Monitoring the coherence of texts : coherence-break detection across development

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Summary and general discussion

The central aim of this dissertation is to examine coherence-monitoring processes and, more specifically, the cognitive processes related to the detection of coherence breaks during reading in children, adolescents, and young adults. Overall, results of the studies reported in this thesis show that good and poor comprehenders as young as 8 years of age are capable of detecting coherence breaks during reading of short narratives. However, results also indicate that when demands on readers' cognitive resources increase, such as when the amount of information intervening contradictory pieces of information increases, then coherence-monitoring processes show age-related improvement into adolescence.

If all goes well, a reader maintains coherence during reading. The cognitive processes related to maintaining coherence in which a reader engages during reading result in the construction of a coherent mental representation of a text. This is one of the most important skills that has to be mastered over the course of development. These cognitive processes include the ability to notice when coherence is disrupted. If a break in coherence is detected during reading, the reader has the opportunity to regulate his/her reading behavior to restore coherence, such as through rereading parts of the text, applying background knowledge, or otherwise trying to resolve the inconsistency. However, if coherence breaks are not noticed during reading of a text, there is also no opportunity for the reader to regulate his/her reading behavior. As a consequence, the mental representation that the reader constructs during reading is likely to lack coherence and, thus, comprehension of the text is limited.

To understand how readers comprehend written text, it is essential to gain insight into the cognitive processes related to building coherence as they occur during reading, because they determine what is encoded into their mental representation of the text. Consideration of these processes during reading is not only important for theoretical models of reading comprehension and coherence monitoring but also for educational practice. With regard to theoretical implications, insight into differences in processing of coherence breaks across development, as well as between good and poor comprehenders, would deepen our understanding of developmental and individual differences in reading comprehension. With regard to practical implications, knowledge on the cognitive processes and mechanisms underlying successful reading comprehension would allow one to improve educational methods or develop targeted interventions.

In this thesis, coherence-break detection was examined by using an adaptation of the contradiction paradigm developed by O'Brien and colleagues (e.g., Albrecht & O'Brien, 1993; Cook, Halleran, & O'Brien, 1998; Long & Chong, 2001; Myers, O'Brien, Albrecht, & Mason, 2004; O'Brien, Rizzella, Albrecht, & Halleran, 1998). The contradiction paradigm is a powerful tool that allows the investigation of coherence-break detection

during reading. In the contradiction paradigm, participants are presented with short narratives that in some of the trials contain a break in coherence. In trials without a coherence break, the target sentence is consistent with information presented in the second sentence. In trials with a coherence break, the same target sentence semantically contradicts prior information presented in the second sentence. In these incoherent trials, prior text information from the second sentence is available in the reader's working memory at the moment the coherence break is encountered during reading of the target sentence, and coherence is disrupted. Detection of this coherence break is reflected in longer reading times for incoherent target sentences compared to coherent target sentences. Thus, coherence-breaks can only be detected if prior text information is available at the moment the potentially contradictory information is encountered.

This discussion chapter consists of three parts. First, main findings of each of the studies are described and integrated. **Chapter 2** concerns a behavioral study in which we examined good- and poor comprehenders' coherence-monitoring ability at ages 8-9 and 10-11 by measuring coherence-break detection offline and online. **Chapter 3** concerns a behavioral study that builds on the study described in chapter 2 in which we examined the protracted development of coherence monitoring in an adolescent population (ages 10-22) using the same task under more challenging circumstances, i.e., we manipulated the textual distance between contradictory pieces of information. **Chapter 4** concerns a neuroimaging study in which we explored the neural correlates of coherence-break detection, using the same experimental materials as described in chapter 2 in young adults. Second, the preliminary results of ongoing research are briefly outlined and discussed. Third, **chapter 5** discusses possible mechanisms underlying coherence-break detection from a broader perspective by giving a theoretical account of cognitive factors and processes involved in reading comprehension

