Discourse Processes

ISSN: 0163-853X (Print) 1532-6950 (Online) Journal homepage: http://www.tandfonline.com/loi/hdsp20

Cognitive Processes in Discourse Comprehension: Passive Processes, Reader-Initiated Processes, and Evolving Mental Representations

Paul van den Broek & Anne Helder

To cite this article: Paul van den Broek & Anne Helder (2017) Cognitive Processes in Discourse Comprehension: Passive Processes, Reader-Initiated Processes, and Evolving Mental Representations, Discourse Processes, 54:5-6, 360-372, DOI: 10.1080/0163853X.2017.1306677

To link to this article: http://dx.doi.org/10.1080/0163853X.2017.1306677

DISCOURSE PROCESSES
2017, VOL. 54, NOS. 5–6, 360–372
http://dx.doi.org/10.1080/0163853X.2017.1306677

Routledge
Taylor & Francis Group

Cognitive Processes in Discourse Comprehension: Passive Processes, Reader-Initiated Processes, and Evolving Mental Representations

Paul van den Broek[a] and Anne Helder[b]

[a]Brain & Education Lab, Leiden University, Leiden, The Netherlands; [b]Learning Research and Development Center, University of Pittsburgh

ABSTRACT

As readers move through a text, they engage in various types of processes that, if all goes well, result in a mental representation that captures their interpretation of the text. With each new text segment the reader engages in passive and, at times, reader-initiated processes. These processes are strongly influenced by the readers' representation of the preceding text and, in turn, update this very same representation. This updated representation forms the backdrop for the processing of the next text segment, and so on. Thus, passive and reader-initiated processes and the evolving representation engage in a continual, intricate interaction as the reader moves through the text. We provide a framework for conceptualizing the interplay between these three components of comprehension and propose that (1) passive and reader-initiated processes interact during reading; (2) a reader's *standards of coherence* moderate what kind and to what extent reader-initiated processes take place; (3) reader-initiated processes lie along a continuum from close-to-the-text, coherence-building processes to far-from-the-text, interpretive processes; and (4) the moment-to-moment processes and the evolving mental representation interact in a reciprocal fashion. We present results from recent experiments on key aspects of the framework, and identify questions the framework raises. We conclude with implications from this conceptualization for theoretical models of reading comprehension.

Introduction

A central question in the investigation of reading comprehension is what the processes or mechanisms are by which a reader arrives at a mental representation of a text as he or she proceeds from sentence to sentence. Models of reading comprehension generally are in agreement that these online processes include both passive and reader-initiated processes (e.g., Gerrig & O'Brien, 2005; Graesser, Singer, Trabasso, 1994; Isberner & Richter, 2014; Kintsch & van Dijk, 1978; Long & Lea, 2005; Myers & O'Brien, 1998; Rapp & van den Broek, 2005; van den Broek, Rapp, & Kendeou, 2005). It is less clear whether these two types of processes are related and how they combine to result in comprehension. Beyond stating that both must play a role, the models generally are silent on this issue; consequently, little research attention has been devoted to the possible interaction between passive and reader-initiated processes.

In this article we present a framework in which the two types of processes, passive and reader-initiated, combine to result in a mental representation. The framework builds on and extends the Landscape Model of reading comprehension processes and representation (Tzeng, van den Broek, Kendeou, & Lee, 2005; van

CONTACT Paul van den Broek broekpwvanden@fsw.leidenuniv.nl Institute of Education and Child Studies, Leiden University, Wassenaarseweg 52, 2333 AK Leiden, The Netherlands.

den Broek, Young, Tzeng, & Linderholm, 1999; van den Broek, 2010). After providing details on the framework, we consider empirical evidence to assess the validity of the framework and to identify possible revisions and elaborations on the framework, thus setting an agenda for future research. We conclude with implications for theoretical models of reading comprehension.

Mental representation of text

Before exploring how various *processes* may contribute to comprehension of a text, it is important to consider briefly the *outcome* of successful comprehension. At the core of comprehension of a text is the construction of a mental representation in which individual elements from the text are combined with elements from the reader's background knowledge and are connected through semantic relations inferred by the reader (e.g., Kintsch, 1988; O'Brien, Cook, & Lorch, 2015; Trabasso, Secco, & van den Broek, 1984; van den Broek, 1994). Various types of semantic relations are possible, but the most frequently inferred relations are those that provide referential, causal/explanatory, and logical coherence (e.g., van den Broek, 1994; Zwaan, Langston, & Graesser, 1995). The resulting, interconnected representation goes beyond the meaning of individual words or sentences. In the final representation after reading has been completed, the elements and relations form a network that provides structure to the reader's comprehension of the text (Goldman & Varma, 1995; Graesser & Clark, 1985; Kintsch, 1988; Trabasso & van den Broek, 1985). Individual elements vary in their role within this structure, with some having greater *structural centrality* than others. For example, elements differ in the number of semantic relations that they have to other elements in the representation and, thus, in their centrality to the semantic structure as a whole (Trabasso, van den Broek, & Suh, 1989). As a second example, the specific semantic relations may create a hierarchy between elements or clusters of elements. For instance, for narrative texts causal relations between protagonists' goals may create a hierarchy with superordinate and subordinate goals (Black & Bower, 1980; van den Broek & Trabasso, 1986); similarly, for informational texts logical relations may create a hierarchy of embedded themes and subthemes, of topics and underlying concrete examples, and so on (Meyer & Freedle, 1984). Elements higher in such hierarchies tend to be more central to the semantic structure of the text than those in lower positions, even if they have the same number of relations (e.g., Lorch & Lorch, 1985; Omanson, 1982; van den Broek, 1988).

