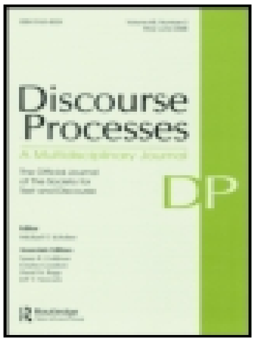

Discourse Processes

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Differentiating Text-Based and Knowledge-Based Validation Processes during Reading: Evidence from Eye Movements

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ABSTRACT

To build a coherent accurate mental representation of a text, readers routinely validate information they read against the preceding text and their background knowledge. It is clear that both sources affect processing, but *when* and *how* they exert their influence remains unclear. To examine the time course and cognitive architecture of text-based and knowledge-based validation processes, we used eye-tracking methodology. Participants read versions of texts that varied systematically in (in)coherence with prior text or background knowledge. Contradictions with respect to prior text and background knowledge both were found to disrupt reading but in different ways: The two types of contradiction led to distinct patterns of processes, and, importantly, these differences were evident already in early processing stages. Moreover, knowledge-based incoherence triggered more pervasive and longer (repair) processes than did text-based incoherence. Finally, processing of text-based and knowledge-based incoherence was not influenced by readers' working memory capacity.

Introduction

Successful comprehension requires readers to build a coherent, meaningful mental representation or situation model of a text (Graesser, Singer, & Trabasso, 1994; van den Broek, 1988; Zwaan & Singer, 2003). An essential aspect of building such mental representation is that readers routinely monitor to what extent incoming information is both coherent and accurate (e.g., Isberner & Richter, 2014; Singer, 2013). Recent theoretical models of epistemic monitoring (Isberner & Richter, 2014) and validation (Richter, 2015; Singer, 2013) suggest that such monitoring consists of evaluative comprehension processes involved in detecting possible inconsistencies and by (optional) epistemic elaboration processes involved in attempting to resolve detected inconsistencies (e.g., Isberner & Richter, 2014; Richter, 2011; Richter, Schroeder, & Wöhrmann, 2009; Schroeder, Richter, & Hoever, 2008). These monitoring processes can be influenced by various sources of information, most notably contextual information (from preceding text) and the reader's background knowledge. Prior behavioral work using self-paced sentence-by-sentence reading paradigms suggests that each of these two sources has a unique influence on monitoring (van Moort, Jolles, Koornneef, & van den Broek, submitted; Van Moort, Koornneef, & Van den Broek, 2018).

Such results highlight the importance of distinguishing between text-based and knowledge-based monitoring processes but do not provide a detailed picture of the constituent processes of validation against each source as reading times aggregate over all such processes. As a result, for example, they cannot distinguish between earlier (e.g., detecting an inconsistency) and later (e.g., repairing an inconsistency)

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validation processes. Also, the self-paced sentence-by-sentence reading task is somewhat unnatural as readers typically are unable to look back in the text (e.g., Hyönä, Lorch, & Kaakinen, 2002). The current study aims to provide a more detailed picture of the component validation processes involved in coherence monitoring by adopting eye-tracking methodology. This method offers high temporal resolution and various indices of processing in a more natural reading situation (as texts are presented in their entirety), allowing us to elucidate when and how processes involved in detecting and resolving inconsistencies are influenced by contextual information and background knowledge, respectively.

Building and validating mental representations of texts

Understanding discourse requires comprehension of individual words and sentences as well as integration across sentences to form a coherent understanding of the discourse as a whole (Perfetti & Frishkoff, 2008). As readers proceed through a text, they continually use various forms of information—for example, semantic (the meaning of words), syntactic (grammatical), and pragmatic (their understanding of the world)—to build an overall representation of the discourse meaning (Johnson-Laird, 1983; Kintsch, 1988). To build a coherent and accurate mental representation, readers validate incoming information against various sources of information, most notably the preceding text and the readers' background knowledge (Isberner & Richter, 2014; Nieuwland & Kuperberg, 2008; O'Brien & Cook, 2016a, 2016b; Schroeder et al., 2008; Singer, Halldorson, Lear, & Andrusiak, 1992). Successful validation is widely considered to be a prerequisite for comprehension accuracy or, more specifically, situational updating (Cook & Myers, 2004; Ferretti, Singer, & Patterson, 2008), but theoretical models differ in how they define the validation process.

For example, the RI–Val model of comprehension (Cook & O'Brien, 2014; O'Brien & Cook, 2016a, 2016b) describes validation as one of three processing stages—resonance, integration, and validation—that comprise comprehension. According to this model, incoming information activates related information from long-term memory via a low-level passive resonance mechanism (Myers & O'Brien, 1998; O'Brien & Myers, 1999). This activated information then is integrated with the contents of working memory. Finally, the initial linkages formed by integration are validated against information in memory that is "readily available" to the reader. Thus, it is validated against information that either already is part of working memory or easily can be made available from long-term memory (e.g., McKoon & Ratcliff, 1995; Myers & O'Brien, 1998; O'Brien & Albrecht, 1992). These contents of active memory includes both portions of the episodic representation of the text (i.e., context) and general world knowledge; therefore, each source has the potential to influence validation at any point during comprehension. The three processes—resonance, integration, and validation—run parallel but their onset is asynchronous: Activation must produce a minimum of two concepts (or ideas) before integration can begin, and integration must produce a minimum of one linkage before validation can begin. Thus, the RI–Val model presents validation as a single, passive pattern-matching process that is part of comprehension and is involved in detecting mismatches between the linkages made during the integration stage and the contents of active memory. RI–Val focuses on the (in)consistency detection component of coherence monitoring rather than on potential (repair) processes triggered by a detected inconsistency.

A second model describes validation as consisting of two components: (1) epistemic monitoring (i.e., detecting inconsistencies) during a comprehension stage, followed by (2) optional epistemic elaboration processes (i.e., attempting to resolve an inconsistency) during an evaluative stage (e.g., Isberner & Richter, 2014; Richter, 2011; Richter et al., 2009; Schroeder et al., 2008). According to this model only the initial detection of inconsistencies (i.e., epistemic monitoring) is a routine part of comprehension. Similar to the RI–Val model, these detection processes are memory-based and carried out routinely and efficiently, that is, they pose little demands on cognitive resources and are not dependent on readers' processing goals (Richter et al., 2009). However, whereas the RI–Val model focuses in detail on the detection component of coherence monitoring, the two-component model focuses on the resources-demanding processes that may be triggered by the detection of the inconsistency in the epistemic monitoring component. Specifically, readers may initiate evaluation processes, including epistemic elaboration or repair processes, in an attempt to resolve an inconsistency. For example, they may doubt the validity of their current mental representation/situation model (e.g., perhaps they misunderstood earlier parts of the text), they may disbelieve the target sentence rather than their situation model (e.g., perhaps the target sentence contains a mistake), or they may try to solve the comprehension problem by elaborating possible solutions to the apparent inconsistency (Hyönä, Lorch, & Rinck, 2003). These processes are optional and only occur when readers are motivated and have enough cognitive resources available, as they are assumed to be slow, resource-demanding, and under at least some strategic control of the reader (Richter, 2015).

These examples illustrate that current theoretical models presume a rudimentary cognitive architecture and time course for validation processes. They generally agree that incoming information is routinely validated against elements of the current situation model or world knowledge during the comprehension stage and that contextual information and background knowledge both have the potential to influence processing (e.g., Cook & Myers, 2004; Kintsch, 1988; O'Brien & Cook, 2016b; Richter, 2011; Richter et al., 2009; Rizzella & O'Brien, 2002; Schroeder et al., 2008; Singer, 2013; van den Broek & Helder, 2017). However, it is unclear when and how contextual information and the readers' background knowledge exert their influence.

General models of discourse comprehension (i.e., without a specific focus on the validation aspect of comprehension) present different viewpoints about the respective influences of context and background knowledge on comprehension. Some accounts presume a fully interactive architecture with contextual information and background knowledge immediately influencing processing (e.g., memory-based text processing view; Cook, Halleran, & O'Brien, 1998; Gerrig & McKoon, 1998; Myers & O'Brien, 1998; O'Brien & Myers, 1999; Rizzella & O'Brien, 2002). Other accounts presume an architecture in which one of the informational sources plays a more dominant (and sometimes earlier) role. In some of these accounts, background knowledge is regarded as the dominant source (i.e., driving comprehension) as incoming information is first connected to general world knowledge and only later integrated in the discourse context (e.g., Garrod & Terras, 2000; Kintsch, 1988; Sanford & Garrod, 1989). In other of these accounts, contextual information is regarded as the dominant source as it can influence language comprehension immediately (e.g., Hess, Foss, & Carroll, 1995; Marslen-Wilson & Tyler, 1980; van Berkum, Hagoort, & Brown, 1999) and can fully override background knowledge (e.g., Nieuwland & Van Berkum, 2006).

