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Modulation of cortical activity during comprehension of familiar and unfamiliar text topics in speed reading and speed listening

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ABSTRACT

Brain activation associated with normal and speeded comprehension of expository texts on familiar and unfamiliar topics was investigated in reading and listening. The goal was to determine how brain activation and the comprehension processes it reflects are modulated by comprehension speed and topic familiarity. Passages on more familiar topics differentially activated a set of areas in the anterior temporal lobe and medial frontal gyrus, areas often associated with text-level integration processes, which we interpret to reflect integration of previous knowledge with the passage content. Passages presented at the faster presentation resulted in more activation of a network of frontal areas associated with strategic and working-memory processes (as well as visual or auditory sensory-related regions), which we interpret to reflect maintenance of local coherence among briefly available passage segments. The implications of this research is that the brain system for text comprehension adapts to varying perceptual and knowledge conditions.

1. Introduction

Language comprehension involves the interaction of several different types of processes, including lower-level cognitive processes such as phonological and lexical analyses, and higher-level cognitive processes such as inference-making and inter-sentence integration (Mason & Just, 2013). It thus relies on a combination of local, word and sentence-level processes (local coherence), and more global, text-level processes (global coherence). Maintaining local coherence involves making associations between smaller units of information in the text passage (words and phrases) as well as monitoring coherent transitions from one clause to another. In contrast, sustaining global coherence involves establishing associations between ideas in the text and some overarching theme.

The higher-level processes of inference-making and integration of discourse information are especially reliant on prior familiarity with the text content. Inferential processes help establish global coherence by relating information in the text with prior knowledge (e.g., Graesser, Singer, & Trabasso, 1994; Kintsch & Dijk, 1978; Long & Prat, 2008; Long, Wilson, Hurley, & Prat, 2006). The more prior knowledge a reader possesses about the topic of a passage, the more likely it is that they will be able to recall information from the text (Bartlett, 1932; Bransford & Johnson, 1972; Long & Prat, 2002; Long et al., 2006). Many brain imaging studies have shown that these higher-level processes are underpinned by a combination of cortical networks that support the integration of information and comprehension (see Mason & Just, 2006, 2011; Prat, Mason, & Just, 2011). One goal of the present study was to investigate these higher-level cognitive processes associated with reading and listening comprehension of text passages about topics that are more familiar or less familiar to the participants. The study aimed to contribute to the understanding of higher-level cognitive processes that underpin comprehension of different types of passages.

Another important aspect of comprehension is the cognitive and brain workload involved. For example, the workload associated with the comprehension processes may be influenced by time pressure for reading a passage. The study also investigated the higher-level cognitive processes associated with this time pressure for understanding text; we simulated speed reading and speed listening situations by speeding up the presentation of visual and auditory information.

Speed reading is a type of skilled reading in which readers attempt to increase their rate of reading without a commensurate loss in comprehension. However, reading at a faster pace may come at a cost of not only poorer comprehension but also a greater consumption of certain types of mental resources. Speed reading

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may require readers to engage comprehension strategies that trade away comprehension accuracy for speed (Just & Carpenter, 1992). Early studies of eye-fixations during speed reading reported that speed readers skipped large portions of the text and that their eye fixations traced a path different from the traditional left-to-right path of normal English readers (McLaughlin, 1969; Taylor, 1962). Just and Carpenter (1992) found that trained speed readers showed better speeded comprehension of high-level information than untrained speed readers, but only when the rapid reading was of a text on a familiar topic. Trained speed readers were better able than untrained speed readers to use their previous knowledge to bridge the information gaps that occur during speed reading (Just & Carpenter, 1992). Thus, speed reading may evoke strategies that focus on global coherence at the expense of local coherence, but such strategies may only be effective for familiar topics. Untrained readers, when faced with the novel task of speed reading, might rely more on executive control processes. In one fMRI study of trained and untrained speed readers of Japanese, trained speed readers' activation of the left inferior frontal gyrus (LIFG, or Broca's Area) and the left posterior superior temporal gyrus (Wernicke's Area) decreased during speed reading, in comparison with normal reading (Fujimaki, Hayakawa, Munetsuna, & Sasaki, 2004). According to the authors, the results suggest that trained speed readers bypass phonological processes during speed reading.