A plethora of empirical research on the representation of text has shown readers to be sensitive to the structural centrality of text elements (for a review, see van den Broek, Helder, & Van Leijenhorst, 2013). For example, after having read a text they tend to remember elements of the text with many semantic relations more often than elements that have fewer relations (Trabasso et al., 1984; Trabasso & van den Broek, 1985), emphasize strongly connected elements in their summaries of the text (van den Broek & Trabasso, 1986), and answer questions about the text by following the relations through the network (O'Brien & Myers, 1987). Likewise, they recall elements higher in a hierarchical structure more frequently than those lower in the structure (Lorch & Lorch, 1985; McCrudden, Magliano, & Schraw, 2011; Seifert, Abelson, & McKoon, 1986; van den Broek & Trabasso, 1986). These findings concern proficient, adult readers, but struggling and younger comprehenders also have been found to be sensitive to structural centrality in their representation of a text they have read, although to a lesser extent (e.g., Kim, Kendeou, van den Broek, White, & Kremer, 2008; Lynch et al., 2008; Miller & Keenan, 2009; van den Broek et al., 2013; Wolman, van den Broek, & Lorch, 1997).

It is plausible that sensitivity to structural centrality would also be reflected in the processes during comprehension, but there is only limited evidence. For example, sentences in expository texts that have many relations are read more slowly than sentences with few relations (Yeari, Oudega, & van den Broek, 2016; Yeari, van den Broek, & Oudega, 2015), and the reading of sentences of new topics is slower if the new topic goes up in hierarchical level than if it remains at the same hierarchical level as the preceding topic (Lorch, Lorch, & Matthews, 1985; Lorch, Lorch, &

Mogan, 1987). We turn to issues concerning the online processes as a reader proceeds through a text in the remainder of this article.

Passive and reader-initiated processes during reading

As mentioned, there is general consensus that readers engage in both passive and reader-initiated processes as they proceed through a text. A considerable amount of research has been devoted to the passive processes during reading. Passive processes typically are conceived as associative processes by which information in the current text element activates information from memory for the prior text and from a reader's semantic memory (background knowledge). They take place outside the reader's conscious control and are "dumb" in that they are nonselective and unrestricted in the kind of information they return. The associative processes are described as *spread of activation* (Anderson, 1983), *resonance* (McKoon & Ratcliff, 1992; Myers & O'Brien, 1998; O'Brien & Myers, 1999), or *cohort activation* (Tzeng et al., 2005; van den Broek et al., 1999). Passive processes are captured in fairly detailed models, which specify various factors that influence the availability of information from memory through passive processes. These factors include the amount of elaboration or strength of encoding of the information in memory, the degree of activation of the triggering information in the current text element, and the strength of association between triggering and memory information (O'Brien & Cook, 2016; O'Brien, Rizzella, Albrecht, & Halleran, 1998; Ratcliff and McKoon 1988; van den Broek et al., 1999).

Besides passive processes there are also reader-initiated processes that take place during reading. Reader-initiated processes do not always take place, and because they require control and attentional resources on the part of the reader, they consume time and effort. But they can lead to comprehension beyond what results from the passive processes alone. There is a wide variety of possible reader-initiated processes (e.g., Duke & Pearson, 2002; Graesser et al., 1994; McNamara, 2004; Pearson, Roehler, Dole, & Duffy, 1992; Pressley & Wharton-McDonald, 1997; Singer, Graesser, & Trabasso, 1994), ranging from simple actions such as rereading a sentence to very involved actions such as reflection, note-taking, comparison with other documents, and so on. Reader-initiated processes have received less systematic research attention than passive processes, in part because they are so varied. As a result, their role and nature tend to be relatively vague and underspecified.

Central to our framework is the notion that reader-initiated processes lie along a continuum reflecting the degree to which they are constrained by the text. The continuum ranges from processes that remain close to the actual text itself to processes that go well beyond the information in the text. The close-to-the-text processes tend to revolve around *coherence-building*, whereas the far-from-the-text processes tend to be more *interpretive*, for example by involving reflection, exploration of connections to other texts or topics from background knowledge, and ad-hoc situation-dependent strategies (Goldman, McCarthy, & Burkett, 2015; Graesser et al., 1994; Singer et al., 1994, van den Broek, 1994, 2010).

Reader-initiated processes are effortful and therefore do not always take place. However, with practice and education they may become more routinized and hence more similar to passive processes in their cognitive demands. This is particularly the case for close-to-the-text, coherence-building processes because they are triggered more frequently and more consistently than the greatly varying and situation-dependent interpretive processes. As a result, in proficient readers coherence-building processes frequently require relatively little effort and are performed routinely (Afflerbach, Pearson, & Paris, 2008; LaBerge & Samuels, 1974; Perfetti & Stafura, 2015).

In the following sections we explore possible interactions between passive and reader-initiated processes. In doing so, we focus on the close-to-the-text end of the continuum of reader-initiated processes, because (1) text-constrained processes are fundamental to reading comprehension and interpretive processes that may follow and (2) they are more defined and better understood than the potentially unlimited variety of far-from-the-text processes.

Framework for conceptualizing reading comprehension

Although most studies and models assume that both passive and reader-initiated processes play a role in text comprehension, they usually focus on one or the other set of processes. Thus, it is unclear exactly how passive and reader-initiated processes combine to create comprehension and whether they interact in doing so. Likewise, although models assume that the online processes lead to the outcome of a mental representation of the text as a whole, they rarely specify in what manner the online processes do so. In this section we provide a framework for conceptualizing the interplay of various comprehension processes that take place during reading and the manner in which these processes lead to and, at the same time, depend on the emerging representation of the text. We do so in three subsections, concerning the relation between passive and reader-initiated processes, their contribution to coherence, and the reciprocal relation between processes and developing representation, respectively. Figure 1 provides a schematic description of the flow of information in the framework triggered by reading a text segment, and Table 1 summarizes the theoretical principles captured in the framework.