Within validation research there are a considerable number of empirical investigations of the effects of contextual information and background knowledge on validation processes (e.g., Albrecht & O'Brien, 1993; Menenti, Petersson, Scheeringa, & Hagoort, 2008; O'Brien & Albrecht, 1992; O'Brien, Cook, & Guéraud, 2010; O'Brien, Cook, & Peracchi, 2004; O'Brien, Rizzella, Albrecht, & Halleran, 1998; Rapp, 2008; Richter et al., 2009). Usually the focus of each investigation is on one source of potential inconsistencies or the other, whereas in reality both sources operate in tandem. With respect to investigations of text-based monitoring detection of within-text incongruencies inevitably depends on background knowledge as well. For example, in paradigms in which targets (e.g., children are building a snowman) presumably are incongruent with preceding context (e.g., it was a hot, sunny day) detection only occurs if readers have certain background knowledge (e.g., snow melts on a hot sunny day). Even blatant incongruencies (e.g., a car is described as solid blue in one sentence but as solid red in the next) require at least a minimal amount of background knowledge (e.g., red and blue are colors and something cannot be solid red and blue at the same time). Thus, although the role of background knowledge is implied because it is essential for detecting the (in)congruency of textual targets it is not explicitly included as a factor. With respect to studies that do include both contextual and world knowledge manipulations, the central question tends to be whether context can override (erroneous) world knowledge, not whether text-based monitoring is an independent process (e.g., Creer, Cook, & O'Brien, 2018; Menenti et al., 2008; Walsh, Cook, & O'Brien, 2018). As a result, it is difficult to distinguish between the respective impacts of textual information and background knowledge and to define possibly unique influences.

To address this issue, Van Moort et al. (2018) contrasted validation against background knowledge and validation against prior text in a single design. Participants read expository texts about well-known historical topics in a self-paced, sentence-by-sentence manner. Each text contained a target sentence that was either true (e.g., the Statue of Liberty was delivered to the United States) or false (e.g., the Statue of Liberty was not delivered to the United States) relative to the reader's background knowledge and that was either supported or called into question by the preceding context (e.g., context that described that the construction of the statue went according to plan vs. context that described problems that occurred during construction of the statue). Results indicated that both prior text and background knowledge influenced readers' moment-by-moment processing on targets, but only inaccuracies with background knowledge elicited spill-over effects. This suggests that both sources of information have unique influences on processing. Furthermore, a recent study used the same reading paradigm while collecting neuroimaging data (functional magnetic resonance imaging) to examine the neural underpinnings of text-based and knowledge-based validation (van Moort et al., submitted). Consistent with Van Moort et al. (2018), the neuroimaging data suggested a "division of labor" for text-based and knowledge-based validation processes. The medial prefrontal cortex seems to be oriented toward knowledge-based processing, whereas the right inferior frontal gyrus is more involved in text-based processing. Interestingly, the precuneus and the left inferior frontal gyrus seem to combine the information provided by a text with the information stored in long-term memory. Taken together, the results from these two studies suggest that both sources impact processing and that text-based and knowledge-based validation processes may involve (partially) different cognitive mechanisms.

Current study

The aim of this study was to provide insight into component validation processes involved in coherence monitoring and into *when* and *how* contextual information and background knowledge influence these processes. Specific questions were whether (parts of) the validation process are more knowledge-driven or text-driven and to what extent text-based and knowledge-based validation processes take place independently or interactively. We used eye-tracking methodology because it offers the possibility to distinguish between relatively early processing (e.g., first-pass reading times) and later processing (e.g., second-pass reading times) (Cook & Wei, 2017; Rayner, 1998). It also allows for relative naturalistic reading as texts are presented in their entirety (e.g., Hyönä et al., 2002). The basic assumption of eye-tracking methods is that increased processing demands, for example when readers encounter a comprehension problem in a text, are associated with increased processing time or changes in the pattern of fixations (e.g., Frazier & Rayner, 1982; Hyönä et al., 2003; Rayner & Slattery, 2009; Rayner, Warren, Juhasz, & Liversedge, 2004; Rinck, Gámez, Díaz, & De Vega, 2003; Stewart, Pickering, & Sturt, 2004). Such changes are assumed to be indicative of underlying processes. For example, readers may detect and attempt to resolve incoherence by spending more time on the critical regions (Yuill & Oakhill, 1991), by engaging in rereading activities to look for the possible source of the incoherence (Hyönä et al., 2003; Zabrucky & Ratner, 1986), or by making regressions to earlier parts of the text to reinstate information from the text they would like to elaborate or reactivate in working memory (Hyönä & Lorch, 2004).

Participants read expository texts containing information that conflicted with the preceding text and/or readers' background knowledge (based on Van Moort et al., 2018), while their eye movements were recorded as they freely read through the texts. Assuming that initial validation processes (i.e., detection of inconsistencies) occur relatively early in processing and elaboration and repair processes (i.e., attempts to resolve the inconsistency) occur later in processing, recording eye movements allows us to investigate whether text and background knowledge affect early and later validation processes independently or interactively and, conversely, whether early and late processes (or both) are predominantly knowledge-driven or context-driven.

The secondary aim was to investigate whether working memory capacity affects text-based and knowledge-based validation processes differentially and whether validation components are impacted by individual differences in processing capacity. An important assumption of most models of validation is that incoming information can only be validated against information that is available and activated during comprehension. Therefore, working memory capacity is likely to play a role in validation as it limits the amount of information that can be activated (e.g., Hannon & Daneman, 2001; Singer, 2006). For instance, two-component models of evaluative comprehension suggest that epistemic elaboration or repair processes may be particularly impacted by individual differences in processing capacity, as they are assumed to be reader-initiated and resource-demanding. Working memory indeed has been found to play a role in at least knowledge-based validation (Van Moort et al., 2018), but it is unclear whether it impacts epistemic elaboration as well. To investigate these possibilities we obtained a measure of participants' working memory capacity.

Methods

Participants

Forty-seven native speakers of Dutch (39 women, 8 men) aged 18 to 27 years (*M* = 21, *SD* = 2) participated in this study.[1] All participants had normal or corrected-to-normal eyesight, and none had diagnosed a reading or learning disability. Participants provided written informed consent before testing and were paid for participating. All procedures were approved by the Leiden University Institute of Education and Child Studies ethics committee and conducted in accordance with the Declaration of Helsinki.

Materials

We used the texts of Van Moort et al. (2018; based on Rapp, 2008). The texts were about well-known historical topics. The texts were normed to ensure the presented facts were common knowledge in our sample (see Van Moort et al., 2018 for a more detailed description of the norming study). Each text contained a target sentence that was either true or false (with respect to the readers' background knowledge); at the same time the preceding text could either support or call into question the information in the targets. More specifically, the context could bias toward either the true or the false target, making the context either congruent or incongruent with the target (see sample text in Table 1). Four different versions of each of the 80 texts were constructed by orthogonally varying the target sentence (i.e., true vs. false) and the context before the target sentence (i.e., congruent vs. incongruent with target). It is important to note that contexts biasing toward false targets did not include erroneous information. Although the phrasing of the context sentences called into question the certainty of events stated in the target, all facts described in the context sentences were historically correct.

Each text consisted of 10 sentences (see Table 1 for a sample text). Sentences 1 and 2 were identical among all conditions, providing an introduction to the topic. Sentences 3 to 7 differed in content, depending on context condition (congruent or incongruent). On average, the context biasing toward the true target consisted of 64 words (*SD* = 4.20) and 399 characters (*SD* = 23.48) and the context biasing toward the false target consisted of 66 words (*SD* = 4.30) and 407 characters (*SD* = 22.79). Sentence 8 was the target sentence and was either true or false. Overall, targets were equated for length: Both true (*SD* = 1.92) and false (*SD* = 1.90) targets contained on average of 9 words and both true (*SD* = 10.51) and false (*SD* = 10.42) targets contained on average 60 characters (including spaces and punctuation). Half of the true targets and false targets included the word "not" or "never" (e.g., "Jack the Ripper was never caught and punished for his crimes") and half did not (e.g., "The Titanic withstood the damage from the iceberg collision"). Sentences 9 and 10 concluded

Table 1. Sample text with the four text versions (translated from Dutch original, Van Moort et al., 2018)

