An fMRI Study of Zoning Out During Strategic Reading Comprehension

Jarrod Moss (jarrod.moss@msstate.edu)
Department of Psychology, Mississippi State University,
Mississippi State, MS 39762 USA

Christian D. Schunn (schunn@pitt.edu)
Walter Schneider (wws@pitt.edu)
Learning Research and Development Center, University of Pittsburgh
Pittsburgh, PA 15260 USA

Danielle S. McNamara (dsmcnamara1@gmail.com)
Department of Psychology, University of Memphis
Memphis, TN 38152 USA

Abstract

Prior neuroimaging studies of discourse comprehension and strategic reading comprehension have shown that there are at least two networks of brain regions that support strategic discourse comprehension. In particular, strategic reading comprehension leads to activation of a domain-general control network as well as a network of regions supporting coherence-building comprehension processes. The present study was designed to further examine the neural correlates of strategic reading comprehension by examining the brain regions associated with zoning out, or mind wandering, while performing reading strategies on expository texts and diagrams. The results show that a region of dorsal prefrontal cortex was associated with increased frequency of zoning out, and the results provide an important replication or prior work by showing a high degree of consistency in the areas that are active while using reading strategies.

Keywords: Reading Strategies; fMRI; Cognitive Control

Introduction

The comprehension of expository text is a common task in learning, but the complexity of text comprehension results in large individual differences in the strategies that students engage in to understand texts as well as what students extract from texts (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989; McNamara, 2004). Reading comprehension strategies improve readers' comprehension of text. Some readers use strategies naturally, and others benefit from being provided with strategy instruction (McNamara, 2007). Self-explanation is one reading strategy that has been shown to be effective at improving readers' comprehension when students are trained or prompted to use it (Chi, Deleeuw, Chiu, & Lavancher, 1994; McNamara, 2004). While there have been neuroimaging studies of narrative comprehension, there have been relatively few studies of expository text comprehension and even fewer that have examined the differences in brain activity associated with different reading strategies. Neuroimaging studies of strategic reading comprehension have the potential to further develop our existing understanding of strategies designed to enhance discourse comprehension.

Because instructing readers to self-explain often benefits readers who are skilled self-explainers more than less skilled self-explainers (Chi et al., 1994), McNamara (2004) developed Self-Explanation Reading Training (SERT) in which students are provided with instruction and practice on using reading strategies while self-explaining texts. This approach combined the technique of self-explanation with reading strategies with demonstrated effectiveness. SERT includes five component reading strategies: comprehension monitoring, paraphrasing, elaboration, bridging, and prediction (McNamara, 2004). Comprehension monitoring is being aware of whether the text is being successfully understood while reading. Paraphrasing is putting the text into one's own words. The process of putting text into one's own words helps to activate relevant semantic knowledge in long-term memory and prepares the reader to make further inferences. Inferences are necessary in most text comprehension situations because most texts do not state all relevant pieces of information explicitly (Kintsch, 1998). Elaboration involves making inferences that aid in understanding the text by using knowledge from memory. Bridging involves making inferences across sentence boundaries to aid in understanding the text. Prediction is making predictions at the end of a sentence or paragraph about what information will be contained in the next section of the text. Collectively, these strategies help the reader to process challenging, unfamiliar material by scaffolding the comprehension process. The process of self-explaining externalizes the comprehension process and the reading strategies help the reader to understand the text (i.e., using paraphrasing and comprehension monitoring) and go beyond the text by generating inferences (i.e., using elaboration, bridging, and prediction).

The results of an initial exploration of the neural correlates of strategic reading comprehension found that a combination of cognitive control and discourse comprehension regions are activated during performance of effective reading strategies (Moss, Schunn, Schneider, McNamara, & VanLehn, 2010). This study examined three reading strategies: rereading, paraphrasing, and self-explaining. The results of this study support the notion that effective reading strategies involve a combination of intentional cognitive control along with engagement of coherence-building processes. Paraphrasing and self-explanation were found to engage a network of regions making up a cognitive control network more than the rereading strategy did. This domain-general network of brain areas have been shown to be active in a variety of tasks involving executive control (Chein & Schneider, 2005). This control network includes dorsolateral prefrontal cortex, anterior cingulate cortex, pre-supplementary motor area, dorsal premotor cortex, anterior insular cortex, inferior frontal junction, and posterior parietal cortex.