Relation between passive and reader-initiated processes

The framework assumes that passive and reader-initiated processes are intertwined and mutually influence each other and, in combination, influence the development of a representation of the text (see also Rapp & van den Broek, 2005; van den Broek et al., 2005). Because passive processes are not controlled by the reader, they always take place. In contrast, reader-initiated processes require effort

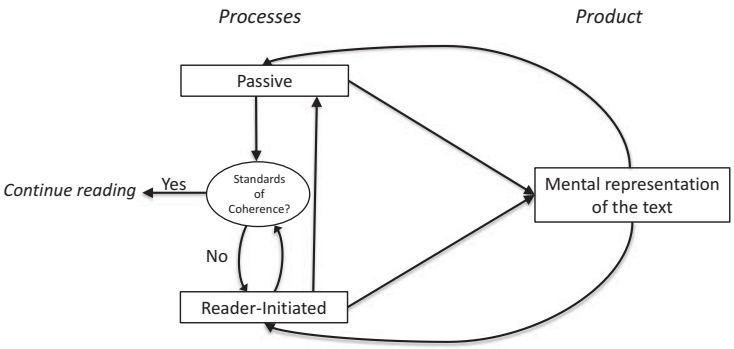

Figure 1. Reading comprehension: Interactions between passive and reader-initiated processes, standards of coherence, and evolving mental representation.

Table 1. Theoretical principles guiding the framework of reading comprehension.

1. **Comprehension is characterized by a combination of passive and reader-initiated processes, moderated by a reader's standard of coherence.**
   → Reader-initiated processes occur when passive processes alone are not sufficient to attain the reader's standards of coherence.
2. **Passive and reader-initiated processes both contribute to inference generation, through their own mechanisms.**
   → With reader-initiated processes lying on a continuum from highly constrained by the text (e.g., coherence-building) to weakly constrained by the text (interpretive, varied, situation-dependent).
3. **Passive processes, reader-initiated processes, and the evolving mental representation interact in a reciprocal relation.**
   → Passive and reader-initiated processes lead to updating/constructing the mental representation. Conversely, the evolving mental representation influences reader's passive and reader-initiated processes.
4. **The combination of processes fluctuates dynamically and cyclically from text segment to text segment.**

on the part of the reader and do not occur always. As mentioned above, reader-initiated processes vary in the degree to which they are constrained by the text, ranging from close-to-the-text, coherence-building processes on the one hand to far-from-the-text, interpretive processes on the other hand. An important factor in determining the extent to which reader-initiated processes take place consists of the reader's *standards of coherence*. A reader's standards of coherence are the (often implicit) criteria that a reader has for what constitutes adequate comprehension and coherence in a particular reading situation (van den Broek, Beker, & Oudega, 2015; van den Broek, Bohn-Gettler, Kendeou, Carlson, & White, 2011; van den Broek, Risden, & Husebye-Hartmann, 1995). Standards of coherence have several important properties. First, they encompass both the types of coherence (e.g., causal, referential, logical, spatial) and the strength of the coherence for each type that is needed for adequate comprehension. Second, there are individual and developmental differences in standards. Third, standards can also vary within an individual as a function of the reader's goal for reading—for example, superficial or deep comprehension—a particular text, his or her motivation of interest in the topic, the presence of distractors or secondary tasks, and physical factors such as fatigue. These factors themselves may depend on properties of the text (e.g., topic, clarity of structure) and of the reading situation (e.g., instructions, perceived or real task). Fourth, standards of coherence and the attention-allocation and reading-comprehension strategies used in the service of attaining the standards can be acquired through practice and study. Moreover, with practice standards and strategies can become more automatized.

In our framework, a powerful circumstance that leads to reader-initiated processes occurs when passive processes alone do not lead to adequate comprehension. When the passive processes alone yield adequate comprehension by attaining the reader's standards of coherence, then no further processing is necessary. However, if passive processes alone lead to comprehension falling short of satisfying the reader's standards, then reader-initiated, coherence-building processes are likely.

Passive and reader-initiated processes contribute to coherence

As the reader proceeds through a text, each consecutive text segment triggers passive and reader-initiated processes, moderated by the reader's standards. Together, these processes allow the reader to infer semantic relations between the current, focal segment and other information and thereby to build a coherent representation of the text. Specifically, the current focal segment can be related to information from three potential sources: (1) to the contents of working memory carried over from processing of the preceding text segment through *connecting* inferences (sometimes called "gap filling" or "bridging"), (2) to information from the earlier text through *reinstating* inferences (e.g., from memory or by rereading), and (3) to information from background knowledge through *elaborative* inferences.[1] Elaborative inferences may be *explanatory* if they contribute to coherence, *predictive* (or "forward") if they anticipate upcoming information, or simply *associative* (in which case they play no or only a minor role in establishing coherence). Details on the various sources and types of inferences they afford can be found elsewhere (e.g., van den Broek et al., 2015).

Concerning the respective roles of passive and reader-initiated processes, there are several important points to be noted. First, both passive and reader-initiated processes operate, through their own mechanisms, on all three sources and therefore contribute to all types of inferences. Passive processes do so by unrestricted spread-of-activation. Reader-initiated processes do so in a restricted manner, as a function of the reader's standards of coherence and of the information returned through the passive processes. Second, each newly read text segment triggers a new set of passive and, if necessary for attaining the standards of coherence, reader-initiated processes. Because the processes and inferences that are needed to attain the reader's standards of coherence vary for

[1]A reader can also search information sources external to the text or reader, such as other documents, the Internet, experts (e.g., Bråten, Britt, Strømsø, & Rouet, 2011; Rouet, 2006). Such processes fall on the "very interpretive" end of the reader-initiated dimension and are not considered here.

different text segments, the particular combinations of passive and reader-initiated processes and the patterns of resulting inferences fluctuate from text segment to text segment as the reader proceeds through a text.