		Background knowledge	
		Target True	Target False
Text	Target congruent with context	[Introduction] In 1865, a Frenchman named Laboulaye wished to honor democratic progress in the U.S. He conceptualized a giant sculpture along with artist Auguste Bartholdi. [Context bias towards true target] Their 'Statue of Liberty' would require extensive fundraising work. They organized a public lottery to generate support for the sculpture. American businessmen also contributed money to build the statue's base. Despite falling behind schedule, the statue was completed. The statue's base was finished as well and ready for mounting. [Target True] The Statue of Liberty was delivered from France to the United States. [Coda] The intended site of the statue was a port in New York harbor. This location functioned as the first stop for many immigrants coming to the U.S	[Introduction] In 1865, a Frenchman named Laboulaye wished to honor democratic progress in the U.S. He conceptualized a giant sculpture along with artist Auguste Bartholdi. [Context bias towards false target] Their 'Statue of Liberty' would require extensive fundraising work. Raising the exorbitant funds for the statue proved an enormous challenge. Because of financial difficulties France could not afford to make a gift of the statue. Fundraising was arduous and plans quickly fell behind schedule. Because of these problems, completion of the statue seemed doomed to failure. [Target False] The Statue of Liberty was not delivered from France to the United States. [Coda] The intended site of the statue was a port in New York harbor. This location functioned as the first stop for many immigrants coming to the U.S
	Target incongruent with context	[Introduction] In 1865, a Frenchman named Laboulaye wished to honor democratic progress in the U.S. He conceptualized a giant sculpture along with artist Auguste Bartholdi. [Context bias towards false target] Their 'Statue of Liberty' would require extensive fundraising work. Raising the exorbitant funds for the statue proved an enormous challenge. Because of financial difficulties France could not afford to make a gift of the statue. Fundraising was arduous and plans quickly fell behind schedule. Because of these problems, completion of the statue seemed doomed to failure. [Target True] The Statue of Liberty was delivered from France to the United States. [Coda] The intended site of the statue was a port in New York harbor. This location functioned as the first stop for many immigrants coming to the U.S	[Introduction] In 1865, a Frenchman named Laboulaye wished to honor democratic progress in the U.S. He conceptualized a giant sculpture along with artist Auguste Bartholdi. [Context bias towards true target] Their 'Statue of Liberty' would require extensive fundraising work. They organized a public lottery to generate support for the sculpture. American businessmen also contributed money to build the statue's base. Despite falling behind schedule, the statue was completed. The statue's base was finished as well and ready for mounting. [Target False] The Statue of Liberty was not delivered from France to the United States. [Coda] The intended site of the statue was a port in New York harbor. This location functioned as the first stop for many immigrants coming to the U.S

the text. They contained a general conclusion that did not elaborate on the fact potentially called into question in the target sentence and maintained historical accuracy. On average, the texts contained 121 words (SD = 5.66) and 766 characters per text (SD = 37.63) across all four text versions.

To implement a repeated-measures design we used a Latin square to construct four lists, with each text appearing in a different version as a function of target (true or false) and text context (congruent or incongruent with target) on each list. Each list was randomized. Each participant was assigned to one list and, hence, read one version of each text.

Reading task

Participants read 80 texts while eye movements were recorded. The texts were presented as a whole, and participants were instructed to read for comprehension at their normal pace and to advance to the next text by pressing a button. A fixation cross was presented at the position of the first word of the first sentence in between texts for 300 ms. The task consisted of two blocks of 40 texts. Each block started with a calibration of the eye tracking apparatus. Participants performed a short practice block.

Measures

Working memory capacity

Working memory capacity was measured with the Swanson Sentence Span task (Swanson, Cochran, & Ewers, 1989). In this task the experimenter read out sets of sentences, with set length increasing from 1 to 6 sentences while they progressed in the test. At the end of each set a comprehension question was asked about one of the sentences in the set. Participants had to remember the last word of each sentence and recall these after answering the comprehension question. The test was terminated when the participant's error rate exceeded a given threshold. Participants earned points for each correct answer on the comprehension questions and each correctly recalled set of words. The sum of these points was the index of working memory capacity.

Apparatus

Eye movements were recorded using an EyeLink 1000 desktop-mounted eye tracker of the SR Research Company (Oakville, Canada, http://sr-research.com/pdf/techspec.pdf). Sampling frequency was 1000 Hz, and spatial accuracy was approximately 0.4 degrees. Viewing was binocular, but only the right eye was tracked. A chin-and-head rest was used to minimize participants' head movements. The texts were presented in their entirety on a 19-inch screen at approximately 65 cm from the participant.

Procedure

Participants were tested individually. The eye tracker was calibrated by means of a nine-point calibration grid that covered the entire computer screen. On successful calibration participants completed the reading task. Next, they completed the Swanson Sentence Span Task and a questionnaire assessing their background knowledge on the text topics. The duration of the total session was approximately 90 minutes.

Eye-fixation measures

For each text eye-fixation measures for two regions of interest were calculated: the target sentence and the spill-over sentence (the sentence following the target). We examined several measures for each of these regions. *First-pass reading times* reflected initial processing of a sentence (Rayner, Sereno, Morris, Schmauder, & Clifton, 1989) and were computed by summing all first-pass fixations for each word (all fixations on a word from the first fixation on that word until the first time the reader exits that word) in the sentence. *First-pass probability of a regression* reflected the probability that a regression was made to an earlier section of the text and was computed for each word in a sentence (Clifton, Staub, & Rayner, 2007). *Second-pass reading times* (or re-reading times) reflected later processing or reprocessing of the words in a sentence after the words were exited for the first time (Rayner et al., 1989). They were computed by summing all fixations on each word in the sentence excluding first-pass fixations on these words. The *probability of rereading* reflected the probability that the sentence was read again after the reader exited the sentence for the first time and was computed binarily (rereading present vs. absent) for each sentence. The *regression path duration* or go-past duration was computed by summing all fixations from first entering a region until exiting in the forward direction (Duffy, Morris, & Rayner, 1988; Rayner & Duffy, 1986; Rayner & Liversedge, 2011). This measure included any regression out of a region before moving forward in the text.

Analyses

To investigate the effects of the manipulations on the reading process, we conducted mixed-effects linear regression analyses using the R package LME4 version 1.1.21 (Bates, Maechler, Bolker, & Walker, 2015). For each measure on each sentence we started with a full interactional model that included the interaction between the fixed factors background knowledge (target true or false), text (target congruent or incongruent), working memory capacity (median centered), and the random factors subjects and items. Effect coding was applied in the main analyses (true was coded as −0.5 and false as 0.5; congruent was coded as −0.5 and incongruent as 0.5). We did not include random slopes in our models. We report the relevant fixed-effects estimates and the associated t-values (for the continuous dependent variables) and z-values (for the categorical dependent variables) in specific tables (see Tables 3 and 4). To obtain fixed-effects estimates and the associated statistics for the relevant simple effects of an interaction, we performed pairwise comparisons. The results of the follow-up analysis are provided in the text. As it is not clear how to determine the degrees of freedom for the t statistics estimated by mixed models for continuous dependent variables (Baayen, 2008), we do not report degrees of freedom and p values. Instead, statistical significance at approximately the 0.05 level is indicated by $t \geq 1.96$. (e.g., Schotter, Tran, & Rayner, 2014).

Results

Data for one of the experimental texts were dropped from the analyses, as it concerned Stephen Hawking whose death changed the truth value of the text. For the regions of interest (target sentence and the spill-over sentence) in the other texts first-pass reading time, first-pass probability of a regression, re-reading probability, second-pass reading time, and regression path duration were determined (see Table 2 for descriptive statistics).

Table 2. Means and SDs for the dependent variables at the regions of interest (target and spill-over sentence) for the experimental manipulations regarding text (target congruent or incongruent with context) and background knowledge (target true or false)

			Target		Spill-over	
	Background knowledge	Text	M	SD	M	SD
First-pass reading time, ms	True	Con	1471	737	1897	846
		Incon	1454	673	1948	943
	False	Con	1611	848	1991	886
		Incon	1658	805	2028	920
Second-pass reading time, ms	True	Con	405	396	476	447
		Incon	439	412	496	488
	False	Con	480	428	452	457
		Incon	543	520	527	559
First-pass probability of regression	True	Con	0.15	0.36	0.15	0.35
		Incon	0.18	0.38	0.16	0.37
	False	Con	0.19	0.39	0.16	0.37
		Incon	0.20	0.40	0.17	0.37
Regression path duration, ms	True	Con	2032	1883	2429	1698
		Incon	2134	2714	2701	2687
	False	Con	2218	2015	2600	1646
		Incon	2360	1619	2773	1870
Re-reading probability	True	Con	0.48	0.50	0.50	0.50
		Incon	0.54	0.50	0.52	0.50
	False	Con	0.58	0.49	0.54	0.50
		Incon	0.62	0.48	0.54	0.50

Table 3. Fixed effects estimates and the associated statistics of the sum-coded models fitted for the dependent variables on the target sentence

