# Cohesive Features of Deep Text Comprehension Processes

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**Abstract**

This study investigates how cohesion manifests in readers' thought processes while reading texts when they are instructed to engage in self-explanation, a strategy associated with deeper, more successful comprehension. In Study 1, college students (n = 21) were instructed to either paraphrase or self-explain science texts. Paraphrasing was characterized by greater cohesion in terms of lexical overlap whereas self-explanation included greater lexical diversity and more connectives to specify relations between ideas. In Study 2, adolescent students (n = 84) were provided with instruction and practice in self-explanation and reading strategies across 8 sessions. Self-explanations increased in lexical diversity but became more causally and semantically cohesive over time. Together, these results suggest that cohesive features expressed in think alouds are indicative of the depth of students' comprehension processes.

**Keywords:** text comprehension, self-explanation, cohesion, think-aloud

## Introduction

Comprehension is a complex cognitive activity that involves the processing of information for the purpose of extracting meaning (McNamara & Magliano, 2009). Within the context of text comprehension, this process relies on the interplay between both lower-level and higher-level processes. Lower-level processes, such as word decoding, relate to the ability to understand the surface-level attributes of a text. However, comprehension does not simply occur once these processes have taken place. Rather, deep comprehension relies on a reader's ability to understand and make connections among the multiple concepts that are activated as a result of these lower-level processes.

The outcome of these comprehension processes is referred to as the mental representation. This representation contains information that was explicitly provided in the text, outside information related to the text, and inferences generated during the comprehension process. Readers achieve deep comprehension when they make connections among these information sources and develop a coherent mental representation of the text (see McNamara & Magliano, 2009, for a review). Importantly, the *coherence* of this mental representation is established through the activation of prior knowledge (from within and outside the text), the incorporation of this knowledge into the mental representation, and the development of connections among the propositions within the mental representation.

Many or most of these coherence-building comprehension processes occur *online* – in other words, they are enacted at the same time that individuals are reading the text (Kintsch, 1988). Consequently, to better understand how readers establish coherence in their mental representations, these online processes must be identified and examined. Unfortunately, most text comprehension assessments only occur after reading is complete. While these assessments can measure recall and recognition of key concepts, they often fail to detect cognitive processes associated with comprehension (Magliano, 2007).

To develop a better understanding of these online reading processes, researchers commonly use think-aloud methodologies (Pressley & Afflerbach, 1995). Generally, think-aloud instructions are designed to prompt individuals to generate the thoughts that are currently in working memory and thus easy to express (Ericsson & Simon, 1994). These methodologies have allowed researchers to identify a number of strategies that readers use to comprehend texts, such as paraphrasing and bridging (McNamara, 2004; Millis, Magliano, & Todaro, 2006).

An important goal for comprehension researchers has been to identify factors that differentiate skilled and less skilled readers. Research has identified a number of individual differences, such as prior knowledge (McNamara et al., 1996), writing ability (Allen et al., 2014), and motivation (Hidi & Harackiewicz, 2000). Relevant to the current study, research suggests that skilled and less skilled readers differ in their *strategic processing* of texts. Skilled readers generate more inferences while reading, which allows them to connect text information to prior knowledge (Oakhill & Yuill, 1996). Further, skilled readers typically establish connections at a more global level, whereas less-skilled readers tend to generate connections in more local contexts (one or two sentences; Millis et al., 2006).

Researchers have additionally *manipulated* the instructional prompts in think-aloud studies to encourage students to engage in different cognitive processes while reading (e.g., Allen, McNamara, & McCrudden, 2015). For example, self-explanation is a commonly employed instructional strategy that encourages the generation of inferences during reading. Broadly, self-explanation is the process of generating explanations to oneself about a particular topic; this strategy has been shown to improve students' deep understanding of complex concepts (Chi et al., 1989; McNamara, 2004). When students produce quality self-explanations (either spontaneously or following an instructional prompt), they make inferences that link text

content together and tie text ideas to their prior knowledge. Thus, self-explanation instructions can prompt students to behave as skilled readers. By contrast, instructions to generate surface level responses to a text (e.g., paraphrasing) do not necessarily prompt students to make connections that are characteristic of skilled readers.