Reciprocal relation between processes and developing mental representation

With each new text segment, the reader engages in passive and, at times, reader-initiated processes. These processes draw strongly on the readers' representation of the preceding text and, in turn, update this very same representation. The now-updated representation forms the backdrop for the processing of the next text segment, and so on. Thus, passive and reader-initiated processes and the evolving representation engage in continual, intricate interaction as the reader moves through the text.

To be complete, models of online processing during reading must include an account of how the processes and the inferences they generate lead to the construction of a memory representation (see McNamara & Magliano, 2009; van den Broek & Gustafson, 1999). It is essential to include an account of the translation of online processes to representation for several reasons. First, studies of online processes during reading almost always are motivated and justified by statements about the importance of the outcome of reading: the importance of people being able to understand texts they read, for work, school, and everyday life. Thus, the relevance of the study of reading processes depends on the representation they presumably generate. Second, as discussed above, the online processes themselves are heavily influenced by the contents and relational structure of the mental representation of the text as it has been constructed so far (O'Brien & Myers, 1987; van den Broek, 1994).

The translation of online processes into a mental representation has received relatively little research attention, as most research has focused on either the online processes or the offline products of comprehension in isolation. A central aspect of such translation concerns the gradual building of a relational structure. In their seminal work, Kintsch and van Dijk (1978; Kintsch, 1988) emphasized the cyclical nature of the reading process and the gradual building of a representation, with the processes triggered by each new text segment expanding and modifying the existing representation. In the context of the above account of passive and reader-initiated processes, these principles are implemented in the Landscape Model of reading comprehension (Tzeng et al., 2005; van den Broek, 2010; van den Broek et al., 1999). At each reading cycle the text and background-knowledge elements processed and the semantic relations inferred via the passive and reader-initiated processes are accumulated into the emerging memory representation. The amount of change in the representation depends on two factors. First, it depends on the activation during the reading cycle. If an element is strongly activated during a reading cycle, its strength in the memory representation will increase more than if it is only weakly activated. Similarly, if two elements and their relation are activated strongly, the semantic relation in the representation will be strengthened more than if the activation of elements and relation is low. Second, the amount of change depends on the strength of elements and relations in the already existing representation. Following connectionist models, the learning curve is asymptotic: The stronger the representation of an element or relation already is in the representation developed in preceding reading cycles, the more activation is necessary to bring about a further increase in representational strength.

Thus, the passive and reader-initiated processes influence the activation of information during reading and the generation of inferences and also affect the development of the offline memory representation in systematic ways through these activations and inferences. Conversely, the online processes at each point during reading are strongly influenced by the representation as it has been built up so far. For example, the information that passive processes return from a reader's memory representation of the preceding text depends on the representational strengths of elements and their relations. Likewise, reader-initiated processes are constrained by properties of the representation.

Empirical investigations of passive and reader-initiated processes

The framework presented in the preceding sections conceptualizes the interplay of various comprehension processes that take place during reading and the manner in which these processes lead to and, at the same time, depend on the emerging representation of the text. The components of the framework—passive processes, reader-initiated processes, and the evolving mental representation—individually have received considerable empirical support. This support was summarized in earlier sections.

In contrast, there has been little empirical investigation of the interaction between passive and reader-initiated processes and of the contribution of the combined processes to the evolving memory representation of the text as a whole. Interestingly, however, even models emphasizing passive processes assume a role for reader-initiated processes. For example, in their Minimalist Hypothesis McKoon and Ratcliff (1992) sketch the minimal inferences that occur always during reading, even in the absence of a particular reading goal. These minimal inferences consist of inferences that use easily available information (i.e., those that use passive processes) but also inferences that are necessary to establish local coherence (McKoon & Ratcliff, 1992). In terms of the framework presented in this article, the latter inferences involve reader-initiated processes, in particular processes at the coherence-building end of the continuum. As a second example, a considerable body of research on passive processes uses behavioral measures that presume coherence-building processes. For instance, studies on text factors that are hypothesized to influence passive processes frequently use the contradiction paradigm (Albrecht & O'Brien, 1993; O'Brien & Cook, 2016; in children: Helder, Van Leijenhorst, & van den Broek, 2016; Wassenburg, Beker, van den Broek, & van der Schoot, 2015; Zabrucky & Ratner, 1992). In this paradigm, participants read texts with target sentences that contradict earlier text statements. Text factors that are hypothesized to influence passive processes are systematically varied and reading times for the target sentences are measured. Increased reading times for the target sentences are taken as indication that the hypothesized factor influenced the availability of the earlier text statements. The reasoning is that if the two contradicting pieces of information are simultaneously activated this may trigger time-consuming repair processes (i.e., reader-initiated processes), which could result in a slowdown in reading. This reasoning rests on the assumption that indeed reader-initiated processes take place and the occurrence of reading-initiated processes is influenced by the products of the passive processes.

A few empirical investigations speak directly to the possible relation between passive and reader-initiated processes. Using computational modeling, Yeari and colleagues simulated the results of 16 experiments from nine published articles on the online generation of predictive and connecting (bridging) inferences (Yeari & van den Broek, 2015, 2016). The prior studies used a variety of psycholinguistic paradigms, varying from speeded recognition to naming. Latent semantic analysis (Landauer & Dumais, 1997; Landauer, Foltz, & Laham, 1998) simulations assuming only passive processes of semantic association captured many but not all the observed patterns of inference activation (Yeari & van den Broek, 2015). By including coherence-based, reader-initiated processes such as described in the Landscape Model into the simulations, they captured the empirical findings reported in virtually all the mentioned studies. This suggests that inference generation during reading is best described as the joint result of passive and reader-initiated processes.