In addition to an increase in control network activation, it was found that a set of areas including bilateral angular gyri, posterior cingulate cortex, and the right middle temporal gyrus were more active during self-explanation than during paraphrasing. These regions have been found to be active during discourse comprehension processes including inference processes (e.g., Ferstl, Neumann, Bogler, & von Cramon, 2008; Xu, Kemeny, Park, Frattali, & Braun, 2005; Yarkoni, Speer, & Zacks, 2008). These results indicate that self-explanation, the most effective strategy examined, further engages coherence-building processes that aid in the construction of a good situation model of the text's content.

However, many of the brain regions found to be associated with self-explanation and discourse comprehension are also part of the brain's default network that is active during rest periods in neuroimaging studies (Buckner, Andrews-Hanna, & Schacter, 2008). It is likely that participants engage in daydreaming and other self-referential thought processes during these rest periods. One explanation for the partial overlap between the default network and discourse comprehension regions are that both activities are making use of inference, memory recall, and coherence-building processes.

The default network has been shown to be more active during periods of mind wandering or zoning out while performing another task (e.g., Christoff, Gordon, Smallwood, Smith, & Schooler, 2009). Zoning out is used here to refer to a period of time when a person is engaged in thought not related to the task he/she is currently supposed to be performing. Zoning out while reading has been shown to affect the amount of material remembered (Schooler, Reichle, & Halpern, 2004). There is also some evidence that the frequency of zoning out during self-explanation is related to the effectiveness of self-explanation in promoting learning from text (Moss, Schunn, VanLehn, Schneider, & McNamara, 2008). One of the purposes of the present study was therefore to examine whether there are neural correlates of mind wandering during strategic reading comprehension.

One possibility is that portions of the default network will be more active during trials where the frequency of zoning out is high. This possibility would be consistent with prior work using much simpler tasks to assess the neural correlates of zoning out (Christoff et al., 2009). An additional possibility is that the control network will be less active during periods of increased zoning out. Such a finding would also be consistent with results showing that activity in the default network is anti-correlated with activity in the control network (Fox et al., 2005).

The present study closely followed the methodology of earlier work on the neural correlates of strategic reading comprehension by contrasting three learning strategies—rereading, paraphrasing, and self-explaining—differing in complexity and effectiveness (Moss et al., 2010). We sought to replicate and extend prior work using similar expository texts about a different topic. One difference from the prior study was that the texts that participants read included diagrams along with the text. However, the main difference from the prior study is that participants were asked to provide a self-rated frequency of zoning out while reading and performing the reading strategies. These ratings were used to examine whether there were brain regions that were associated with zoning out.

Method

Participants

Fifteen right-handed, native English speakers were recruited from the University of Pittsburgh and Carnegie Mellon University communities (12 female, M age = 20.7; SD = 1.8). None of the participants had taken college physics.

Materials and Design

Three new texts that taught material related to physics were constructed. Each text consisted of 15 paragraphs, each containing 2-4 sentences, so that they could be presented one paragraph at a time. The topics of the texts were DC circuits, pulley systems, and classical mechanics (forces and motion of objects). For each text, 13-14 diagrams that corresponded to individual paragraphs were also constructed. A set of 15 multiple choice questions that tested the content of each text were also created. Pilot studies were used to refine the materials to equate difficulty for all texts and associated questions.

Each participant performed all three reading strategies: rereading, paraphrasing, and self-explaining. Each was instructed to use a given reading strategy to read all of a given text. The assignment of reading strategies to texts was counterbalanced across participants. The order in which participants performed the strategies was randomized.