Measure	Fixed Effect	Statistics		
		B	SE	t/z
First-pass reading time	Intercept	7.23	0.04	197.69*
	Text	0.21	0.01	1.71
	Background	0.10	0.01	7.45*
	WM	−0.05	0.05	−10.64*
	Text * Background	0.05	0.03	2.16*
	Text * WM	0.03	0.02	1.47
	Background * WM	−0.02	0.02	−1.25
	Text * Background * WM	0.02	0.04	0.38
First-pass probability of a regression	Intercept	−1.59	0.09	−18.22*
	Text	0.16	0.04	3.82*
	Background	0.22	0.04	5.20*
	WM	−0.23	0.13	−1.83
	Text * Background	−0.17	0.08	−2.01*
	Text * WM	−0.01	0.07	−0.12
	Background * WM	−0.05	0.07	−0.73
	Text * Background * WM	−0.16	0.13	−1.19
Regression path duration	Intercept	7.50	0.04	192.39*
	Text	0.06	0.02	3.68*
	Background	0.10	0.02	6.33*
	WM	−0.11	0.05	−2.14*
	Text * Background	0.05	0.03	1.43
	Text * WM	0.004	0.02	0.19
	Background * WM	−0.01	0.02	−0.39
	Text * Background * WM	−0.02	0.05	−0.47
Re-reading probability	Intercept	0.29	0.15	2.03*
	Text	0.29	0.08	3.75*
	Background	0.41	0.08	5.23*
	WM	−0.45	0.21	−2.19*
	Text * Background	0.01	0.15	0.09
	Text * WM	0.004	0.12	0.04
	Background * WM	0.01	0.12	0.07
	Text * Background * WM	−0.17	0.23	−0.73
Second-pass reading time	Intercept	5.78	0.04	146.30*
	Text	0.16	0.03	4.60*
	Background	0.07	0.03	2.18*
	WM	−0.13	0.06	−2.23*
	Text * Background	0.04	0.07	0.51
	Text * WM	−0.05	0.06	−0.84
	Background * WM	−0.01	0.06	−0.22
	Text * Background * WM	0.03	0.11	0.30

The following R code was used for all models: dependent variable ~ 1 + Text * Background * Working Memory + (1|Subject)+(1|Item).
*Indicates |z| or |t| score < 1.96 and thus significance at the 0.05 level.

Target sentence

First-pass reading times

Wald chi-square tests revealed a main effect of BACKGROUND KNOWLEDGE, but no main effect of TEXT. Furthermore, we observed a BACKGROUND KNOWLEDGE * TEXT interaction on the log-transformed first-pass reading times (see Table 3 for fixed-effects estimates and associated statistics). Post-hoc multiple comparisons showed increased first-pass reading times for false targets than true targets, both when the target was presented in a congruent context (β = −0.07, SE = 0.02, z = −3.92) and when it was presented in an incongruent context (β = −0.12, SE = 0.02, z = −6.90). This effect of background knowledge was modulated by congruency of the target with the preceding context: False targets presented in a incongruent context (e.g., target states that the Statue of Liberty was not delivered to the United States but context suggests it was) elicited longer first-pass reading times than false targets presented in a congruent context (e.g., the target states that the Statue of Liberty was not delivered to the United States and context also suggests that it was not) (β = −0.05, SE = 0.02,

Table 4. Fixed-effects estimates and the associated statistics of the sum-coded models fitted for the dependent variables on the spill-over sentence

		Statistics		
Measure	Fixed Effect	B	SE	t/z
First-pass reading time	Intercept	7.48	0.04	183.26*
	Text	0.15	0.01	1.27
	Background	0.04	0.01	3.18*
	WM	−0.02	0.05	−0.45
	Text * Background	0.02	0.03	0.74
	Text * WM	0.02	0.05	1.15
	Background * WM	−0.03	0.05	−1.71
	Text * Background * WM	0.06	0.04	1.75
First-pass probability of a regression	Intercept	−1.77	0.09	−19.19*
	Text	0.18	0.04	2.05*
	Background	0.11	0.04	2.91*
	WM	−0.32	0.14	−2.35
	Text * Background	0.01	0.08	0.18
	Text * WM	−0.05	0.06	−0.81
	Background * WM	0.02	0.06	0.27
	Text * Background * WM	0.09	0.12	0.80
Regression path duration	Intercept	7.71	0.04	175.51*
	Text	0.53	0.01	3.70*
	Background	0.05	0.01	3.70*
	WM	−0.10	0.06	−1.68
	Text * Background	0.01	0.03	0.27
	Text * WM	0.01	0.02	0.23
	Background * WM	−0.004	0.02	−0.18
	Text * Background * WM	0.06	0.04	1.27
Re-reading probability	Intercept	0.13	0.14	0.89
	Text	0.04	0.07	0.49
	Background	0.16	0.08	2.17*
	WM	−0.42	0.20	−2.06*
	Text * Background	−0.08	0.15	−0.52
	Text * WM	−0.10	0.11	−0.89
	Background * WM	−0.06	0.11	−0.48
	Text * Background * WM	0.09	0.23	0.37
Second-pass reading time	Intercept	5.79	0.04	139.91*
	Text	0.002	0.03	−0.06
	Background	0.10	0.03	2.89*
	WM	−0.19	0.06	−3.24*
	Text * Background	0.11	0.07	1.65
	Text * WM	0.01	0.05	0.16
	Background * WM	−0.02	0.05	−0.37
	Text * Background * WM	0.03	0.11	0.31

The following R code was used for all models: dependent variable ~ 1 + Text * Background * Working Memory + (1|Subject)+(1|Item).
*Indicates |z| or |t| score < 1.96 and thus significance at the 0.05 level.

z = −2.64). However, true targets showed no effect of (in)congruency with the preceding context (β = 0.01 SE = 0.02, z = 0.38) (Figure 1a). We did not find any effects of working memory capacity on the first-pass reading times (Table 3).

First-pass probability of regression

In addition to a TEXT * BACKGROUND KNOWLEDGE interaction, results showed main effects of BACKGROUND KNOWLEDGE and of TEXT on the first-pass probability of regressions (see Table 3 for fixed-effects estimates and associated statistics). Post-hoc multiple comparisons showed that readers were more likely to make regressions on false targets than true targets, both when the target was presented in a congruent context (β = −0.03 SE = 0.06, z = −5.02) and when it was presented in an incongruent context (β = −0.14 SE = 0.06, z = −2.44) (Figure 1b). However, there was only an effect of (in) congruency with the context on targets containing true world knowledge information: Readers were more likely to make first-pass regressions when true targets were presented in an incongruent