Central to the framework are the reader's standards of coherence while reading a text, because the standards determine the relative roles of passive and reader-initiated, coherence-building processes. Standards may vary across reading situations as a function of reader characteristics (such as reading skills, reading goal, the reader's interpretation of tasks/instructions) and text characteristics. Whereas it may be rather obvious that a reader's standards influence the degree to which he or she engages in processes at the reflective, strategic end of the dimension of reader-initiated processes (e.g., when a reader makes an outline, consults other sources, reflects on deep levels of comprehension), the more challenging question is whether standards influence processes that are at the close-to-the-text, end of the dimension. Many aspects of this issue are yet to be investigated, but there is some evidence that a reader's standards of coherence indeed influence such local inferential processes.

One line of investigations on the effects of standards of coherence on coherence-based processes focuses on the reader's goals in reading a text. Initial studies of these effects used think-aloud methods to investigate possible differences in processes when readers read narrative and expository texts for study versus for entertainment. The results indicate that readers indeed adjust their processing to reading goals (Narvaez, van den Broek, & Ruiz, 1999; van den Broek, Lorch, Linderholm, & Gustafson, 2001): Having a study goal elicited more processes focused on building coherence (connecting and explanatory inferences, predictive inferences, rephrasing the current sentence), whereas having an entertainment goal elicited more text-external processes (associative elaborations, evaluations and comments on the text). Interestingly, these effects interacted with reader characteristics: They were strongest for readers with large working-memory capacity (Linderholm & van den Broek, 2002).

Recent studies used eye-tracking methods, which are less intrusive and less reliant on readers' conscious introspections. In one study participants read expository texts with one of four reading goals (Yeari et al., 2015). Reading times per syllable and fixations for first-pass reading and for second-pass reading (e.g., reinspection) of text elements were recorded. Through pilot studies, text elements had been divided into elements central to text structure (i.e., had many connections to other elements), elements peripheral to text structure (i.e., had few connections to other elements), and elements that were neither strongly central nor strongly peripheral. The results showed that first-pass reading of text elements was influenced by the centrality of elements: Elements that were central were read more slowly than elements that were peripheral. There was no effect of reading goal. Second-pass reading, however, was strongly affected by reading goal: Some goals systematically led readers to do more and longer rereading than other goals. Thus, as readers proceed through a text coherence-based factors influence their processing. Text elements that are connected to many other elements are read more slowly than elements with few connections—perhaps because some of these connections may take time to construct—and different reading goals prompt the reader to reinspect text elements to different degrees.

Readers also adjust their processing of the content of a text in response to noncontent properties of that text. In a study similar to that described in the preceding paragraph, readers' read expository texts in which some parts of the text were highlighted (Yeari et al., 2016). In one condition some elements central to the structure were highlighted, in a second condition peripheral elements were highlighted, and in a third condition no elements were highlighted. Overall, there was a strong effect of centrality: Text elements that were connected to many other elements were read more slowly than elements with few connections. Highlighting did prompt readers to adjust their processing but only for peripheral text elements: Highlighting central text elements decreased the amount of rereading of peripheral elements, whereas highlighting peripheral elements increased the amount of rereading of peripheral elements.

The effects of centrality on first-pass reading times and of reading goals and highlighting on backward fixations indicate that factors associated with standards of coherence influence processes at the close-to-the-text, coherence-building end of the dimension of reader-initiated processes. Together with the results from the computational simulations of online inference generation, they suggest that online inference generation is the joint product of passive and reader-initiated processes and standards of coherence influence reader-initiated processes, even at the level of eye movements.

These results are the outcomes of initial studies, so they should be considered suggestive rather than definitive. Additional studies need to be conducted to investigate aspects of the framework that have not yet been explored in detail, whereas others need to be conducted to eliminate alternative explanations for already observed findings. Thus, the framework also sets an agenda for future studies. We elaborate on this agenda in the final section.

Discussion

In this article we have argued that complete models of online reading-comprehension processes would describe not only the passive and reader-initiated processes that take place during reading but also the interactions between these two types of processes and the interaction between processes and

the developing mental representation of the text. The reason is that these components—passive processes, reader-initiated processes, and developing memory representation—continually interact with and influence each other. As a step toward such a complete model, we presented a framework for conceptualizing the interplay between these three components as well as some initial empirical support for key components of the framework. Figure 1 and Table 1 summarize the main principles embodied in the framework.

In this conceptualization, each newly read text segment triggers in the reader passive processes that activate information from background knowledge and from the memory representation or situation model for the text read so far. If the results of passive processes do not meet the reader's standards of coherence, then reader-initiated processes will also take place. These reader-initiated processes are varied, ranging from close-to-the-text, coherence-building to far-from-the-text, interpretive processes, and also operate on both background knowledge and the memory representation of the preceding text. Thus, both passive and reader-initiated processes strongly depend on the mental representation that the reader has gradually built up over the course of reading the prior text segments. The products of the combined passive and reader-initiated processes, in turn, update this very same representation. This updated representation forms the backdrop for the processing of the next text segment, and so on. Ultimately, this leads to a mental representation of the text as a whole. Thus, passive and reader-initiated processes and the evolving representation engage in continual, intricate interaction as the reader moves through the text. With each step, passive and reader-initiated processes occur in constantly changing combinations, influenced by the textual input, the reader's standards of coherence, and the contents and nature of the memory representations of the text and of background knowledge.

The framework is intended as a step toward building a complete model of online processes involved in reading comprehension. It is based on findings and models of components from various labs and researchers, but it also raises issues that have not yet or only sparsely been investigated. These issues comprise an agenda for future research. We discuss a few of such issues.

In this article—and in most research on comprehension processes—the focus is on comprehension processes *during initial reading*. Comprehension processes may also occur *after* a text has been read and these processes would further change the memory representation of the text. For example, readers may give (portions of) the text a second reading, take time to reflect on their understanding of the text, retell and thereby reprocess, and so on. These after-reading processes are similar to online process at the relatively weakly text-constrained end of the spectrum of reader-initiated processes. Readers do not always engage in such after-reading processes, and the processes themselves are likely to vary widely. Therefore, they may be more intractable than those that occur during reading. Nevertheless, they are part of reading comprehension and hence of theoretical interest. They also are of considerable educational interest because these processes are likely to result in comprehension ability differences and to be important targets for intervention and because they may be integral part of "deep" comprehension (Best, Rowe, Ozuru, & McNamara, 2005; Fisher & Frey, 2012).