We consider these connections in the reader's mental representation to be representative of *coherence* because research suggests that successful readers generate more inferences (connections) and those inferences are associated with enhanced comprehension. Hence, coherence is a construct that is indirectly inferred about the mental representation of the reader, generally from comprehension tests, but also based on computational models that simulate readers' performance (e.g., Kintsch, 1988).

*Cohesion*, on the other hand, refers to the incidence of explicit text cues that facilitate readers in making connections among ideas in texts (Gernsbacher, 1990; McNamara et al., 2014). For instance, words that overlap between sentences signify to the reader that the sentences are related. It has been assumed that cohesion cannot be *observed* in the mind of the reader, and that the elements of cohesion that might be related to coherence would vary with individual differences and the task requirements, among other factors (O'Reilly & McNamara, 2007).

Our goal here is to challenge that assumption.

## Current Study

In the current study, we examine the extent to which elements of cohesion detected within the (expressed) thoughts of readers are indicative of the type of coherence-building processes in which readers are engaging. We adopt a multi-step methodological approach that relies on natural language processing (NLP) techniques to investigate the cohesion of students' think-alouds and self-explanations. In Study 1, we manipulate the think-aloud instructions students are given while reading texts, instructing them to either paraphrase or self-explain. We then extract the linguistic indices related to the cohesion of these different types of think-alouds that we hypothesize will be indicative of particular strategies. In Study 2, we examine how the different cohesive properties of students' think-alouds change over the course of self-explanation strategy training. The purpose of this second analysis is to examine the extent to which strategy training and practice that prompts students to engage in deeper text processing is evident in the forms of cohesion established in their self-explanations.

Cohesion in text can be established in a number of ways. For the sake of simplicity, we refer to three forms of cohesion that differ in the way in which they express relationships among ideas in texts. *Lexical cohesion* is cohesion that is established through overlapping words in a text. For instance, a text that repeats similar words will have higher lexical cohesion. *Causal cohesion* is signaled by overlapping actions (verbs) and connectives that serve to describe explicit connections among people, objects, events, and actions. Finally, *semantic cohesion* emerges from relationships among concepts, without relying on specific word overlap. For instance, two paragraphs that describe doctors and nurses, respectively, would still be *semantically* cohesive, even if they had no overlapping words.

In this study, we examine the extent to which these three forms of cohesion manifest in students' think alouds when they are engaged in tasks that lead to more coherent mental representations. To this end, we utilize an NLP tool, Coh-Metrix, to investigate the forms of cohesion present in students' think-alouds. Coh-Metrix (McNamara et al., 2014) calculates a number of linguistic indices, ranging from lower level word information to higher level information about cohesion. We selected Coh-Metrix indices that were representative of lexical cohesion (lexical overlap, lexical diversity), causal cohesion (connectives, causal ratio), and semantic cohesion (givenness, global cohesion).

*Lexical overlap* measures the degree to which words and phrases overlap across sentences. We selected the argument overlap index, which specifically measures overlap between nouns, noun phrases, and pronouns in adjacent sentences.

*Lexical diversity* is based on type-token ratios, which increase when the words in a text are less repetitive. In Coh-Metrix, lexical diversity is calculated using multiple algorithms that control for text length. Here, we used the *D* measure (Malvern, Richards, Chipere, & Durán, 2004). Lower lexical diversity is indicative of greater cohesion. In this context, higher lexical diversity can be associated with bringing in more information from outside of the text, or prior knowledge, when talking about the text.

*Connectives* (because, therefore) specify relationships between ideas and provide information about the properties of those relationships. Coh-Metrix provides the incidence of connectives per 1000 words in a text.