6.1 Main findings

The aims of the study described in **chapter 2** were to investigate coherence-monitoring skills in 8-9 and 10-11-year-old primary-school students with either good or poor reading comprehension ability and to determine, for each age group, whether potential difficulties that primary-school students experience originate in difficulties detecting coherence breaks during reading (online) or in subsequent encoding of these detected coherence breaks after reading (offline). The online results indicate that readers in all age and ability groups detected coherence breaks during reading, as evidenced by a significant slowing down when reading incoherent target sentences, suggesting no developmental change. However, the offline results show that the ability to correctly judge whether there was a break in coherence improves with age: 10-11-year-old

readers outperformed 8-9-year-old readers. Furthermore, within each age group readers with poor comprehension skills were less able to correctly judge whether there was a break in coherence than were readers with good comprehension skills. Together, these findings indicate that difficulties that younger and, within each age group, poor comprehenders experience in reporting coherence breaks from the texts they read are likely to originate in the processing *after* the phase of initial coherence-break detection.

It is possible that the demands of this specific task used in the experiment described in chapter 2 had an influence on how participants approached the task for two reasons. First, all narratives had the same structure; in incoherent narratives contradictory information was separated by three filler sentences and participants encountered a break in coherence that was always presented in the sixth and final sentence. Second, participants were asked explicitly to judge whether each narrative made sense or not. Both the position of the target sentence and the explicit consistency question could have influenced participants' task approach; they may have been expecting to encounter a coherence break at the end of a narrative and thus specifically focused on detecting coherence breaks, an approach that differs from reading for comprehension as they would in a reading situation in daily life. Thus, although the experimental task used in chapter 2 suited the research aims of that specific study, in that it allowed us to measure both online and offline coherence-break detection, it may have influenced participants' coherence-monitoring processes. This reasoning led to the design of a second behavioral study (chapter 3) as well as an fMRI study (chapter 4) to further examine the development of coherence-monitoring processes.

Chapter 3 presents the results of a second behavioral study in which we varied the textual distance between contradictory pieces of information without asking explicitly whether a break in coherence was noticed during reading. Based on the results from the first behavioral study indicating that students at ages 8-11 are able to detect coherence breaks during reading when contradictory pieces of information were separated by three filler sentences, we examined the potential influence of an increase in textual distance between contradictory pieces of information on processes related to coherence-break detection during reading. We predicted that increasing this distance would put a greater burden on readers' cognitive resources, and could reveal age-related changes in coherence-monitoring processes in a slightly older population. Results from studies outside the field of reading comprehension show that cognitive-control processes related to coherence monitoring, such as working memory, inhibition of irrelevant information, and allocation of attention continue to develop well into adolescence (Diamond, 2013; Huizinga, Dolan, & van der Molen, 2006; Luna, Garver, Urban, Lazar, & Sweeney, 2004). The continued development of cognitive-control processes during adolescence is taken to suggest that coherence-monitoring processes also continue to

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develop during adolescence. Therefore, we examined younger (ages 10-14) and older (ages 16-22) adolescents. In addition, we omitted the explicit coherence judgment following each narrative, to obtain a more spontaneous measure of coherence-break detection during reading. Results described in chapter 3 show that both younger and older adolescents are able to detect coherence breaks during reading, as evidenced by longer reading times for target sentences in incoherent narratives compared to reading times for the same target sentences in coherent narratives. However, results indicate that the likelihood that prior context information is available when reading target information and, thus, that a coherence break can be detected, decreases when textual distance increases in younger adolescents, but not in older adolescents. This suggests that coherence-monitoring processes, such as those related to coherence-break detection, are still developing during the first half of adolescence and, in the context of this specific experimental task, are relatively mature in the second half of adolescence.

The notion that cognitive-control processes continue to develop well into adolescence, together with the increased demands on adolescents' coherence-monitoring ability, point to the importance of investigating factors related to availability of information in a reader's working memory in an adolescent population and, more specifically, in the second half of adolescence. One factor that influences the availability of information is the textual distance (chapter 3). However, texts in school are typically longer than the narratives used in this study. With longer texts, other factors that influence the availability of information may come into play. For example, proficient readers have shown to be sensitive to the causal structure of a text and are likely to have a stronger representation of information related to the gist of the text, than of information related to details (e.g., O'Brien & Myers, 1987; Trabasso & van den Broek, 1985). I would expect that coherence would be more likely to be disrupted when contradictory information is important to the causal structure of the text than when it is not (or less) important. Because sensitivity to structural centrality increases with age (for a review see van den Broek, Helder, & Van Leijenhorst, 2013), it is likely that the degree to which information is central to the structure of the text influences readers' developing coherence-monitoring processes as well. To fully understand the development of processes related to coherence monitoring, future studies could take these and other factors into account.