An open question is whether passive and reader-initiated processes take place consecutively or in parallel. One possibility is that passive processes start and run to completion before reader-initiated processes commence. Another (in our eyes more likely) possibility is that reader-initiated processes start before the passive processes have run to completion. Within this second possibility, one can conceive the two sets of processes to start at (nearly) the same time or the onset of reader-initiated processes to be after a critical amount of passive processes have taken place (and provide input to the reader-initiated processes). In either case, a question is whether both run to completion or whether they engage in a horse race, with both types of processes to stop as soon as one set of processes has resulted in attainment of the reader's standards of coherence. A related question is whether information activated through reader-initiated processes triggers new waves of passive processes, for example, because the activated information initiates its own spread of activation. Answering these questions involves detailed modeling and investigation of the relation between passive and

reader-initiated processes (e.g., issues concerning validation; Isberner & Richter, 2014; O'Brien & Cook, 2016; Singer, 2013).

There is a considerable amount of empirical evidence that after reading has completed, proficient readers are sensitive to the structural role of elements in the mental representation of the text. There also is some evidence that readers show such sensitivity during the reading process itself as well. For instance, the results by Lorch and colleagues referred to above (Lorch et al., 1985, 1987) and those of the eye-tracking studies described above show that readers pay more attention to information that is central to the semantic structure of the text during reading relative to information that is not central. It is unknown what the mechanisms and content of this extra attentional processing are. Results from an ongoing series of ERP-studies examining word-level sensitivity to a central theme during reading of short passages suggest that mental representation updating is facilitated when a word is related to a central theme compared with when it is not. Interestingly, this effect appears only at words at the end of a sentence; there seems to be no effect of centrality on processing of words at the beginning of a sentence (Helder, Stafura, Calloway, van den Broek, & Perfetti, 2015). In general, sensitivity to structural centrality is likely to be a fruitful topic of future research.

Understanding the nature and mechanisms of comprehension processes during reading and how they interact with the evolving mental representation of the text is essential for comprehensive theoretical models of reading comprehension. In this article we have focused on reading comprehension processes in proficient adult readers. Several aspects of these processes are likely to show individual and developmental differences. Differences are likely, for example, in the toolbox of reader-initiated processes, particularly at the far-from-the-text, interpretive end of the range; in standards of coherence and the ability to monitor/apply them; in background knowledge; and in sensitivity to structural centrality. The framework presented in this article provides a foundation for capturing such individual and developmental differences in reading-comprehension ability and, by giving insight in the processes that underlie success and failure in comprehension, for educational applications ranging from the design of interventions to the development of diagnostic tools.

Acknowledgment

We thank Dr. Robert F. Lorch, Jr. and an anonymous reviewer for their insightful comments on the framework presented in this article.

References

Afflerbach, P., Pearson, P., & Paris, S. (2008). Skills and strategies: Their differences, their relationships, and why it matters. In K. Mokhtari & R. Sheorey (Eds.), *Reading strategies of first- and second-language learners: See how they read* (pp. 11–24). Norwood, MA: Christopher Gordon.

Albrecht, J. E., & O'Brien, E. J. (1993). Updating a mental model: Maintaining both local and global coherence. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 1061–1070.

Anderson, J. R. (1983). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior*, *22*, 261–295.

Best, R. M., Rowe, M., Ozuru, Y., & McNamara, D. S. (2005). Deep-level comprehension of science texts: The role of the reader and the text. *Topics in Language Disorders*, *25*, 65–83.

Black, J. B., & Bower, G. H. (1980). Story understanding as problem-solving. *Poetics*, *9*, 223–250.

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J. F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist*, *46*, 48–70.

Duke, N. K., & Pearson, P. (2002). Effective practices for developing reading comprehension. In A. E. Farstrup & S. J. Samuels (Eds.), *What research has to say about reading instruction* (pp. 205–242). Newark, DE: International Reading Association.

Fisher, D., & Frey, N. (2012). Close reading in elementary schools. *The Reading Teacher*, *66*, 179–188.

Gerrig, R. J., & O'Brien, E. J. (2005). The scope of memory-based processing. *Discourse Processes*, *39*, 225–242.

Goldman, S. R., McCarthy, K. S., & Burkett, C. (2015). Interpretive inferences in literature. In E. J. O'Brien, A. E. Cook, & R. F. Lorch (Eds.), *Inferences during reading* (pp. 386–415). Cambridge, UK: Cambridge University Press.

Goldman, S. R., & Varma, S. (1995). CAPping the construction-integration model of discourse comprehension. In C. A. Weaver, S. Mannes, & C. R. Fletcher (Eds.), *Discourse comprehension: Essays in honor of Walter Kintsch* (pp. 337–358). Hillsdale, NJ: Lawrence Erlbaum.

Graesser, A. C., & Clark, L. F. (1985). *Structures and procedures of implicit knowledge*. Norwood, NJ: Ablex

Graesser, A., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative comprehension. *Psychological Review*, *101*, 371–395.

Helder, A., Stafura, J. Z., Calloway, R., van den Broek, P., & Perfetti, C. A. (2015, July). Centrality effects on word-to-text-integration during reading: An ERP study. Presentation at the annual meeting of the Society for Text and Discourse, Minneapolis, MN.

Helder, A., Van Leijenhorst, L., & van den Broek, P. (2016). Coherence monitoring by good and poor comprehenders in elementary school: Comparing offline and online measures. *Learning and Individual Differences*, *48*, 17–23.

