States
[f] Department of Psychiatry, University of Iowa, University of Iowa Hospitals and Clinics, 200 Hawkins Drive, Iowa City, IA 52242, United States

ARTICLE INFO

Article history:
Accepted 30 December 2013
Available online 19 February 2014

Keywords:
Narrative comprehension
Text coherence
Text inferences
Spatial inferences
Emotional inferences
Ventromedial Prefrontal Cortex

ABSTRACT

Two hypotheses about the role of the ventromedial prefrontal cortex (vmPFC) in narrative comprehension inferences, global semantic coherence versus socio-emotional perspective, were tested. Seven patients with vmPFC lesions and seven demographically matched healthy comparison participants read short narratives. Using the consistency paradigm, narratives required participants to make either an emotional or visuo-spatial inference, in which a target sentence provided consistent or inconsistent information with a previous emotional state of a character or a visuo-spatial location of an object. Healthy comparison participants made the inferences both for spatial and emotional stories, as shown by longer reading times for inconsistent critical sentences. For patients with vmPFC lesions, inconsistent sentences were read slower in the spatial stories, but not in the emotional ones. This pattern of results is compatible with the hypothesis that vmPFC contributes to narrative comprehension by supporting inferences about socio-emotional aspects of verbally described situations.

1. Introduction

Narratives form the social fabric of people's lives and become ever more important in clinical settings and verbal-based therapies for behavioral and psychiatric disturbances. Understanding narratives is a complex task that involves basic processing at phonological, lexical-semantic and syntactic levels. Additionally, inferential processes are specific to the discourse level and are required to connect the parts of the narrative to build a mental representation of the events. Thus, inferences consist of information not explicitly stated that has to be added to establish referential and thematic continuity across sentences in order to grasp the gist of a story (Graesser, Singer, & Trabasso, 1994; Singer, 2007; van Dijk & Kintsch, 1983). Local (Graesser et al., 1994) or bridging inferences (Singer, 2007) are needed to solve the referents of pronouns or nominal constructions, and also to unravel some explicit temporal (e.g., *before, after, during, and, then*) or causal (e.g., *because, so, in order to*) connectors. Global inferences are required to build a coherent semantic representation of the text or discourse, including causal, spatial and thematic relations between agents, objects and events (Graesser et al., 1994); this is achieved by elaborative inferences (Singer, 2007).

Traditional behavioral studies of inferences started with offline tasks, such as asking questions; however, this procedure confounds comprehension with reasoning and text recall (Singer, 2007). Alternative experimental approaches were designed to capture inferences as they occur online during comprehension (Haberlandt, 1994). In the experimental paradigm termed *consistency tasks* (McKoon & Ratcliff, 1992; ÓBrien & Albrecht, 1992), subjects read a narrative that involves a protagonist and a situation describing his or her state, spatial location, time frame, and/or causal chain of events. At the end of the narrative, a critical phrase refers to the protagonist in an emotional state, in a location, or performing an action, which may be consistent or inconsistent with his or her previous status. For example, in ÓBrien and Albrecht (1992, p. 781) "As Kim stood *inside* (*consistent*)/*outside* (*inconsistent*) the health club she felt a little sluggish. She decided to go *outside* and stretch her legs for a little." Longer reading times for the

* Corresponding author.
E-mail address: dburin@psi.uba.ar (D.I. Burin).
[1] Present address: Menninger Department of Psychiatry and Behavioral Sciences, Baylor College of Medicine, 1 Baylor Plaza, Houston, TX 77030, United States.

http://dx.doi.org/10.1016/j.bandl.2013.12.003
0093-934X/

critical sentence in the inconsistent condition compared to the consistent condition suggest that readers infer the narrative dimension (i.e., spatial location in the example) even though it is not explicitly stated at the moment. The consistency effect is robust and has been established for the visuo-spatial dimension (De Vega, 1995; Glenberg, Meyer, & Lindem, 1987; Irrazabal & Burin, 2006; ÓBrien & Albrecht, 1992; Therriault & Rinck, 2006), emotional or personal traits of the protagonist (Albrecht & ÓBrien, 1993; De Vega, León, & Diaz, 1996; Gernsbacher, Goldsmith, & Robertson, 1992; Gygax, Garnham, & Oakhill, 2004; Molinari et al., 2009; Therriault & Rinck, 2006), temporal inferences (Rinck, Hähnel, & Becker, 2001; Therriault & Rinck, 2006), and other dimensions that lead to causal relations between characters and actions (see Singer, 2007).