Each text was broken up into three sections consisting of five paragraphs each. Each of these five-paragraph sections was presented in a single data acquisition run. Because strategies were assigned to texts, participants were always performing a single strategy during each acquisition run. Each five-paragraph section for each of the three texts was presented before the next section for each text. For example, this organization implies that the first (second) and second (third) blocks of paragraphs from a particular text were separated by a block of each of the other two texts (e.g., Text1-Block1, Text2-Block1, Text3-Block1, Text1-Block2,

…). The blocks were presented in this fashion so that each reading strategy would be performed once in each third of the acquisition session in order to help control for potential confounding effects (e.g., fatigue).

Procedure

This study took place over two sessions, separated by 2-5 days, with fMRI data collected during the second session.

Session 1 During the first session, participants were given up to 30 minutes to complete a pretest including all of the questions for the three texts. Participants then completed a 90-minute iSTART session which provided instruction on how to self-explain using reading strategies. iSTART, described in greater detail by McNamara and colleagues (2004) provides instruction and practice on how to self-explain texts using the five SERT reading strategies: comprehension monitoring, paraphrasing, elaboration, bridging, and prediction.

After iSTART training, the participants were provided with task practice in an MRI simulator. The MRI simulator was designed to closely simulate the physical conditions of the MRI scanner and included a magnetic tracking system to track and present feedback to the participant regarding head movement. In the simulator, participants were presented with 14 paragraphs from two practice texts that were of a similar expository nature but contained different content than the texts in the experiment. Instructions on the screen indicated the reading strategy to use for that block.

The title of the text was centered on the top of the screen with the paragraph appearing on the center of the screen. Along the bottom of the screen was a prompt reminding the participant of the current strategy. Participants were instructed to read the paragraph aloud once, and then to press a button on a response glove. Once they did so, the color of the paragraph's text changed from black to blue which served as a cue that they were to perform the given reading strategy aloud. The participants then reread, paraphrased, or self-explained the text and pressed a button to move to a zoneout rating screen. On this screen, the participant was asked to rate on a scale from 1-5 how frequently they caught themselves zoning out and thinking about non-text material. Following the zoneout rating, participants started to read the next paragraph.

The paraphrasing and self-explanation strategies had been introduced within iSTART, and thus, participants were provided only brief instructions on how to either paraphrase or self-explain out loud each sentence in the text. In the paraphrase condition, participants were told to put each sentence in the paragraph into their own words without using any of the other SERT strategies. In the self-explanation condition, participants were instructed to self-explain each paragraph using the reading strategies covered in iSTART. For the rereading condition, they were told to read and then reread each paragraph out loud until the computer indicated it was time to move to the next paragraph of text. A flashing prompt at the bottom of the screen instructed the participant to stop rereading. The rereading condition was designed this way in order to roughly equate the amount of time spent rereading with the amount of time spent paraphrasing and self-explaining. The amount of time allotted for rereading was 45 seconds, which was determined from a pilot study. Paraphrasing and self-explanation were self-paced with the constraint that the participant was prompted to move on using the same flashing prompt if they reached 60 s.

Session 2 The second session occurred 2-5 days after the first session in order to reduce the chance that participants would read the passages with the pretest questions in mind. This session began with a 30-minute iSTART practice session for additional practice self-explaining. fMRI data was collected for the remainder of the session. All tasks were presented using E-Prime (Schneider et al., 2002). To verify strategy use within each condition, verbal responses were collected using an active noise canceling microphone system (PST, Inc., Pittsburgh, PA).

The first task presented to the participants in the MRI was the line search task that served as a functional localizer to localize activity in control areas (Saxe et al., 2006). The task involved detecting a target line orientation by monitoring lines of differing orientation in four locations on the screen. The lines in these four locations changed over time, and the participants were asked to press a button when one of the locations matched the target orientation. This task has been used in prior research on executive control (Cole & Schneider, 2007). This task was used to functionally identify the control network in this study. All participants in the imaging portion of the study performed the line search task well; d' was greater than 2 for all participants.