In the fMRI study described in **chapter 4**, with the aim to explore the neural correlates of coherence-break detection, the potential limitations of using an explicit coherence-break detection task were in fact beneficial. On the one hand, presenting the target sentence at the end of the narrative allowed us to estimate participant's full BOLD-response to a break in coherence. On the other hand, the explicit measure of coherence-break detection served as an indicator of whether participants were

engaging in cognitive processes related to coherence-break detection while their brain responses were collected. It is possible that the behavioral measure of coherence-break detection (reading times for incoherent vs coherent target sentences) used in this thesis is not sensitive enough to pick up potentially subtle developmental, as well as individual differences between readers. Although there is a rich behavioral literature on the cognitive processes related to reading comprehension, the neural correlates of these cognitive processes are still poorly understood. However, insight into the brain mechanisms underlying cognitive processes has the potential to inform cognitive models on reading comprehension by providing additional information to what is known from behavioral measures alone. Similarly, it can inform models of brain functioning during comprehension of texts. To gain insight into the brain regions involved in coherence monitoring, as well as to lay a solid foundation for a larger, developmental study, we investigated young adults' (ages 19-27) neural responses to the detection of coherence breaks during reading of narratives while obtaining a behavioral measure of coherence-break detection during (online), as well as after reading (offline).

The online behavioral results showed increased reading times for incoherent compared to coherent target sentences, indicating that participants engaged in cognitive processes related to detecting breaks in coherence. This was confirmed by the offline behavioral results; accuracy on the explicit consistency question was high.

The imaging results indicate that a large network of cortical regions –including the dorsomedial prefrontal cortex, precuneus, right temporal pole, left inferior frontal gyrus, right supramarginal gyrus and left inferior and bilateral middle temporal gyri, as well as subcortical regions including the left amygdala, left hippocampus and bilateral caudate– was involved in coherence-break detection. In this network, brain activation in response to incoherent target sentences was increased relative to coherent target sentences. Whereas most regions were active in response to both incoherent and coherent information, the dorsomedial prefrontal cortex, precuneus, hippocampus and amygdala were uniquely responsive to incoherent target sentences. Moreover, the slow event-related design of our study allowed us to speculate on the possible roles of these brain regions, based on the results from our ROI analyses. The time course of neural activation in response to a coherence break suggests relatively early activation of subcortical regions in the temporal lobe in response to an incoherent target sentence that may reflect early re-activation of prior text information and/or background knowledge (Frankland & Bontempi, 2005) as well as an alerting response to noticing when something does not make sense (Phelps & Ledoux, 2005), such as when detecting a break in coherence. A relatively late peak in the BOLD response was observed in cortical regions such as the dorsomedial prefrontal cortex and the precuneus, which may reflect coherence-building processes (Ferstl, Rinck, & von Cramon, 2005; Ferstl, Neumann, Bogler, von Cramon, 2008; Whitney et al., 2009).

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Our imaging findings contribute to our knowledge on the functional contributions of these regions in relation to coherence-monitoring processes during reading. For example, our results show that the network of brain regions involved in reading incoherent target sentences largely overlaps with the network of brain regions involved in reading coherent target sentences. This suggests that the cognitive processes underlying reading incoherent and coherent target sentences are similar but that those cognitive processes are recruited more when reading incoherent target sentences. However, whereas some regions appear uniquely related to the processing of incoherent information, there were no regions uniquely related to the processing of coherent target sentences. The time course of neural activation in those brain regions specifically involved in reading incoherent target sentences suggest a distinction between detection and subsequent coherence-building processes. Given the relatively poor temporal resolution of fMRI, future studies using techniques with better temporal resolution such as EEG or MEG could further explore the temporal order of cognitive processes involved in the construction of coherent mental representations from narrative texts.