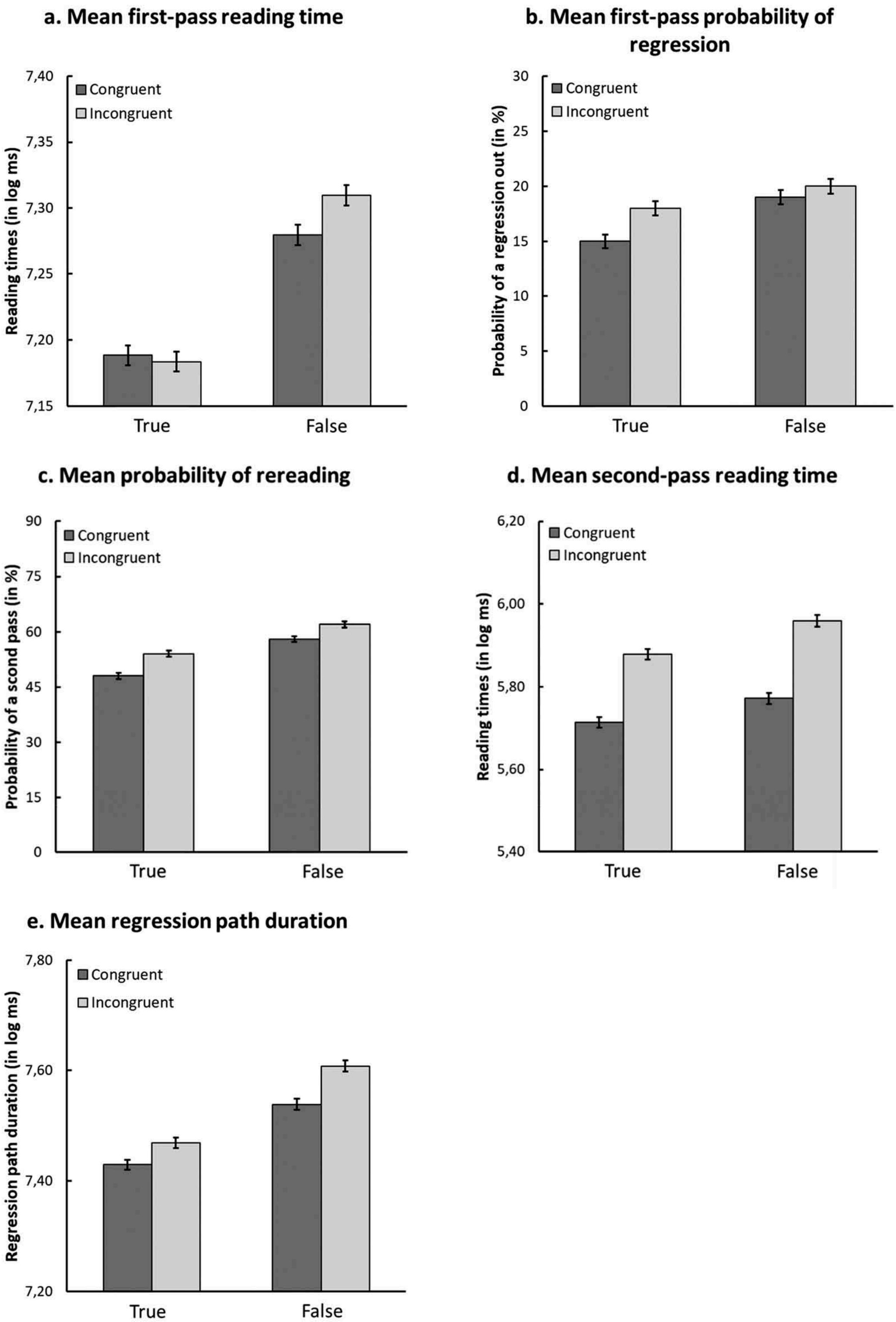

Figure 1. Reading patterns for (a) first-pass reading time, (b) first pass probability of regression, (c) probability of rereading, (d) second-pass reading time and (e) regression path duration on target sentences as a function of match with text (congruent or incongruent) and background knowledge (true or false). Error bars represent standard errors of the means.

context than when they were presented in a congruent context (β = −0.02 SE = 0.06, z = −3.96). False targets showed no effect of (in)congruency with the preceding context (β = −0.08 SE = 0.06, z = −1.40) (Figure 1b). We did not find any effects of working memory capacity on the first-pass probability of a regression (Table 3).

Regression path duration

Results showed main effects of BACKGROUND KNOWLEDGE, TEXT, and WORKING MEMORY CAPACITY on the regression path duration (see Table 3 for fixed-effects estimates and associated statistics). False targets elicited longer regressions than true targets (Figure 1e). Similarly, incongruent targets elicited longer regressions than congruent targets (Figure 1e). Furthermore, participants with a larger working memory made shorter regressions than participants with a smaller working memory.

Re-reading probability

Results showed main effects of BACKGROUND KNOWLEDGE, TEXT, and WORKING MEMORY CAPACITY on the probability of rereading targets (see Table 3 for fixed-effects estimates and associated statistics). Participants were more likely to reread false targets than true targets (Figure 1c). Similarly, they were more likely to reread incongruent targets than congruent targets (Figure 1c). Furthermore, participants with a larger working memory were less likely to reread targets than participants with a smaller working memory.

Second-pass reading times

Results showed main effects of BACKGROUND KNOWLEDGE, TEXT, and WORKING MEMORY CAPACITY on the second pass reading times on targets[2] (see Table 3 for fixed-effects estimates and associated statistics). Participants spent more time re-reading false targets than true targets (Figure 1d). Similarly, participants spent more time re-reading incongruent targets than congruent targets (Figure 1d). Furthermore, participants with a larger working memory spend less time re-reading targets than participants with a smaller working memory.

Spill-over sentence

First-pass reading times

Results showed a main effect of BACKGROUND KNOWLEDGE on the first-pass reading times on spill-over sentences (see Table 4 for fixed-effects estimates and associated statistics). Readers were slower to read spill-over sentences after false targets than those after true targets. We did not find any effects of TEXT and WORKING MEMORY CAPACITY.

First-pass probability of regression

Results showed a main effect of BACKGROUND KNOWLEDGE, TEXT, and WORKING MEMORY CAPACITY on the first pass chance of regressions on spill-over sentences (see Table 4 for fixed-effects estimates and associated statistics). Spill-over sentences that were preceded by false targets were more likely to elicit regressions to earlier text than those preceded by true targets. Similarly, spill-over sentences after incongruent targets were more likely to elicit regressions than those after congruent targets. Furthermore, readers with a larger working memory were less likely to engage in regressions on the spill-over sentence than readers with a smaller working memory.

Regression path duration

Results showed main effects of BACKGROUND KNOWLEDGE and TEXT on the regression path duration on spill-over sentences (see Table 4 for fixed-effects estimates and associated statistics). Spill-over sentences following false targets elicited longer regressions than those following true targets. Similarly, spill-over sentences after incongruent targets elicited longer regressions than those after congruent targets.

Re-reading probability

Results showed main effects of BACKGROUND KNOWLEDGE and WORKING MEMORY CAPACITY on the re-reading probability on spill-over sentences (see Table 4 for fixed-effects estimates and associated statistics). Participants were more likely to reread spill-over sentences preceded by false targets than those preceded by true targets. Furthermore, readers with a smaller working memory were more likely to reread spill-over sentences than readers with a larger working memory.

Second-pass reading times

Results showed main effects of TEXT and WORKING MEMORY CAPACITY on the second pass reading times on spill-over sentences[3] (see Table 4 for fixed-effects estimates and associated statistics). Participants spent more time re-reading spill-over sentences after incongruent targets than those after congruent targets. Furthermore, readers with a larger working memory spent less time re-reading the spill-over sentence than readers with a smaller working memory.

Discussion

The aim of the current eye-movement study was to investigate when and how contextual information and background knowledge, respectively, influence validation processes during text comprehension. Additionally, we examined the role of working-memory capacity in validating against these two sources of information.

During first-pass reading, target sentences that contained world-knowledge inconsistencies induced longer reading times than did target sentences that did not contain such inconsistencies. Sentences that contained text-based incongruencies induced longer reading times than did sentences that contained congruent targets but, interestingly, only when the target contained *false* (inaccurate) world-knowledge information. In addition, knowledge-based inaccuracies elicited more regressions during first-pass reading. Text-based incongruencies also elicited more regressions during first-pass reading but only in the absence of a knowledge-based inaccuracy (i.e., when targets contained *true* world-knowledge information). No interactions between text-based and knowledge-based processing were observed in later processing measures (i.e., regression-path duration, re-reading probability, and second-pass reading time). Instead, these later measures revealed reliable main effects of both context and background knowledge: Readers were more likely to re-read the target and displayed both longer regressions and longer re-reading when they encountered targets that either were false with their world knowledge or incongruent with the preceding context.

In addition to these effects on target sentences, we observed a spill-over effect of knowledge-based inaccuracies during first pass reading (i.e., longer first-pass reading times on the spill-over sentence if it was preceded by a target containing false world knowledge information) but not of contextual incongruencies. Furthermore, readers were more likely to regress to earlier parts of the text and displayed longer regressions on spill-over sentences following false or incongruent targets. Finally, they were more likely to re-read spill-over sentences after false or incongruent targets and, when they re-read a sentence, spent more time doing so.

Working memory did not affect early processing but it did influence later processing (e.g., regressions and re-reading). Readers with a larger working memory were less likely to make regressions or re-read targets and, if they did re-read, spent less time doing so. Importantly, working memory did not interact with the two types of inconsistencies, indicating that the effects of incongruency with text or inaccuracy with background knowledge did not depend on readers' working-memory capacity.

Differentiating text-based and knowledge-based validation processes

These findings point to several conclusions. First, they support the notion that both incongruencies with context and inaccuracies with background knowledge have a profound impact on validation processes during reading, as evidenced by early and later eye-movements on both target and spill-over sentences. Second, although contextual incongruencies and knowledge-based inaccuracies are not completely independent (i.e., contextual incongruencies must involve, at the very least, some violation of logic that exist in the reader's background knowledge), the results show that they trigger distinct processes. Third, the distinct patterns of processing for text and background knowledge violations already are evident at an early stage in the processing of incoming text information.

Fourth, first-pass reading times and regression probabilities revealed interaction patterns that further differentiate processing of text-based and knowledge-based contradictions. Knowledge-based inaccuracies consistently disrupted initial processing (i.e., longer first-pass reading times and more first-pass regressions), whereas text-based incongruencies also disrupted initial processing but the way in which they did depended on whether there also was a knowledge-based inaccuracy present. If the target also violated background knowledge, then the contextual incongruency resulted in further slowdown in reading (additional first-pass reading times). In contrast, if the target was accurate according to background knowledge, then the contextual incongruency elicited more re-readings (more first-pass regressions). Thus, the target's accuracy/inaccuracy with respect to background knowledge modulates the type of effect that a text-based incongruence elicits: If incoming text information is inconsistent with both earlier text and the reader's knowledge, then reading becomes extra slow, but if the incoming information is inconsistent only with earlier text, then it is more likely to be reread.