Participants then began the strategic reading portion of the experiment. The only difference from the MRI simulator procedure was that a 30-second rest period was placed before and after each block of paragraphs. A fixation cross was presented in the middle of the screen for this period. The participants completed a total of 9 fMRI runs with each run consisting of 5 paragraphs (3 runs while performing each of the 3 strategies). Following these runs, participants were presented with a posttest for each text. We do not examine the posttest imaging data in this paper.

In order to increase statistical power in the pretest/posttest comparison while constraining the number of fMRI participants, a second group of 24 behavioral participants was run using the same reading strategy paradigm..

Data Acquisition and Analysis

Structural and functional images were collected on a whole body Siemens Trio 3-T scanner at the Magnetic Resonance Research Center of the University of Pittsburgh during a 2-hour scanning session. The functional runs were acquired as 39 oblique-axial slices parallel to the AC-PC plane using an echo-planar imaging pulse sequence (TE = 25 ms, TR = 2000 ms, FOV = 21, thickness = 3.5 mm with no gap, flip angle = 76, in-plane resolution = 3.28 mm^2).

The raw data were preprocessed and analyzed using the AFNI software package (Cox, 1996). Preprocessing included slice scan time correction, three-dimensional motion correction, and spatial smoothing. All functional images were realigned to the first image of each run, which were aligned to the first run of each subject. The signal for each voxel was spatially smoothed (7 mm FWHM). Each subject's anatomical images were co-registered to their functional images and the images were transformed into canonical Talairach space.

Analyses of the fMRI data used voxel-based statistical techniques. Unless otherwise specified, all results were corrected for multiple comparisons using family-wise error (FWE) cluster size thresholding to an FWE corrected p-value of less than .05. At the individual subject level, general linear models were fit to the data using a set of boxcar functions convolved with a standard hemodynamic response function. Separate regressors for reading, rereading, paraphrasing, and self-explaining were included in the model. Each group-level analysis used a mixed effects model with subjects treated as a random factor.

Results

Behavioral Results

The proportion correct on the pretest and posttest were used to calculate a learning gain score adjusting for the fact that questions already answered correctly on the pretest cannot be improved upon, gain = (posttest – pretest) / (1 – pretest).

Due to time constraints, two of the fMRI participants did not complete the posttest. The gain scores for the behavioral and imaging participants did not differ on any of the three conditions (for all comparisons, $p > .09$), so the data for these two groups were combined. Planned comparisons showed that rereading gain (M = .30, SD = .23) did not differ from paraphrasing (M = .35, SD = .24), $t < 1$. As expected, self-explanation led to greater learning (M = .41, SD = .21) than rereading, $t(36) = 2.30$, $p = .028$, Cohen's d = 0.38. However, self-explanation learning gains did not differ from paraphrasing, $t(36) = 1.50$, $p = .14$. Prior research has shown self-explanation to be more effective than paraphrasing (Moss et al., 2010).

The zoning out ratings were analyzed in a set of planned comparisons. Frequency of zoning out was rated higher for rereading (M = 2.49, SD = .97) than for self-explaining (M = 2.04, SD = .67), $t(14) = 2.95$, $p = .01$, and marginally higher than for paraphrasing, $t(14) = 2.05$, $p = .06$. Zoning out ratings for paraphrasing and self-explaining did not differ.

Imaging Results

In order to examine differences in activation between the different strategies, a voxel-wise ANOVA with strategy (reread, paraphrase, self-explain) as a within-participant factor was conducted followed by three planned contrasts (paraphrase – reread, self-explain – reread, and self-explain – paraphrase). For each of these contrasts, activation in the line search task was examined to identify clusters of activation that fell both inside and outside of the control net. In addition, positively activated areas from these contrasts were examined to see if the same regions were also active in a prior study of reading strategies (Moss et al., 2010). Figures 1 and, 2 show the active areas along with the extent of overlapping results from the two studies.