Together, results from the studies described in this thesis indicate that readers as young as 8 years of age –and at various levels of comprehension ability–, as well as adolescents and adults, are able to detect coherence breaks during the reading of short narratives. Thus, at a first glance, it appears that coherence-monitoring ability does not develop with age. However, there are two indications that coherence-break detection in fact does undergo protracted development. First, the encoding of coherence breaks into the reader's mental representation *after* reading improves with age: younger reader (ages 8-9) are less able to report coherence breaks than older readers (ages 10-11). Other studies have shown that performance on offline measures of coherence-break detection continues to increase into adolescence (e.g., Barth et al., 2015; Hacker, 1997). Second, when the demands on a reader's cognitive resources are increased when reading texts, measures of coherence-break detection processes indicate developmental change at least throughout the first half of adolescence. Although the results from the study with adolescent readers could be taken to suggest that older adolescents perform at an adult level and coherence-break detection processes are fully developed in the second half of adolescence, we are hesitant to draw this conclusion. Rather, it is conceivable that under more challenging circumstances, for example when using more complex texts, even older adolescents' and adults' ability to detect coherence breaks during reading may be affected. Further investigation of differences in the processing of coherence breaks across development, as well as between good and poor comprehenders, would deepen our understanding of developmental and individual differences in comprehension skill and support the development of interventions targeted specifically at the processes that distinguish such differences between readers.

In **chapter 5** I present a theoretical account of developmental and individual differences in cognitive processes related to reading comprehension. This content of this chapter serves as a framework to provide several suggestions on what the underlying processes and factors to the development of coherence-monitoring might entail and are provided in section 6.3. Before turning to that chapter, I briefly outline two studies currently ongoing, which may shed light on some of the open questions.

6.2 Ongoing research

Based on the results presented in this thesis, there are several open questions. Two of these open questions have been translated into follow-up research questions and data have been collected. The preliminary results of these ongoing studies will be reviewed in this section.

Explicit vs implicit coherence-break detection

As mentioned above, there is a possibility that the explicit question of whether the narrative made sense or not following each narrative, such as described in chapter 2 and chapter 4, influenced participant's task approach by prompting them to use a strategy of searching for coherence breaks, rather than reading for comprehension as they would normally do. To examine the influences of this specific task demand we combined the methods used in the two behavioral studies described in chapter 2 and 3 in a third behavioral study (Helder, Van Leijenhorst, & van den Broek, in preparation). Readers at ages 10-11 were assigned to either an explicit (with a yes/no coherence judgment and a yes/no comprehension question following each story) or an implicit coherence-break detection task (with a yes/no comprehension question only). In addition, textual distance was varied across experimental narratives. Preliminary results show that the explicit coherence judgment had an effect on participants' online coherence-break detection: in the explicit task, textual distance between pieces of contradictory information did not influence the likelihood that coherence breaks were detected during reading, whereas in the implicit task, when participants were not explicitly asked to judge a narrative's coherence, the likelihood that coherence breaks were detected during reading did decrease as a function of textual distance. Thus, the preliminary results suggest that the explicit question of whether each narrative makes sense or not had an influence on how readers at ages 10-11 approached the task. This suggests that readers are more likely to detect coherence breaks during reading when they are explicitly asked to do so compared to when they are not. This may imply that asking questions during reading helps readers to monitor the coherence of their mental representation of a text successfully.

Neural correlates of coherence-break detection: children vs adults

The reasoning on the influence of participants' task approach could also be applied to interpret the preliminary results of an fMRI study in which our goal was to compare the neural correlates of coherence-break detection of children (ages 9-12) with those of adults (ages 19-27) (Van Leijenhorst, Helder, Karlsson, & van den Broek, 2014), using the same materials as described in chapter 2 and 4. Behavioral results mirror the general findings as described in this thesis: after reading, children have more difficulties to report coherence breaks than young adults although overall accuracy was high. During reading, both children and adults detect coherence breaks: children as well as adults were slower to read incoherent target sentences compared to coherent target sentences. Imaging results show that coherence-break detection processes were associated with a large bilateral network of brain regions that was similar for children and adults, suggesting that this network is adult-like in 9-12-year-old children. However, brain activation associated with overall reading of target sentences *did* differ between age-groups: During reading of target sentences adults recruited a network associated with cognitive control (right inferior parietal lobe, middle frontal gyrus (DLPFC), precuneus) (Diamond, 2013; Duncan, 2010; Niendam et al., 2012) more than children did (Van Leijenhorst, Helder et al., 2014).