Isberner, M.-B., & Richter, T. (2014). Comprehension and validation: Separable stages of information processing? A case for epistemic monitoring in language comprehension. In D. N. Rapp & J. Braasch (Eds.), *Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences*. (pp. 245–276). Boston, MA: MIT Press.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction- integration model. *Psychological Review*, *95*, 163–182.

Kintsch, W., & Van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological Review*, *85*, 363.

Kim, O., Kendeou, P., van den Broek, P., White, M.J., & Kremer, K. (2008). Cat, rat, and Rugrats: Narrative comprehension in young children with Down syndrome. *Journal of Developmental and Physical Disabilities*, *20*, 337–351.

LaBerge, D., & Samuels, S. J. (1974). Toward a theory of automatic information process in reading. *Cognitive Psychology*, *6*, 293–323.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review*, *104*, 211–240.

Landauer, T. K., Foltz, P., & Laham, D. (1998). An introduction to latent semantic analysis. *Discourse Processes*, *25*, 259–284.

Linderholm, T., & van den Broek, P. (2002). The effects of reading purpose and working memory capacity on the processing of expository text. *Journal of Educational Psychology*, *94*, 778–784.

Long, D. L., & Lea, R. B. (2005). Have we been searching for meaning in all the wrong places? Defining the "search after meaning" principle in comprehension. *Discourse Processes*, *39*, 279–298.

Lorch, R. F., & Lorch, E. P. (1985). Topic structure representation and text recall. *Journal of Educational Psychology*, *77*, 137–148.

Lorch, R. F., Lorch, E. P., & Matthews, P. D. (1985). On-line processing of the topic structure of a text. *Journal of Memory and Language*, *24*, 350–362.

Lorch, R. F., Lorch, E. P., & Mogan, A. M. (1987). Effects of reading task on on-line processing of a text's topic structure. *Discourse Processes*, *10*, 63–80.

Lynch, J. S., van den Broek, P., Kremer, K. E., Kendeou, P., White, M. J., & Lorch, E. P. (2008). The development of narrative comprehension and its relation to other early reading skills. *Reading Psychology*, *29*, 327–365.

McCrudden, M., T., Magliano, J.P., & Schraw, G. (2011). Toward an integrated view of relevance in text comprehension. In M.T. McCrudden, J.P. Magliano, & G. Schraw (Eds), *Text relevance and learning from text* (pp. 395–414). Charlotte, NC: Information Age.

McKoon, G., & Ratcliff, R. (1992). Inference during reading. *Psychological Review*, *99*, 440–466.

McNamara, D. S. (2004). SERT: Self-explanation reading training. *Discourse Processes*, *38*, 1–30.

McNamara, D. S., & Magliano, J. (2009). Toward a comprehensive model of comprehension. In B. Ross (Ed.), *The psychology of learning and motivation* (pp. 297–384). New York, NY: Elsevier.

Meyer, B. J., & Freedle, R. O. (1984). Effects of discourse type on recall. *American Educational Research Journal*, *21*, 121–143.

Miller, A. C., & Keenan, J. M. (2009). How word decoding skill impacts text memory: The centrality deficit and how domain knowledge can compensate. *Annals of Dyslexia*, 59, 99–113.

Myers, J. L., & O'Brien, E. J. (1998). Accessing the discourse representation during reading.*Discourse Processes*, *26*, 131–157.

Narvaez, D., van den Broek, P., & Ruiz, A. B. (1999). The influence of reading purpose on inference generation and comprehension in reading. *Journal of Educational Psychology*, *91*, 488–496.

O'Brien, E. J., & Cook, A. E. (2016). Coherence threshold and the continuity of processing: The RI-Val model of comprehension. *Discourse Processes 53*, 326–338.

O'Brien, E. J., Cook, A. E., & Lorch, R. F. (Eds). (2015). *Inferences during reading*. Cambridge UK: Cambridge University Press.