The strategy results are very similar to those from our prior study (Moss et al., 2010). In particular, the control net was more active for self-explaining and paraphrasing than it was for rereading, but the control net was equally active for the self-explanation and paraphrase strategies. The areas in the contrast between paraphrasing and rereading were a subset of the areas in the self-explanation and rereading contrast so only the self-explanation vs. reread contrast is shown in Figure 1. For the paraphrase vs. reread contrast, areas outside of the control net included left pre-supplementary motor area, left inferior frontal gyrus, right lingual gyrus, right cerebellum, and bilateral areas of the basal ganglia. In addition to the areas outside of the control net seen in the paraphrase vs. reread contrast, regions of activation in the self-explanation vs. reread contrast included left middle frontal gyrus, left superior frontal gyrus, left precuneus, left middle temporal gyrus, and the thalamus. These results are consistent with the hypothesis that there is engagement of a domain-general control network with the use of complex reading strategies.

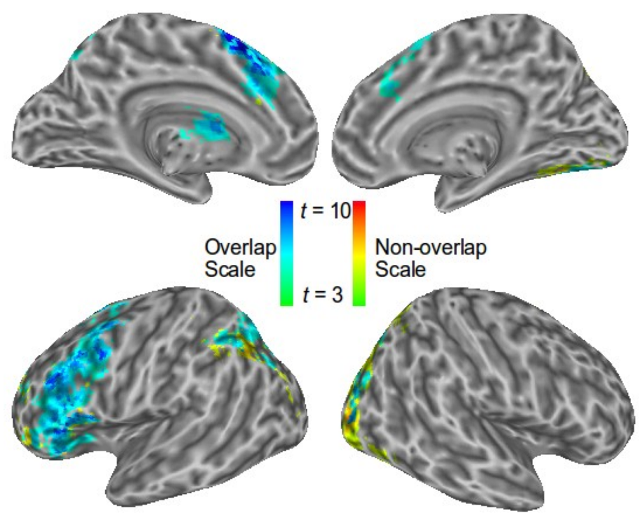

Figure 1: Results of the self-explanation vs. reread contrast. Overlap with contrast of self-explanation vs. reread from prior study shown in blue color scale.

The contrast between the self-explanation and paraphrase conditions shows a different pattern of results as seen in Figure 2. The only active region is the left angular gyrus, which is not part of the control network.

Areas related to zoning out ratings were examined by creating an amplitude modulated regressor for each subject. The regressor for the analysis was formed by convolving a boxcar function whose value was determined by the zoneout rating with a hemodynamic response function. The mean zoneout rating for each subject was subtracted from the amplitudes to yield a regressor that was used to identify brain areas exhibiting a linear relation to zoneout ratings (e.g., Buchel et al., 1998). As can be seen in Figure 3, one significant cluster of activation was found including bilateral medial PFC and right superior frontal gyrus.

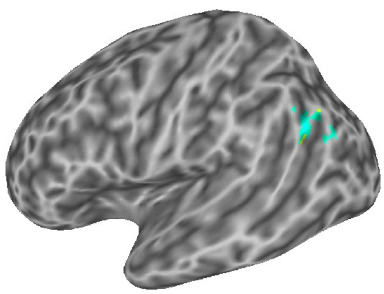

Figure 2: Results of the self-explanation vs. paraphrase contrast. Overlap with contrast of self-explanation vs. paraphrase from prior study shown in blue color scale.

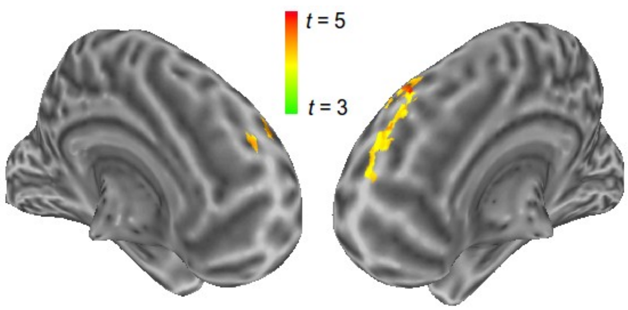

Figure 3: Regions correlated with mind wandering frequency ratings.