Fifth, text-based and knowledge-based contradictions differed in the strength of the disruption they caused. Knowledge-based inaccuracies appeared to induce a more intensive, prolonged disruption of the reading process than did text-based incongruencies, as reflected in spill-over effects (i.e., effects on first-pass reading of the spill-over sentence) for background-knowledge but not for context contradictions. This pattern is consistent with the notion of dissociable text-based and knowledge-based validation processes.

It is interesting to speculate about possible mechanisms underlying these findings. Drawing an analogy to sentence-processing literature, one possibility is to assume a serial mechanism where knowledge-based information is processed first and text-based information comes into play at a later stage during processing (e.g., Frazier, 1987; Frazier & Fodor, 1978; Frazier & Rayner, 1982). Another possibility is an interactive, constraint-based mechanism in which both sources of information are processed simultaneously (similar to interactive constraint models; Bates & MacWhinney, 1989; MacDonald, Pearlmutter, & Seidenberg, 1994; Marslen-Wilson, 1973; Tanenhaus & Trueswell, 1995). The serial account fits with the finding that contextual incongruence increases first-pass reading time only if a knowledge-based inaccuracy is detected. However, in the absence of a knowledge inaccuracy, contextual incongruencies do increase the probability of a first-pass regression. In so far as first-pass regressions reflect early processes, this latter finding suggests an interactive mechanism. To distinguish between these two possible mechanisms, a more detailed investigation of the discourse-level processes is necessary. Within the eye-tracking context this would require a fine-grained analyses of the moments at which the lengthening of reading times and the regressions occur, but other methods with high temporal resolution, such as Event-Related Potential (ERP)/electroencephalogram, may also be useful. Regardless, the current results do show that context and background knowledge interact very early in the processing of incoming information and together constrain validation. Such conclusion is in line with spread-of-activation mechanisms posited in the discourse comprehension literature, such as the memory-based processing view (e.g., Cook et al., 1998; Gerrig & McKoon, 1998; Myers & O'Brien, 1998; O'Brien & Myers, 1999; Rizzella & O'Brien, 2002) and cohort activation within the Landscape model view (van den Broek & Helder, 2017; van den Broek, Young, Tzeng, & Linderholm, 1999).

In this context, the observation in the current study that inconsistency with world knowledge had stronger and longer effects than inconsistency with context may reflect a structural property of the monitoring mechanisms—that validation always occurs first or primarily against the reader's background knowledge. It is also possible, however, that the observed dominance of world knowledge is not an inherent property of the system but emerged due to other factors. For example, the dominance of one informational source over the other may depend on the strength of the reader's text-relevant general world knowledge (Cook & O'Brien, 2014) versus the strength of the contextual information (e.g., Cook & Guéraud, 2005; Myers, Cook, Kambe, Mason, & O'Brien, 2000; O'Brien & Albrecht, 1991). In the current study, knowledge-based inaccuracies tended to be stronger than the text-based incongruencies, as the former were outright errors and the latter merely unlikely. To determine whether background knowledge structurally is dominant, future studies could systematically vary the strength of background knowledge, similar to studies have varied the strength of the context (e.g., Creer et al., 2018; Walsh et al., 2018).

Early and late processes in validation

Theoretical models of validation assume distinct components to validation: a coherence-detection component and a post-detection processing component (Cook & O'Brien, 2014; Isberner & Richter, 2014; Richter, 2015; Singer, 2019; van den Broek & Helder, 2017). Models such as the RI–Val model (Cook & O'Brien, 2014; O'Brien & Cook, 2016a, 2016b) focus on the passive, memory-based processes that are presumed to be involved in the initial detection of an inconsistency. Once detected, inconsistencies may trigger further processes, for example, processes aimed at repairing the inconsistency (as described in the two-step model of evaluative comprehension; Isberner & Richter, 2014; Richter, 2011; Richter et al., 2009; Schroeder et al., 2008). The models are not specific with respect to the relation between these components (e.g., does the detection component finish before possible repair processes, do the two components overlap, do detection processes interact with post-detection processes by triggering renewed detection processes?) but generally agree that, as processing proceeds, the balance gradually shifts from detection to postdetection (repair) processes. Thus, although all eye movements may be influenced by both components of validation, early eye-tracking measures such as first-pass reading times are considered to reflect early processing (e.g., Clifton et al., 2007; Rayner & Liversedge, 2011) and therefore are relatively close to the detection processes. Conversely, later eye-tracking measures such as rereads and spill-over effects on subsequent sentences reflect later processing and are relatively more sensitive to reader-initiated (including possible repair) processes.

The current findings show that text-based and knowledge-based validation processes follow distinct trajectories in the very early stages of the processing of incoming information. Whereas knowledge-based validation influences all early processes considered in this study, validation against earlier text also influences these processes but in qualitatively different ways depending on the presence or absence of knowledge violations. If the textual information is incongruent with the preceding text but fits the reader's background knowledge, then the reader is likely to reinspect the textual information. In contrast, if the textual information is incongruent with prior text and *also* violates the reader's background knowledge, then the combined inconsistencies lead to longer reading time (over and above the already longer time due to the background knowledge inaccuracy), possibly reflecting more pervasive checking of textual input with background knowledge.

Interestingly, whereas initial text-based and knowledge-based validation processes show different processing patterns, later text-based and knowledge-based validation processes (e.g., regression path duration, re-reading probability, second-pass reading time, and several measures on the spill-over sentences) seem relatively similar. In so far as that later processing measures reflect repair processes, results suggest that repair processes for both types of inconsistencies involve a similar pallet of actions and sources. This may reflect that the final, adjusted mental representation of readers must fit with both contextual information and the existing knowledgebase. It is worth noting that the processing of knowledge-based inaccuracies required a more intensive, prolonged validation process (in line with Van Moort et al., 2018), reflected in the presence of some spill-over effects (i.e., effects on first-pass reading of the spill-over sentence), for inconsistencies with background knowledge but not with text. Thus, knowledge-based inaccuracies in our study seemed more difficult to repair than textual incongruencies. It could be that in the case of knowledge-based inaccuracies the information has to be validated against a more elaborate network (i.e., the existing knowledgebase) than the episodic memory trace of the text representation, and therefore it may take longer to activate relevant information. As mentioned above, this could also be caused by differences in strengths for the two types of inconsistencies.

In all, the results provide compelling evidence that the source of the incoherence influences processing from a very early stage. Both types of inconsistencies are detected early in processing with each triggering different processes. In comparison, in later processing the toolbox of (repair) processes for text-based and knowledge-based inconsistencies seems rather similar.

Role of working memory in validation

The findings indicate that working memory modulates later processing (i.e., regressions, rereading): Readers with a larger working-memory capacity made fewer regressions and were less likely to reread targets than those with smaller working-memory capacity. This suggests that readers adapt their later processing strategies depending on the resources they have available. Speculatively, readers with a larger working-memory capacity may have more relevant information available for processing, enabling them to avoid costly re-reading and reprocessing. In contrast, readers with a smaller working-memory capacity have less relevant information activated and thus may need to look back in the text to construct a coherent situation model.

No working-memory capacity effects were observed for the early processes. This suggests that early validation processes require few resources and is consistent with the notion that such processes are relatively passive (e.g., RI–Val and two-step model of evaluative comprehension), whereas later validation processes are more resource demanding and reader-initiated.

In an earlier study using sentence-by-sentence self-paced reading, Van Moort et al. (2018) did observe an effect of working-memory capacity on reading times for knowledge-based but not text-based inconsistencies, suggesting that knowledge-based validation is, in fact, resource demanding. Because the studies used the same materials but differed in presentation mode (sentence-by-sentence vs. texts presented in their entirety), it seems plausible that the constraints imposed by presentation mode may account for the different patterns of results. For example, during sentence-by-sentence presentation readers cannot look back to related information to resolve an inconsistency. Therefore, they may attempt to validate information for each sentence immediately and meticulously before proceeding in the text (Chung-Fat-Yim, Peterson, & Mar, 2017; Koornneef, Kraal, & Danel, 2019; Koornneef & Van Berkum, 2006) and also may need to rely more on their memory representation to conduct the validation (Gordon, Hendrick, Johnson, & Lee, 2006). As a result, sentence-by-sentence reading may elicit a greater effect of differences in working-memory capacity than reading of a text presented in its entirety. The potential effect of presentation mode on discourse-level comprehension processes is worth closer scrutiny as it would have important consequences for the interpretation of results from studies using sentence-by-sentence reading.