O'Brien, E. J., & Myers, J. L. (1987). The role of causal connections in the retrieval of text. *Memory & Cognition*, *15*, 419–427.
O'Brien, E. J., & Myers, J. L. (1999). Text comprehension: A view from the bottom-up. In S. R. Goldman, A. C. Graesser, & P. van den Broek (Eds.), *Narrative comprehension, causality, and coherence: Essays in honor of Tom Trabasso* (pp. 35–53). Mahwah, NJ: Lawrence Erlbaum.
O'Brien, E. J., Rizzella, M. L., Albrecht, J. E., & Halleran, J. G. (1998). Updating a situation model: A memory-based text processing view. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 1200–1210.
Omanson, R. C. (1982). An analysis of narratives: Identifying central, supportive, and distracting content. *Discourse Processes*, *5*, 195–224.
Pearson, P. D., Roehler, L., Dole, J., & Duffy, G. (1992). Developing expertise in reading comprehension. In S. J. Samuels & A. E. Farstrup (Eds.), *What research says to the teacher* (pp. 145–199). Newark DE: International Reading Association.
Perfetti, C., & Stafura, J. (2015). Comprehending implicit meanings in text without making inferences. In E. J. O'Brien, A. Cook, & R. F. Lorch (Eds.), *Inferences during reading* (pp. 1–18). Cambridge UK: Cambridge University Press.
Pressley, M., & Wharton-McDonald, R. (1997). Skilled comprehension and its development through instruction. *School Psychology Review*, *26*, 448–467
Rapp, D. N., & van den Broek, P. (2005). Dynamic text comprehension: An integrative view of reading. *Current Directions in Psychological Science*, *14*, 276–279.
Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review*, *95*, 385–408.
Rouet, J.-F. (2006). *The skills of document use: From text comprehension to Web-based learning*. Mahwah, NJ: Lawrence Erlbaum.
Seifert, C. M., Abelson, R. P.., McKoon, G. (1986). The role of thematic knowledge structures in reminding. In J. A. Galambos, R. P. Abelson, & J. B. Black (Eds), *Knowledge structures* (pp. 185–210). Hillsdale, NJ: Erlbaum.
Singer, M. (2013). Validation in reading comprehension. *Current Directions in Psychological Science*, *22*, 361–366.
Singer, M., Graesser, A., & Trabasso, T. (1994). Minimal or global inference during reading. *Journal of Memory and Language*, *33*, 421–441.
Trabasso, T., Secco, T., & van den Broek, P. W. (1984). Causal cohesion and story coherence. In H. Mandl, N. L. Stein, & T. Trabasso (Eds.), *Learning and comprehension of text* (pp. 83–111). Hillsdale, NJ: Lawrence Erlbaum.
Trabasso, T., & van den Broek, P. W. (1985). Causal thinking and the representation of narrative events. *Journal of Memory and Language*, *24*, 612–630.
Trabasso, T., van den Broek, P., & Suh, S. Y. (1989). Logical necessity and transitivity of causal relations in stories. *Discourse Processes*, *12*, 1–25.
Tzeng, Y., van den Broek, P., Kendeou, P., & Lee, C. (2005). The computational implementation of the Landscape Model: Modeling inferential processes and memory representations of text comprehension. *Behavioral Research Methods, Instruments & Computers*, *37*, 277–286.
van den Broek, P. (1988). The effects of causal relations and hierarchical position on the importance of story statements. *Journal of Memory and Language*, *27*, 1–22.
van den Broek, P. (1994). Comprehension and memory of narrative texts: Inferences and coherence. In M. A. Gernsbacher (Ed.), *Handbook of Psycholinguistics* (pp. 539–588): New York, NY: Academic Press.
van den Broek, P. (2010). Using texts in science education: Cognitive processes and knowledge representation. *Science*, *328*(5977), 453–456. doi: 10.1126/science.1182594
van den Broek, P., Beker, K., & Oudega, M. (2015). Inference generation in text comprehension: Automatic and strategic processes in the construction of a mental representation. In E. J. O'Brien, A. E. Cook, & R. F. Lorch (Eds.), *Inferences during reading* (pp. 94–121). Cambridge, UK: Cambridge University Press.
van den Broek, P., Bohn-Gettler, C., Kendeou, P., Carlson, S., & White, M. J. (2011). When a reader meets a text: The role of standards of coherence in reading comprehension. In M. T. McCrudden, J. P. Magliano, & G. Schraw (Eds.), *Text relevance and learning from text* (pp. 123–139). Greenwich, CT: Information Age.
van den Broek, P., & Gustafson, M. (1999). Comprehension and memory for texts: Three generations of research. In S. R. Goldman, A. C. Graesser, & P. van den Broek (Eds.), *Narrative comprehension, causality, and coherence: Essays in honor of Tom Trabasso* (pp. 15–34). Mahwah, NJ: Lawrence Erlbaum.
van den Broek, P. W., Helder, A., & Van Leijenhorst, L. (2013). Sensitivity to structural centrality: Developmental and individual differences in reading comprehension skills. In M. A. Britt, S. R. Goldman, & J-F Rouet (Eds), *Reading: From words to multiple texts* (pp. 132–146). New York: Routledge, Taylor & Francis.
van den Broek, P., Lorch, R. F., Linderholm, T., & Gustafson, M. (2001). The effects of readers' goals on inference generation and memory for texts. *Memory & Cognition*, *29*, 1081–1087.
van den Broek, P., Rapp, D. N., & Kendeou, P. (2005). Integrating memory-based and constructionist processes in accounts of reading comprehension. *Discourse Processes*, *39*, 299–316.
van den Broek, P., Risden, K., & Husebye-Hartmann, E. (1995). The role of readers' standards for coherence in the generation of inferences during reading. In R. F. Lorch Jr., & E. J. O'Brien (Eds.), *Sources of coherence in reading* (pp. 353–373). Hillsdale, NJ: Lawrence Erlbaum.

van den Broek, P., & Trabasso, T. (1986). Causal networks versus goal hierarchies in summarizing text. *Discourse Processes*, *9*, 1–15.

van den Broek, P., Young, M., Tzeng, Y., & Linderholm, T. (1999). The landscape model of reading. In H. van Oostendorp & S. R. Goldman (Eds.), *The construction of mental representations during reading* (pp. 71–98). Mahwah, NJ: Lawrence Erlbaum.

Wassenburg, S. I., Beker, K., van den Broek, P., & Van der Schoot, M. (2015). Children's comprehension monitoring of multiple situational dimensions of a narrative. *Reading and Writing: An Interdisciplinary Journal*, *28*, 1203–1232.

Wolman, C., van den Broek, P., & Lorch, R. F. (1997). Effects of causal structure on immediate and delayed story recall by children with mild mental retardation, children with learning disabilities, and children without disabilities. *Journal of Special Education*, *30*, 439–455.

Yeari, M., Oudega, M., & van den Broek, P. (2016). The effect of text highlighting on online processing, memory, and comprehension of central and peripheral information: Evidence from eye-movements. *Journal of Research in Reading*. doi: 10.1111/1467-9817.12072

Yeari, M., & van den Broek, P. (2015). The role of textual semantic constraints in knowledge-based inference generation during reading comprehension: A computational approach. *Memory*, *23*, 1193–1214.

Yeari, M., & van den Broek, P. (2016). A computational modeling of semantic knowledge in reading comprehension: Integrating the landscape model with latent semantic analysis. *Behavior Research Method*, *48*, 880–896.

Yeari, M., van den Broek, P., & Oudega, M. (2015). Processing and memory of central versus peripheral information as a function of reading goals: Evidence from eye-movements. *Reading and Writing*, *28*, 1071–1097.

Zabrucky, K., & Ratner, H. H. (1992). Effects of passage type on comprehension monitoring and recall in good and poor readers. *Journal of Reading Behavior*, *24*, 373–391.

Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The construction of situation models in narrative comprehension: An event-indexing model. *Psychological Science*, *6*, 292–297.