Discussion

The results of the strategy contrasts show that the pattern of activation for each of the contrasts largely replicated prior findings using other expository texts. The main difference between the prior study of strategic reading comprehension and this one is that the topic of the expository text was different and the texts included associated diagrams.

In the SE-RR contrasts shown in Figure 1, the main location of non-overlapping activation was in the right middle occipital gyrus and the right fusiform gyrus. These areas are part of the 'what' visual processing stream, and so their activation likely reflects additional visual processing and interpretation of the diagrams included with the texts. The prior study being replicated did not contain diagrams. In addition, the extent of activation in left anterior prefrontal cortex (aPFC) (BA 9/10) was greater in this study than in the prior study. The peak of activation was the same in both studies, but more voxels adjacent to the peak were active in this study employing diagrams. Although the function of this region of aPFC is not clear, left aPFC has been associated with memory retrieval and coordination of attention (Ramnani & Owen, 2004). It is possible that integrating diagrams with the text places additional load on this area due to coordinating attention between diagram and text or due to retrieval of information incorporated in the diagram.

Unlike the results of the SE-RR contrast, the left angular gyrus (BA 39; talairach: -46, -58, 29) was the only significant region in the SE-P contrast completely, and the active region overlapped with the prior study's contrast of self-explanation and paraphrasing. This region has been posited to be involved in processes such as coordinating representations necessary to construct a scene from text (Mellet et al., 2002) and maintaining situation models constructed from narrative texts (Yarkoni et al., 2008). These functions are consistent with the idea that self-explanation is enhancing the situation model that the reader has developed during the initial reading of the text. The fact that there were not any regions associated with the SE-P contrast in this study with texts/diagrams that were not found in the prior study of expository text without diagrams implies that the processes of producing elaboration and bridging inferences do not seem to depend on a separate representation of the diagram.

The zoning out results show that regions of dorsal aPFC (BA 9/10; talairach: 11, 41, 45) were correlated with the ratings that participants gave of how often they had been thinking of other things while performing strategies on the texts. This region includes dorsomedial prefrontal cortex (dmPFC) areas found to be active during discourse comprehension that are thought to be involved with self-referential processing, inference generation, and other reasoning processes (e.g., Ferstl & von Cramon, 2002; Gusnard, Akbudak, Shulman, & Raichle, 2001; Yarkoni et al., 2008). However, many studies of dmPFC show left lateralized activity in this region. dmPFC has been shown to be active during other studies of mind wandering or stimulus-independent thoughts (e.g., Christoff et al., 2009; McGuire, Paulesu, Frackowiak, & Frith, 1996). Given that left dmPFC is active during studies of discourse processing, it could be that the right lateralized activity seen here is due to left dmPFC being engaged throughout the task when engaged with discourse processing or mind wandering, but that right dmPFC was only engaged during mind wandering and therefore showed a stronger correlation to the mind wandering ratings. In any case, it appears that the processing occurring in this area may be similar for discourse and self-referential processing during mind wandering.

No regions were negatively correlated with the zoning out ratings. At least in this task, there was no evidence that the control network was less active during periods of zoning out. There was also no evidence of a decrease of activity in the discourse comprehension regions or in the regions that were more active for the processing of diagrams. One possible explanation for these results is that some cue from the environment or the text led the participants to start pursuing self-referential thoughts leading to greater activation in right dmPFC. In fact, the elaboration strategy of self-explanation explicitly encourages associating the text to prior knowledge. The current data do not allow us to examine the specific time course of zoning out so it is impossible to determine if other regions may be more or less active while participants are starting to zone out or when they catch themselves doing so. Future work should examine combining the study of strategic reading comprehension with the methodology employed in studies of simpler tasks that do allow for a finer grained examination of zoning out (e.g., Christoff et al., 2009).

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