*Causal ratio* is calculated as the ratio of causal verbs to causal particles (McNamara et al., 2014). The causal verb count is calculated with WordNet and the causal particle count is based on a pre-defined set of causal verbs. A higher causal ratio is associated with greater causal cohesion.

*Givenness* measures the amount of semantic information that can be recovered from earlier in a text. In Coh-Metrix, givenness is calculated using LSA, which is a statistical method that uses large corpora to represent semantic knowledge (Landauer et al., 2007).

*Global semantic cohesion* is also analyzed using LSA. We utilized a paragraph-to-paragraph LSA cosine, which reflects the semantic similarity of paragraphs to each other.

## Study 1

Study 1 investigates whether the form of cohesion established in readers' think-aloud responses differ when they are prompted to self-explain or paraphrase a text. Paraphrases of text focus primarily on the targeted sentence, and thus place a less emphasis on thinking about the relationships to other ideas or sentences in the text. By contrast, self-explanations are intended to create links to prior knowledge and between ideas and sentences in the text. As such, we expected paraphrases to be characterized

by higher lexical cohesion and a lower diversity of ideas. We also expected students to emphasize the causal connections between ideas more so when self-explaining than when paraphrasing.

## Method

**Participants** Data from this study was collected as part of a larger study that examined neural correlates of strategic reading comprehension (Moss et al., 2011). Participants were undergraduate students (n = 21) recruited from large universities in the Northeastern United States. The majority of the participants were female (n = 14), with a mean reported age of 20.7 (*SD* = 2.4; range = 18-28). All participants were native speakers of English.

**Procedure** Participants completed two sessions, which occurred 2-5 days apart. The first session consisted of a pretest and training with a self-explanation tutoring system, iSTART (described below). During the second session, participants spent 30 minutes practicing the self-explanation strategies in iSTART. The purpose of the self-explanation tutoring during these two sessions was to ensure that all of the participants were familiar with the strategies and had practiced using them while reading. Participants then read three separate Biology texts and, for each text, they were provided instructions to engage in rereading, paraphrasing, or self-explaining. Thus, each participant performed all three of the strategies. The order in which participants performed the strategies was randomized and the assignment of reading strategies to texts was counterbalanced across the participants.

## iSTART

iSTART is an automated version of the SERT (McNamara, 2004) intervention (McNamara, Levinstein, & Boonthum, 2004). It is an intelligent tutoring system (ITS) that provides high school and college students with training and practice on reading comprehension strategies to improve self-explanation and comprehension of complex texts.

iSTART training is separated into three modules, which map onto the three principles of modeling, scaffolding, and fading instruction. After training, students interact with the practice module, where direct instruction is faded and students are required to engage more deeply with the self-explanation strategies. Here, students are asked to self-explain target sentences in science texts and a teacher agent provides feedback and prompts the use of other strategies.

**Text Reading Procedure** Each text was divided into three text sections that consisted of four paragraphs each. These sections were presented to students one at a time. Because each text was assigned a specific reading strategy, participants were never asked to switch strategies within a particular section. Each of the four-paragraph text sections was presented before a section of another text. For instance, a student might self-explain the first text section of the text on DNA, then reread the first text section of a text on Heat, and finally paraphrase the first text section on the text about Cells. In the next section, the student would self-explain the second text section on DNA, and proceed accordingly. The texts were divided in this manner so that no reading strategy was performed more than once in each of the trials in order to control for confounding effects, such as fatigue.

**Corpus** To prepare students' think-aloud statements for text analysis, we first aggregated the self-explanations and paraphrases into two files (this method is discussed in greater detail in Varner et al., 2013). Paragraph breaks were added to each of the aggregated files for each of the blocks in the trial (i.e., to preserve the three separate text sections). Ultimately, this yielded two aggregated files per student: one paraphrase file and one self-explanation file.