Following the logic of the possible influence of how participants approached the task described in the previous paragraph, these findings could be taken to suggest that adults approached the task differently than children did. Specifically, adults may have been expecting to encounter a break in coherence when reading the target sentence and, therefore, may have recruited brain regions related to cognitive-control processes, whereas children may have adopted another task approach, for example, by judging the coherence of the story at the moment when they were explicitly asked (after reading).

Although we cannot draw firm conclusions based on these preliminary results, insight into developmental differences with regard to the recruitment of brain regions involved in higher-order processes related to reading comprehension, such as coherence-break detection, has the potential to provide additional information to what we know from behavioral measures alone. This study serves as a first step and shows that although there seem to be no age-related differences on the behavioral measure of coherence-break detection during reading, children and adults do differ on the recruitment of brain regions during reading of target sentences.

6.3 Cognitive factors and processes related to the construction of a coherent mental representation

The findings outlined in this thesis raise the question of what the underlying cognitive processes to coherence-break detection are and how they relate to the development of the ability to monitor the coherence of an emerging mental representation of a text, an essential component of successful reading comprehension. The results presented in this thesis contribute to our knowledge of coherence-monitoring processes across development. We have examined various conditions under which readers at different ages detect coherence breaks during reading, including whether initial coherence-break detection during reading resulted in explicit recognition of such coherence breaks after reading. The imaging results show that many brain regions are involved in coherence-break detection and suggest that coherence monitoring, an essential component of the complex ability to understand texts, itself is composed of multiple processes. The studies presented in this thesis have tried to shed light on the cognitive processes underlying the construction of a coherent mental representation and, more specifically, to shed light on the cognitive processes underlying the detection of coherence breaks. I am aware of the fact that, based on the results of the current studies, it is not possible to give a conclusive answer to the question of what the cognitive processes underlying the construction of a coherent mental representation, and, more specifically, underlying the detection of coherence breaks are. However, insights from recent theoretical and experimental investigations of possible stages in the processing of incoming information, for example concerning activation, integration and validation processes to construct coherence during reading in adults (Cook & O'Brien, 2014; Isberner & Richter, 2014a; Singer, 2013), as well as those from studies with children that examined more general cognitive factors and processes related to reading comprehension (for an overview see chapter 5) allow me to speculate on these underlying mechanisms that determine whether readers notice when coherence is disrupted during reading of a text. In **chapter 5** three clusters of cognitive factors and processes involved in reading comprehension (See Table 5.1 at page 72) that have been shown to develop with age and contribute to individual differences between readers are described. These three clusters are used here as a framework to speculate on the underlying mechanisms of coherence-break detection.

First, general cognitive resources such as executive functions, including working memory, and adequate background knowledge allow readers to interact flexibly with texts, to notice coherence breaks in texts, and to repair or resolve them when needed. Even though these general cognitive resources improve with development, difficulties in the representation of coherence breaks that younger or less proficient comprehenders

experience appear to originate in problems in processing them subsequent to detection (Helder et al., 2016). The underlying mechanisms of these developmental differences as well as differences between good and poor comprehenders are not clear. One possibility is that readers differ in the amount of cognitive resources they have available. For instance, there is considerable evidence that working-memory capacity dramatically increases with development (Gathercole, Pickering, Ambridge, & Wearing, 2004; Huizinga et al. 2006; Luna et al., 2004). In addition, differences in working-memory capacity have been related to comprehension difficulties (Cain, 2006; Cain, Oakhill, & Bryant, 2004; Carretti, Cornoldi, De Beni, & Romano, 2005; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Seigneuric & Ehrlich, 2005; Swanson & Berninger, 1995). It could be that readers with a smaller working-memory capacity have relatively little information of prior text available relative to readers with a larger working-memory capacity and, as a consequence, are less likely to notice when coherence is disrupted. Another possible underlying mechanism concerns differences in readers' semantic knowledge about the information in the text and, hence, in the extent to which they recognize a break in coherence. For example, when a reader does not know the meaning of the word Summer and as a consequence fails to infer that there typically is no snow to build a snowman in Summer, he or she will likely not notice the break in coherence. In the context of the studies described in this thesis, it is unlikely that differences in semantic knowledge are the cause of the observed differences in the current studies because the narratives were designed to be age-appropriate for the youngest, 8-year-old participants, and describe common, everyday life events.