Broader implications and future directions

Successful comprehension requires readers to build a coherent, meaningful mental representation or situation model of a text. An essential aspect of building such mental representation is that readers routinely validate to what extent incoming information is consistent with what they already know. The current study shows that the processes involved in coherence monitoring depend on validation against both contextual information and background knowledge. Moreover, these sources exert their influence very early in the processing of new text information and they do so in distinct ways. The current conclusions are consistent with but also expand considerably current models of validation (e.g., RI–Val [Cook & O'Brien, 2014] and the two-step model of evaluative comprehension [Isberner & Richter, 2014]). They also are consistent with neuroimaging findings (van Moort et al., submitted), revealing brain regions that seem mostly involved in either knowledge-based processing (e.g., dorsomedial prefrontal cortex) or text-based processing (right inferior frontal gyrus) and regions that are affected by the two sources of information interactively (e.g., precuneus and left inferior frontal gyrus).

In addition to the text features that were the focus of this study, individual differences are likely to affect monitoring processes, especially in the later components of validation. We considered working memory, which indeed seemed to impose a capacity constraints on these later processes. Other individual difference factors that may differentially affect monitoring and repair processes are the standards of coherence that the reader applies or the toolbox of repair strategies he/she has available.

Comprehension monitoring occurs in the context of reading, as in this study and most validation research, but of course also in many other contexts of life. When encountering (fake) news, for example, one needs to validate whether the news is internally congruent and accurate with respect to world knowledge. Paradigms and models such as those discussed in this article may provide a fruitful starting point for investigations of people's susceptibility to such (un)reliable information sources.

Notes

1. In total, 70 participants were tested. Due to technical issues with the eye tracker at the start of the study, data of 23 participants were of insufficient quality and could not be analyzed.
2. Note that second-pass reading times were only included in this measure if a second pass was made.
3. Note that second-pass reading times were only included in this measure if a second pass was indeed made.

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References

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*(5), 1061–1070.

Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge, UK: Cambridge University Press.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. doi:10.18637/jss.v067.i01

Bates, E., & MacWhinney, B. (1989). Functionalism and the competition model. *The Crosslinguistic Study of Sentence Processing*, *3*, 73–112.

Chung-Fat-Yim, A., Peterson, J. B., & Mar, R. A. (2017). Validating self-paced sentence-by-sentence reading: Story comprehension, recall, and narrative transportation. *Reading and Writing*, *30*(4), 857–869. doi:10.1007/s11145-016-9704-2

Clifton, C., Staub, A., & Rayner, K. (2007). Eye movements in reading words and sentences. In R. P. G. Van Gompel, M. H. Fischer, W. S. Murray, & R. L. Hill (Eds.), *Eye movements* (pp. 341–371). Oxford: Elsevier.

Cook, A. E., & Guéraud, S. (2005). What have we been missing? The role of general world knowledge in discourse processing. *Discourse Processes*, *39*(2–3), 265–278. doi:10.1207/s15326950dp3902&3_9

Cook, A. E., Halleran, J., & O'Brien, E. J. (1998). What is readily available during reading? A memory-based view of text processing. *Discourse Processes*, *26*(2–3), 109–129. doi:10.1080/01638539809545041

Cook, A. E., & Myers, J. L. (2004). Processing discourse roles in scripted narratives: The influences of context and world knowledge. *Journal of Memory and Language*, *50*(3), 268–288. doi:10.1016/j.jml.2003.11.003

Cook, A. E., & O'Brien, E. J. (2014). Knowledge activation, integration, and validation during narrative text comprehension. *Discourse Processes*, *51*(1–2), 26–49. doi:10.1080/0163853X.2013.855107

Cook, A. E., & Wei, W. (2017). Using eye movements to study reading processes: Methodological considerations. In W. Christopher, S. Frank, & M. Bradley (Eds.), *Eye-tracking technology applications in educational research* (pp. 27–47). Hershey, PA: IGI Global.

Creer, S. D., Cook, A. E., & O'Brien, E. J. (2018). Competing activation during fantasy text comprehension. *Scientific Studies of Reading*, *22*(4), 308–320. doi:10.1080/10888438.2018.1444043

Duffy, S. A., Morris, R. K., & Rayner, K. (1988). Lexical ambiguity and fixation times in reading. *Journal of Memory and Language*, *27*(4), 429–446. doi:10.1016/0749-596X(88)90066-6

Ferretti, T. R., Singer, M., & Patterson, C. (2008). Electrophysiological evidence for the time-course of verifying text ideas. *Cognition*, *108*(3), 881–888. doi:10.1016/j.cognition.2008.06.002

Frazier, L. (1987). Sentence processing: A tutorial review. In *Attention and performance 12: The psychology of reading* (pp. 559–586). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Frazier, L., & Fodor, J. D. (1978). The sausage machine: A new two-stage parsing model. *Cognition*, *6*(4), 291–325. doi:10.1016/0010-0277(78)90002-1

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, *14*(2), 178–210. doi:10.1016/0010-0285(82)90008-1

Garrod, S., & Terras, M. (2000). The contribution of lexical and situational knowledge to resolving discourse roles: Bonding and resolution. *Journal of Memory and Language*, *42*(4), 526–544. doi:10.1006/jmla.1999.2694

Gerrig, R. J., & McKoon, G. (1998). The readiness is all: The functionality of memory-based text processing. *Discourse Processes*, *26*(2–3), 67–86. doi:10.1080/01638539809545039

Gordon, P. C., Hendrick, R., Johnson, M., & Lee, Y. (2006). Similarity-based interference during language comprehension: Evidence from eye tracking during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(6), 1304. doi:10.1037/0278-7393.32.4.716

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review*, *101*(3), 371–395. doi:10.1037/0033-295X.101.3.371

Hannon, B., & Daneman, M. (2001). Susceptibility to semantic illusions: An individual-differences perspective. *Memory & Cognition*, *29*(3), 449–461. doi:10.3758/BF03196396

Hess, D. J., Foss, D. J., & Carroll, P. (1995). Effects of global and local context on lexical processing during language comprehension. *Journal of Experimental Psychology: General*, *124*(1), 62. doi:10.1037/0096-3445.124.1.62

Hyönä, J., & Lorch, R. (2004). Effects of topic headings on text processing: Evidence from adult readers' eye fixation patterns. *Learning and Instruction*, *14*(2), 131–152. doi:10.1016/j.learninstruc.2004.01.001

Hyönä, J., Lorch, R. F., & Kaakinen, J. K. (2002). Individual differences in reading to summarize expository text: Evidence from eye fixation patterns. *Journal of Educational Psychology*, *94*(1), 44–55. doi:10.1037/0022-0663.94.1.44

Hyönä, J., Lorch, R. F., & Rinck, M. (2003). Eye movement measures to study global text processing. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye* (pp. 313–334). Amsterdam, The Netherlands: North-Holland.

Isberner, M.-B., & Richter, T. (2014). Comprehension and validation: Separable stages of information processsing? A case for epistemic monitoring in language. In D. N. Rapp & J. L. G. Braasch (Eds.), *Processing inaccurate information* (pp. 245–276). Cambridge, MA: MIT Press.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA: Harvard University Press.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*(2), 163–182. doi:10.1037/0033-295X.95.2.163

Koornneef, A., Kraal, A., & Danel, M. (2019). Beginning readers might benefit from digital texts presented in a sentence-by-sentence fashion. But why? *Computers in Human Behavior*, *92*, 328–343. doi:10.1016/j.chb.2018.10.024

Koornneef, A., & Van Berkum, J. A. (2006). On the use of verb-based implicit causality in sentence comprehension: Evidence from self-paced reading and eye tracking. *Journal of Memory and Language*, *54*(4), 445–465. doi:10.1016/j.jml.2005.12.003

MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review*, *101*(4), 676. doi:10.1037/0033-295X.101.4.676

Marslen-Wilson, W. (1973). Linguistic structure and speech shadowing at very short latencies. *Nature*, *244*(5417), 522. doi:10.1038/244522a0

Marslen-Wilson, W., & Tyler, L. K. (1980). The temporal structure of spoken language understanding. *Cognition*, *8*(1), 1–71. doi:10.1016/0010-0277(80)90015-3

McKoon, G., & Ratcliff, R. (1995). How should implicit memory phenomena be modeled? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(3), 777–784. doi:10.1037/0278-7393.21.3.777

Menenti, L., Petersson, K. M., Scheeringa, R., & Hagoort, P. (2008). When elephants fly: Differential sensitivity of right and left inferior frontal gyri to discourse and world knowledge. *Journal of Cognitive Neuroscience*, *21*(12), 2358–2368. doi:10.1162/jocn.2008.21163

Myers, J. L., Cook, A. E., Kambe, G., Mason, R. A., & O'Brien, E. J. (2000). Semantic and episodic effects on bridging inferences. *Discourse Processes*, *29*(3), 179–199. doi:10.1207/S15326950dp2903_1