**Computational Analysis of Text Cohesion** Students' paraphrase and self-explanation files were analyzed using Coh-Metrix. For the purposes of the current study, we selected Coh-Metrix indices that were representative of text cohesion: lexical overlap, lexical diversity, incidence of connectives, causal ratio, givenness, and global cohesion.

## Results

Our first research question regarded whether students' self-explanations and paraphrases differed in their explicit markers of cohesion. A repeated-measures MANOVA was conducted to examine the differences in the cohesion indices across the aggregated paraphrase and self-explanation files (see Table 1 for descriptive statistics). This analysis revealed that there was a main effect of task instructions (i.e., paraphrase vs. self-explain) on the cohesion of think-alouds, $F$ (6, 15) = 9.24, $p < .001$. Paraphrases were characterized by higher lexical cohesion, both in terms of higher lexical overlap, $F$ (6, 15) = 11. 26, $p = .003$, and lower lexical diversity, $F$ (6, 15) = 18.94, $p < .001$. Paraphrases also included somewhat greater semantic cohesion as measured by givenness, $F$ (6, 15) = 3.20, $p = .089$. By contrast, more connectives were included in the self-explanations, $F$ (6, 15) = 4.41, $p = .049$, indicative of greater specification of relationships between ideas. There were no differences between conditions in terms of the causal ratio or global semantic cohesion.

Table 1: Descriptive Statistics [Means and (SD)] for Paraphrase and Self-Explanation Conditions

| Index | Paraphrase | Self-Explain |
|---|---|---|
| Lexical Overlap | **0.77** (0.17) | 0.63 (0.16) |
| Lexical Diversity | 50.84 (13.92) | **60.82** (9.75) |
| Connectives | 88.76 (24.20) | **101.26** (15.48) |
| Causal Ratio | 1.75 (1.85) | 1.19 (0.85) |
| Givenness | **0.49** (0.05) | 0.46 (0.04) |
| Global Cohesion | 0.65 (0.09) | 0.64 (0.13) |

## Discussion

The results from Study 1 indicate that cohesion manifested in think-aloud statements differently as a function of

whether students were instructed to paraphrase versus self-explain text. In particular, when readers were prompted to self-explain segments of the text, they used more diverse language and more connectives. However, given these same instructions, they also exhibited lower overlap among ideas, and less frequently referred to ideas that they had previously discussed. Self-explanation aims to promote the generation of inferences and, ideally, the establishment of connections between ideas in the text and prior knowledge of the world. When asked to self-explain, readers used more diverse words and less redundant information, suggesting that they may have been activating and thus referring to information from outside the text. Additionally, the self-explanation instructions prompted readers to utilize a greater number of connectives. This may suggest that when readers activated their prior knowledge, they used connectives to ensure that they explicitly established the nature of the relationships between the concepts they were discussing.

## Study 2

Study 1 provides preliminarly evidence that the form of cohesion established in readers' think-aloud statements can serve as a proxy for the processes involved in deep comprehension. One possibility is that these findings are simply a by-product of readers being explicitly told when to use each of the strategies. Therefore, an important question relates to the extent to which these different cohesion indices are indicative of coherence-building processes over the course of extended practice.

The participants in Study 1 were relatively skilled, adult readers who were provided with brief self-explanation training with iSTART. Many readers, however, struggle to self-explain well (McNamara, 2004), and require extended self-explanation practice (Jackson & McNamara, 2013). Without thorough training and practice, less skilled readers are more likely to engage in shallow cognitive processes, which do not stimulate new connections among text concepts. Hence, our goal in Study 2 was to examine how cohesion manifests in the think-alouds of less-skilled (i.e., adolescent) readers and whether these aspects of cohesion change over the course of extensive training and practice.