Second, coherence-building processes such as those related to inference making allow individuals to construct a mental representation in which the various pieces of information –whether acquired from texts or other forms of discourse such as movies or conversations– are connected to each other as well as to their background knowledge (e.g., Gernsbacher, Varner, & Faust, 1990; Kendeou, Bohn-Gettler, White, & van den Broek, 2008). Inference generation itself is a complex ability that involves processes that vary in the degree to which they are under conscious control of the reader (for a recent overview see O'Brien, Cook, & Lorch, 2015). In the context of coherence-break detection, inferential processes play a role in the sense that incoming information is validated against prior text information, as well as to a reader's background knowledge (Cook & O'Brien, 2014; Isberner & Richter, 2014a; Singer, 2013). Other inferential processes related to coherence-break detection may be executed more strategically (Graesser, Singer, & Trabasso, 1994). For example, a person may actively search his or her background knowledge to restore coherence during reading. Developmental studies on inferences have revealed that children engage in inference generation well before the start of reading education and that both the quantity and quality of the inferences that

readers make increase with development (Lynch et al. 2008; van den Broek, 1997). To detect coherence breaks, it is essential that the to-be connected pieces of information are available to the reader and are connected through inferential processes. Thus, it is likely that a reader's developing inferential skills play a role in the development of coherence-break detection.

Third, readers have strategies and knowledge specific to written material that may play a role in coherence-break detection. For example, readers may use their knowledge of different text genres to guide their comprehension processes; narratives usually follow a more or less standard sequence of events and different narratives often have similar elements, such as settings, initiating events, goals, reactions and outcomes (Mandler & Johnson, 1977; Stein & Glenn, 1979), allowing the reader to use a similar approach across narrative texts. In contrast, expository texts contain more complex relations and come in different formats, and therefore demand more sophisticated and varied reading strategies (Meyer & Freedle, 1984; Meyer & Ray, 2011). With age, readers are increasingly exposed to various text genres and structures and their use of knowledge of text structure increases accordingly (Williams, Hall, & Lauer, 2004; Oakhill & Cain, 2011; Ray & Meyer, 2011). For example, around fourth grade the focus of reading instruction typically shifts from learning to read through narratives to reading to learn through expository texts (e.g., Sweet & Snow, 2003). This may have an effect on coherence-monitoring ability in the sense that the dimension of coherence of a reader's mental representation of texts varies as a function of text genre. For example, a narrative representation can be thought of as a conceptual network of text elements with its connections based on what is causally and referentially inferred by the reader (e.g., Trabasso, Secco, & van den Broek, 1984; van den Broek, Helder, & Van Leijenhorst, 2013), whereas a mental representation of an expository text may be centered around a central problem with solutions, comparisons, or a collection of descriptions (e.g., Meyer & Freedle, 1984). Also specific to written material is the decoding of the visual information (i.e., letters, words) into meaningful units of information. These basic reading processes together with higher-order comprehension processes and skills, such as those outlined in this section, determine a reader's reading comprehension ability (Gough & Tunmer, 1990; Kendeou, White, van den Broek, & Lynch, 2009; Oakhill & Cain, 2011). The relative contribution of basic and higher-order reading processes changes throughout development; as basic reading processes become more automatized with age, more cognitive resources are available for higher-order reading skills and processes (Kendeou, Papadopoulos, & Spanoudis, 2012; Perfetti, 1985; 2007), including monitoring the coherence of texts.

To conclude, all of these factors and processes described in this section and their interactions contribute to reading comprehension ability and differ across reading situations within a reader as well as between readers (van den Broek, Bohn-Gettler,

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Kendeou, Carlson, & White, 2011; van den Broek, Risden, & Husebye-Hartmann, 1995). Therefore, it is unlikely that there is a single process or skill that explains all of the variance of developmental and/or individual differences in reading comprehension ability (Cain & Oakhill, 2006). However, understanding the developmental trajectory of each of these cognitive factors and processes individually contributes to our understanding of both developmental and individual differences in the ability to understand texts. This thesis contributes to this bigger picture of the development of reading comprehension ability by isolating and examining how and whether readers across different ages are engaging in coherence-monitoring processes during reading.