Myers, J. L., & O'Brien, E. J. (1998). Accessing the discourse representation during reading. *Discourse Processes*, *26* (2–3), 131–157. doi:10.1080/01638539809545042
Nieuwland, M. S., & Kuperberg, G. R. (2008). When the truth is not too hard to handle: An event-related potential study on the pragmatics of negation. *Psychological Science*, *19*(12), 1213–1218. doi:10.1111/j.1467-9280.2008.02226.x
Nieuwland, M. S., & Van Berkum, J. J. A. (2006). When peanuts fall in love: N400 evidence for the power of discourse. *Journal of Cognitive Neuroscience*, *18*(7), 1098–1111. doi:10.1162/jocn.2006.18.7.1098
O'Brien, E. J., & Albrecht, J. E. (1991). The role of context in accessing antecedents in text. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(1), 94–102. doi:10.1037/0278-7393.17.1.94
O'Brien, E. J., & Albrecht, J. E. (1992). Comprehension strategies in the development of a mental model. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(4), 777–784. doi:10.1037//0278-7393.18.4.777
O'Brien, E. J., & Cook, A. E. (2016a). Coherence threshold and the continuity of processing: The RI-val model of comprehension. *Discourse Processes*, *53*(5–6), 326–338. doi:10.1080/0163853X.2015.1123341
O'Brien, E. J., & Cook, A. E. (2016b). Separating the activation, integration, and validation components of reading. In B. H. Ross (Ed.), *Psychology of learning and motivation* (Vol. 65, pp. 249–276). Cambridge, MA: Academic Press.
O'Brien, E. J., Cook, A. E., & Guéraud, S. (2010). Accessibility of outdated information. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(4), 979–991. doi:10.1037/a0019763
O'Brien, E. J., Cook, A. E., & Peracchi, K. A. (2004). Updating situation models: Reply to Zwaan and Madden (2004). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(1), 289–291. doi:10.1037/0278-7393.30.1.289
O'Brien, E. J., & Myers, J. L. (1999). Text comprehension: A view from the bottom up. In S. R. Goldman, A. C. Graesser, & P. W. van den Broek (Eds.), *Narrative comprehension, causality, and coherence: Essays in honor of tom trabasso* (pp. 35–53). Mahwah, NJ: 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*(5), 1200.
Perfetti, C. A., & Frishkoff, G. A. (2008). The neural bases of text and discourse processing. In B. Stemmer & H. A. Whitaker (Eds.), *Handbook of the neuroscience of language* (pp. 165–174). Cambridge, MA: Elsevier.
Rapp, D. N. (2008). How do readers handle incorrect information during reading? *Memory & Cognition*, *36*(3), 688–701. doi:10.3758/MC.36.3.688
Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*(3), 372–422. doi:10.1037/0033-2909.124.3.372
Rayner, K., & Duffy, S. A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition*, *14*(3), 191–201. doi:10.3758/BF03197692
Rayner, K., & Liversedge, S. P. (2011). Linguistic and cognitive influences on eye movements during reading. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The Oxford handbook of eye movements* (pp. 751–766). New York, NY: Oxford University Press.
Rayner, K., Sereno, S., Morris, R. K., Schmauder, A., & Clifton, C. (1989). Eye movements and on-line language comprehension processes. *Language and Cognitive Processes*, *4*, SI21–SI49. doi:10.1080/01690968908406362
Rayner, K., & Slattery, T. J. (2009). Eye movements and moment-to-moment comprehension processes in reading. In R. K. Wagner & C. P.-S. Schatschneider, C. (Eds.), *Beyond decoding: The behavioral and biological foundations of reading comprehension* (pp. 27–45). New York, NY: Guilford Press.
Rayner, K., Warren, T., Juhasz, B. J., & Liversedge, S. P. (2004). The effect of plausibility on eye movements in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(6), 1290–1301. doi:10.1037/0278-7393.30.6.1290
Richter, T. (2011). Cognitive flexibility and epistemic validation in learning from multiple texts. In J. Elen, E. Stahl, R. Bromme, & G. Clarebout (Eds.), *Links between beliefs and cognitive flexibility: Lessons learned* (pp. 125–140). Dordrecht, The Netherlands: Springer Netherlands.
Richter, T. (2015). Validation and comprehension of text information: Two sides of the same coin. *Discourse Processes*, *52*(5–6), 337–355. doi:10.1080/0163853X.2015.1025665
Richter, T., Schroeder, S., & Wöhrmann, B. (2009). You don't have to believe everything you read: Background knowledge permits fast and efficient validation of information. *Journal of Personality and Social Psychology*, *96*(3), 538–558. doi:10.1037/a0014038
Rinck, M., Gámez, E., Díaz, J. M., & De Vega, M. (2003). Processing of temporal information: Evidence from eye movements. *Memory & Cognition*, *31*(1), 77–86. doi:10.3758/bf03196084
Rizzella, M. L., & O'Brien, E. J. (2002). Retrieval of concepts in script-based texts and narratives: The influence of general world knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(4), 780–790. doi:10.1037/0278-7393.28.4.780
Sanford, A. J., & Garrod, S. C. (1989). What, when, and how? Questions of immediacy in anaphoric reference resolution. *Language and Cognitive Processes*, *4*(3–4), SI235–SI262. doi:10.1080/01690968908406369
Schotter, E. R., Tran, R., & Rayner, K. (2014). Don't believe what you read (only once): Comprehension is supported by regressions during reading. *Psychological Science*, *25*(6), 1218–1226. doi:10.1177/0956797614531148

Schroeder, S., Richter, T., & Hoever, I. (2008). Getting a picture that is both accurate and stable: Situation models and epistemic validation. *Journal of Memory and Language*, *59*(3), 237–255. doi:10.1016/j.jml.2008.05.001

Singer, M. (2006). Verification of text ideas during reading. *Journal of Memory and Language*, *54*(4), 574–591. doi:10.1016/j.jml.2005.11.003

Singer, M. (2013). Validation in reading comprehension. *Current Directions in Psychological Science*, *22*(5), 361–366. doi:10.1177/0963721413495236

Singer, M. (2019). Challenges in processes of validation and comprehension. *Discourse Processes*, *56*(5–6), 465–483. doi:10.1080/0163853X.2019.1598167

Singer, M., Halldorson, M., Lear, J. C., & Andrusiak, P. (1992). Validation of causal bridging inferences. *Journal of Memory and Language*, *31*, 507–524. doi:10.1016/0749-596X(92)90026-T

Stewart, A. J., Pickering, M. J., & Sturt, P. (2004). Using eye movements during reading as an implicit measure of the acceptability of brand extensions. *Applied Cognitive Psychology*, *18*(6), 697–709. doi:10.1002/acp.1024

Swanson, H. L., Cochran, K. F., & Ewers, C. A. (1989). Working memory in skilled and less skilled readers. *Journal of Abnormal Child Psychology*, *17*(2), 145–156. doi:10.1007/BF00913790

Tanenhaus, M. K., & Trueswell, J. C. (1995). *Sentence comprehension*. San Diego, CA: Academic Press. doi:10.1016/B978-012497770-9.50009-1

van Berkum, J. A., Hagoort, P., & Brown, C. M. (1999). Semantic integration in sentences and discourse: Evidence from the N400. *Journal of Cognitive Neuroscience*, *11*(6), 657–671. doi:10.1162/089892999563724

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), 1–22. doi:10.1016/0749-596X(88)90045-9

van den Broek, P., & Helder, A. (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

van den Broek, P., Young, P. 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.

van Moort, M. L., Jolles, D., Koornneef, A., & van den Broek, P. (submitted). *What you read vs what you know: Neural correlates of accessing context information and prior knowledge in constructing a mental representation during reading.*

Van Moort, M. L., Koornneef, A., & Van den Broek, P. (2018). Validation: Knowledge- and text-based monitoring during reading. *Discourse Processes*, *55*(5–6), 480–496. doi:10.1080/0163853x.2018.1426319

Walsh, E. K., Cook, A. E., & O'Brien, E. J. (2018). Processing real-world violations embedded within a fantasy-world narrative. *Quarterly Journal of Experimental Psychology*, *71*(11), 2282–2294. doi:10.1177/1747021817740836

Yuill, N., & Oakhill, J. (1991). *Children's problems in text comprehension: An experimental investigation*. New York, NY: Cambridge University Press.

Zabrucky, K., & Ratner, H. H. (1986). Children's comprehension monitoring and recall of inconsistent stories. *Child Development*, *57*(6), 1401–1418. doi:10.2307/1130419

Zwaan, R. A., & Singer, M. (2003). Text comprehension. In A. C. Graesser, M. A. Gernsbacher, & S. R. Goldman (Eds.), *Handbook of discourse processes* (pp. 83–121). Mahwah, NJ: Erlbaum.