The data in Study 2 were collected as a part of a larger study that investigated the impact of self-explanation training on readers' ability to generate high-quality self-explanations (Jackson et al., 2013). Results from this study confirmed the benefit of this training, revealing higher self-explanation scores over the course of the extended practice sessions. Our goal in the current study is to conduct a linguistic analysis of the self-explanations that students produced during these training sessions. The purpose of this analysis is to examine the cohesive devices that are related to students' comprehension processes and to determine whether these cohesion indices can provide critical information about the deep comprehension processes developed by readers during this self-explanation training.

### Method

**Participants** Participants were 84 high school students from a mid-south urban environment (51% male; 81% African American, 13% White, 6% other; average grade completed = $10^{th}$ grade; average age 15.8 years). All participants were monetarily compensated for their time.

**Procedure** The current study took place over 11 sessions, with a pretest, 8 training sessions, a posttest, and a delayed retention test. Students completed a pretest during the first session, which included measures of their reading and self-explanation ability. During the following eight sessions, students received training and practice in the iSTART system. This study focuses on the self-explanations generated by the students during practice.

**Computational Analysis of Text Cohesion.** Students' self-explanations in the iSTART systems were analyzed in a similar manner as in Study 1 with two notable exceptions. First, the aggregated self-explanations preserved the paragraph structure of the texts in iSTART. For a target text with $p$ paragraphs and $n$ target sentences, the resulting aggregated self-explanation file would contain $p$ paragraphs and $n$ self-explanations corresponding to the relative position of the target sentence. This is because iSTART prompted students to self-explain at specific target sentences, whereas in Study 1, students self-explained or paraphrased entire text segments. The second difference relates to the calculation of the cohesion indices. Students in this study self-explained multiple texts per day. Therefore, for each student, we calculated an average score for each cohesion index on each day of training.

### Results

Separate repeated-measures ANOVAs for each cohesion index across the 8 training days were conducted to investigate the effect of self-explanation training on the cohesion of students' self-explanations. Table 2 presents the descriptive statistics for the first and last session of training. The results revealed that there was a significant effect of training session for all six cohesion indices. Over the course of iSTART training, students produced self-explanations that had lower lexical cohesion, both in terms of lower lexical overlap, $F$ (1, 83) = 3.47, $p$ = .005, and greater lexical diversity, $F$ (1, 83) = 4.23, $p$ = .001. Although the students decreased in their use of connectives, $F$ (1, 83) = 9.90, $p$ < .001, the causal ratio increased, $F$ (1, 83) = 3.27, $p$ = .026, indicating that the students were using connectives that were linked to causal verbs. While the self-explanations included less lexical cohesion (as found in Study 1), they were more semantically cohesive, including more given information, $F$ (1, 83) = 6.99, $p$ < .001, and an increase in global semantic cohesion across training, $F$ (1, 83) = 11.99, $p$ < .001. This suggests that students improved in establishing connections among the self-explanations produced across texts (rather than simply paraphrasing individual sentences).

Table 2: Descriptive Statistics [Means and (SD)] for Sessions 1 and 8 of Self-Explanation Practice

| Index | Session 1 | Session 8 |
|---|---|---|
| Lexical Overlap | **0.76** (0.20) | 0.61 (0.23) |
| Lexical Diversity | 50.94 (13.73) | **54.29** (12.72) |
| Connectives | **101.31 (16.42)** | 85.03 (17.86) |
| Causal Ratio | 0.83 (0.74) | **0.96 (1.40)** |
| Givenness | 0.35 (0.68) | **0.37 (0.09)** |
| Global Cohesion | 0.46 (0.18) | **0.62 (0.11)** |

Note: Analyses included all 8 sessions as a repeated measure

### Discussion

The results revealed important information about the role of cohesion in students' self-explanations. The self-explanation training provided by iSTART promoted changes in students' use of cohesion across their self-explanations. In particular, over time, students' self-explanations became less cohesive lexically, but more cohesive at the global, semantic level. The explanations also included fewer connectives, but increased in terms of the causal ratio. The causal ratio is indicative of the use of connectives that are tied to causal verbs, and thus higher causal cohesion. These results indicate that self-explanation training prompted students to generate more inferences and establish more connections across the texts they were reading. This finding is important as it provides further confirmation that self-explanation training and practice can promote changes in students' on-line comprehension processes. Further, and most relevant to the current study, the results indicate that these coherence-building comprehension processes can be identified (at least in part) through automated analyses of the forms of cohesion in students' think-alouds.