Neuroimaging research of diverse higher-language comprehension tasks such as reading connected sentences vs. unconnected sentences or words (Robertson et al., 2000), reading text with and without title (St. George, Kutas, Martinez, & Sereno, 1999), and comprehension of fables (Nichelli et al., 1995), suggests that an extended language network involving frontal (dorsolateral, middle, and ventrolateral), temporal (anterior, middle, inferior), temporo-parietal, and posterior cingulate areas of both hemispheres is involved in language comprehension at the discourse level (Ferstl, Neumann, Bogler, & von Cramon, 2008). In particular, studies with online tasks presenting two or several sentences needing cohesive inferences across them, highlight the role of medial prefrontal regions in detection of coherence (or the lack of it) (Ferstl, Rinck, & von Cramon, 2005; Hasson, Nusbaum, & Small, 2007; Kuperberg, Lakshmanan, Caplan, & Holcomb, 2006; Mason & Just, 2004; Virtue, Haberman, Clancy, Parrish, & Jung-Beeman, 2006; Virtue, Clancy, Parrish & Jung-Beeman, 2008; Xu, Kemeny, Park, Frattali, & Braun, 2005). Studies vary in design, and so do contrasts of active areas; they include varying portions of temporal, dorso and ventrolateral prefrontal, ventromedial prefrontal, and cingulate regions. Mason and Just (2004), Kuperberg et al. (2006), and Virtue et al. (2008) varied the predictability or causal relatedness of the inference and found that bilateral dorsolateral and inferior prefrontal areas showed increased activation as the sentences became less causally related, thus forcing strategic interpretation and taxing working memory. But medial prefrontal cortex was observed to be active in all of the studies mentioned, even when passive listening was examined (including cingulate areas, Hasson et al., 2007), suggesting that its role in extracting coherence is not driven by exogenous task demands, effort, or working memory demands. According to these studies, the medial prefrontal cortex would carry on implicit processes of semantic activation and inhibition in order to extract global coherence; while on the other hand, dorsolateral prefrontal areas would process strategic, elaborative search, and tasks with high working memory load. Synthesizing these results, it appears that the ventral and medial prefrontal brain structures are a key component of text semantic integration and coherence across sentences.

An alternative interpretation of these results posits that the ventral medial prefrontal cortex (vmPFC) might be selectively involved in understanding a socio-emotional perspective akin to the theory of mind (ToM) conceptual framework (e.g., Stone, Baron-Cohen, & Knight, 1998). The overlap between narrative comprehension and ToM neural network has been underlined by many of the authors in the text comprehension literature (Ferstl & Von Cramon, 2002; Ferstl et al., 2008; Mar, 2004; Mason & Just, 2004; Mason & Just, 2009). For example, Mason and Just (2009), Mason and Just (2011) have proposed that narrative comprehension includes parallel networks for coherence monitoring (which would be carried by bilateral dorsolateral prefrontal areas) and for text integration (left inferior frontal/left anterior temporal), and a "protagonist perspective" network (bilateral medial frontal/posterior right temporal /parietal), by which the reader applies ToM processes for interpreting the intentions, goals, and actions of characters within a narrative. Thus, emotional inferences would stem from a socio-emotional stance. Several neuroimaging studies with healthy participants (Ferstl & von Cramon, 2002; Fletcher et al., 1995; Mason & Just, 2011; Vogeley et al., 2001) have compared stories with socio-emotional versus physical or logical inferences, but required an explicit social or emotional judgment, and results are mixed. An early study addressing this issue (Fletcher et al., 1995) asked participants to read three types of texts: ToM stories (which required the reader to make inferences about the internal mental states of the characters), physical stories (about physical events, not the mental processes of the characters in the story), and unrelated sentences. Relative to sentences, both story conditions showed increased activation at the temporal poles and left superior temporal gyrus; activation in mid frontal cortex was specifically associated with ToM stories. However, it is not clear whether activation was related to differential difficulty or cognitive demands of the tasks (Tompkins, 2008, who placed the discussion regarding the role of the right hemisphere). On the other hand, Ferstl and von Cramon (2002) presented pairs of coherent or incoherent sentences eliciting inferences based on socio-emotional or logical, inanimate causation, and asked for an explicit consistency judgment. In the logical pairs (e.g. "Sometimes a truck drives by the house./That's when the dishes start to rattle" vs. "/The car doesn't start") the instruction called to judge if there was a logical connection between sentences. In the ToM pairs (e.g., "Mary's exam was about to begin./Her palms were sweaty" vs. "/Some friends had remembered the birthday") instructions asked to understand the protagonist's motivations, feelings, and actions, and judge if both sentences made sense. Although medial prefrontal activation was stronger in ToM stimuli, it was also active in coherence judgments for logical pairs, thus arguing for a domain-general initiation and maintenance of coherence function. Furthermore, the extent to which activation is related to an implicit semantic inference is not known, since in Ferstl and von Cramon (2002) an explicit judgment of coherence was required. In a similar vein, Mason and Just (2011) studied narratives with intentional (mental) versus physical content requiring inferences for coherence. There were differences in regional activation as a function of type of inference: intentional inferences elicited more activation in the right temporo-parietal junction, right inferior, middle and superior frontal gyrus; while physical inferences did so in middle occipital regions. However, drawing an inference of either type activated the "extended language network": medial and superior frontal areas, bilateral inferior frontal gyri, the left posterior superior temporal gyrus, and the anterior temporal lobes bilaterally. Thus, neuroimaging studies comparing mental versus physical inferences have been scarce and do not adjudicate between accounts of the critical role of medial prefrontal structures as being specific to socio-emotional understanding or performing general semantic coherence processes.

Neuroimaging experiments in healthy subjects have delineated the brain networks activated by narrative comprehension and ToM; but such findings alone cannot identify whether any or all of these regions play a critical role. Complementary studies in patients with focal injuries can help identify which brain structures are key components for normal functioning. In general, subjects with vmPFC lesions present deficits in verbal and non-verbal ToM paradigms (Beadle & Tranel, 2011; Rowe, Bullock, Polkey, & Morris, 2001; Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003; Stone et al., 1998). However, recent findings reported that subjects with this type of lesion did not have problems in developing and using common ground in social communication (e.g., using labels or verbal play) (Gupta, Tranel, & Duff, 2012). On the other hand, these patients typically show deficits in judgment and decision making under uncertainty and risk, as shown in the Iowa