2. Neural substrates of discourse comprehension: the extended language network

The "language network" is a left-hemisphere-dominant cortical network traditionally implicated in the processing of language, and it centrally includes the left inferior frontal gyrus (LIFG, Broca's area), and the superior and middle areas of the posterior temporal lobe (Constable et al., 2004; Keller, Carpenter, & Just, 2001; Michael, Keller, Carpenter, & Just, 2001). In addition to these two classical language areas, various other areas of the brain have been associated with discourse processing, with the network constituency depending on the particular task. The dorsomedial prefrontal cortex and the anterior temporal lobes are part of this "extended language network" (Ferstl, Neumann, Bogler, & von Cramon, 2008). The anterior temporal lobe (aTL) areas (bilaterally) together with the left inferior frontal gyrus, have been associated with text integration processes in discourse comprehension (Mason & Just, 2006). Text integration, the construction of a meaning-based, integrated representation of the text, has been shown to activate the aTL when readers encounter an inconsistency in the text (Ferstl, Rinck, & von Cramon, 2005). In sum, both the dmPFC and aTL are activated in association with high-level, global comprehension processes. In the reading of familiar passages, readers should have sufficient background knowledge to perform an adequate level of text integration. Hence, we hypothesized that passage familiarity would modulate the activation in the brain areas associated with maintaining global coherence.

3. Working memory and local coherence processes in discourse comprehension

Local coherence processes depend on the reader's ability to establish connections between successive segments of information in text. To maintain local coherence, short-term maintenance of the text information is required. This maintenance of information may load on areas involved in the rehearsal of information in working memory, including temporoparietal and frontal cortex (e.g. Buchweitz, Mason, Hasegawa, & Just, 2009; Buchweitz, Mason, Tomitch, & Just, 2009). Increased working memory load for both letters and words has been associated with activation in prefrontal and parietal areas of the brain (Crottaz-Herbette, Anagnoson, & Menon, 2004; Smith & Jonides, 1998). When information from different parts of a sentence or from adjacent sentences has to be related to each other, the earlier-occurring information has to be maintained in working memory until the later occurring information is encountered. For example, a person's name might have to be maintained until a subsequent pronoun occurs in order for the correct deictic reference to be made. The cortical areas associated with maintenance and rehearsal of information include the left inferior parietal lobe (LIPL), the left inferior frontal gyrus (LIFG), and the dorsolateral prefrontal cortex (DLPFC). LIPL and DLPFC form a frontoparietal loop that plays an important role in storage and manipulation of information in verbal working memory (Crottaz-Herbette et al., 2004; Petrides, Alivisatos, Evans, & Meyer, 1993).

The processes that support short-term coherence may be disrupted in speeded reading and listening. A fast rate of incoming information may result in a sampling of the text rather than an exhaustive intake of the information. In that case, information may have to be maintained for an unspecified amount of time until a segment of related information occurs or until the missing information is provided by making an inference or by tolerating the lack of coherence. We hypothesized that speeded comprehension would result in more activation in areas associated with maintaining local coherence processes.

Two experiments were carried out, one with listening comprehension and one with reading comprehension, with both studies comparing speeded and normal comprehension. Participants were college students untrained in the skill of speed reading. It was hypothesized that comprehending texts on unfamiliar topics would result in increased activation in brain regions involved in higher-level integration of text information. It was also hypothesized that increasing the speed of presentation for the passages would increase the activation levels in brain regions associated with working memory processes. These two hypotheses were expected to apply in both reading and listening, and modality-specific activation was expected in sensory/perceptual regions.

4. Material and methods

4.1. Design

Two experiments were conducted (each using a 2×2 within-subjects factorial design) in which the independent variables were passage type (Familiar versus Unfamiliar) and presentation rate (Fast versus Normal). Participants read (Experiment 1) or listened to (Experiment 2) 16 passages in each experiment, including four passages per experimental condition.

4.1.1. Stimuli

The familiar passages were adapted from *U.S. News and World Report* articles on current technical topics, such as nutrition and health or forest fires. They were written in a way that made prior knowledge of the topic unnecessary for comprehension. The unfamiliar passages were adapted from an introductory physiology textbook (Sheeler, 1996) and focused on physiological information and principles, such as inheritance patterns of sex-linked diseases and information transfer within and between neurons. Although these passages dealt with less familiar topics, they were written in a straightforward, easy-to-understand style, consistent with the introductory nature of the textbook. The stimulus passages are included in the Supplementary material.

The passages were the same in both experiments to facilitate comparisons across presentation modalities. The topics in the four