Importantly, however, the changes observed in the cohesion of students' self-explanations across training do not directly map onto the findings from Study 1. In particular, the indices that were positively associated with self-explanation instructions in Study 1 did not necessarily increase over the course of iSTART training in Study 2. In Study 1, lexical overlap and givenness were higher for paraphrases than self-explanations, whereas connectives and lexical diversity were greater for self-explanations compared to paraphrases. In Study 2, lexical overlap and lexical diversity changed in a manner that was "consistent" with the results of Study 1, in so far as the cohesive devices become more indicative of deeper processing over time.

The incidence of connectives and givenness, however, behaved inconsistently with Study 1. These results potentially point toward important differences between the contexts of the two studies. In Study 1, skilled readers were explicitly prompted to engage in different reading strategies before generating any text. In Study 2, however, less-skilled readers were practicing a host of self-explanation strategies over extended practice. Therefore, these students were likely increasing in their use of certain deep comprehension strategies, but in some contexts, may have also needed to engage in "shallow" text processing, such as paraphrasing.

## General Discussion

The current study investigated whether the cognitive processes associated with deep comprehension manifested in the cohesive properties of students' think-aloud statements. The results confirmed this prediction. In particular, cohesive indices of students' think-aloud statements differed according to task instruction and changed across time as students received self-explanation training. These results suggest that deep comprehension processes can be detected through analyses of readers' typed, verbal responses while reading texts.

The results from Study 1 indicated that prompting students to engage in shallow text processing (i.e., paraphrasing) or deep processing (i.e., self-explaining) led them to establish different levels of cohesion in their think-aloud statements. In particular, when students self-explained texts (as compared to paraphrasing), they used more diverse information and established more explicit connections among the ideas. This finding is important for a number of reasons. First, it provides further confirmatory evidence for the fact that instructions to either self-explain or paraphrase a text can dramatically alter students' on-line reading processes. Second, the results suggest that these instructional differences can be detected through analyses of the cohesion found in students' think-aloud statements. Thus, the coherence-building processes important for text comprehension may manifest in the overt cohesive cues students use when reading through the text.

Study 2 investigated whether the benefits of iSTART training could be detected through analysis of the cohesion of readers' self-explanations. The results suggested that all of the cohesion indices changed across training days and that the majority became more *consistent* with deeper levels of processing (as evidenced by the results of Study 1). In particular, after training, students produced self-explanations that were less lexically cohesive, but more causally and semantically cohesive. In particular, their self-explanations contained less explicit lexical overlap, with greater semantic connections established across the statements. These results suggest that changes in coherence-building comprehension processes can be identified by investigating the forms of cohesion in self-explanations.

Of course, this study is only an initial step in answering our questions. First, additional studies will be necessary to examine the relationship between these cohesive cues and comprehension more directly by examining students' comprehension on specific texts that they have self-explained. In the current study, we were interested in the specific influence of instructional prompts on these cohesive cues; however, future studies investigating how these cues relate to comprehension on specific question types will be necessary. Second, further research is needed to examine the generality of these effects across different types of texts and different types of comprehension goals.

Overall, the current study takes an important step towards understanding the role of cohesion in students' think-alouds during text comprehension. These findings can strengthen

our theoretical understanding of text comprehension processes, as well as for comprehension more broadly. Additionally, the results may be used to inform educational reading interventions and tutoring systems. If specific cohesion indices can be identified that systematically relate to certain comprehension processes and outcomes, educators may be able to use this information to provide more adaptive instruction and feedback to their students.

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