Robust Inference Processes in the Comprehension of Expository Text

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Abstract

Expository text offers particular challenges to the reader because of the abstract and unfamiliar concepts that it presents and its distinctive structure. In three experiments, we applied a paradigm designed to diagnose readers' derivation of causal bridging inferences from expository text. Experiment 1 compared readers' inference computation for short and long passages. The joint pattern of reading times for target sentences and answer time for questions probing the inference indicated that the inferences had accompanied reading, an outcome previously detected for short passages only. Experiments 2a and 2b indicated that the scrutinized inferences accompanied reading only in the presence of appropriate causal connectives. We interpreted these findings with reference the inference validation model (e.g., Singer & Halldorson, 1996).
Expository texts pervade many realms of human activity. These texts are instrumental in presenting new ideas to the reader, and appear in forms including the technical journal paper, the college textbook, and the nonprofessional magazine article. This study was undertaken to inspect people's ability to derive inferences during the reading of expository text. The main goal was to determine whether inference processes revealed in prior investigations of very brief expository passages generalize to longer texts.

There are numerous reasons to scrutinize the inference processes specifically associated with expository text. First, the structure of expository text differs systematically from those of other genres. Expository texts frequently present abstract categories, such as mechanisms and descriptions. These categories, in turn, are organized into abstract structures, such as lists, rhetorical networks, and hierarchies (Black, 1985; Seely & Long, 1994). Second, people may approach expository text with goals, explicit or implicit, that differ from the ones that they adopt for other genres. These goals are realized in the form of genre-specific orienting tasks (Zwaan, 1994).

Third, expository texts present less familiar information than do narratives and texts of other types. The impact of familiarity on text comprehension has been clarified by the study of comprehension by readers high and low in the knowledge relevant to text. Knowledgeable readers derive more detailed representations from text than do less knowledgeable readers (McNamara, Kintsch, Songer, & Kintsch, 1996; Rukavina & Daneman, 1996) and can inferentially apply the information that they derive from text better than uninformed readers. This is likely because knowledgeable readers continuously interpret text with reference to a rich knowledge base (McNamara et al., 1996; Wineburg, 1998). There is evidence that this knowledge is brought to bear on the text ideas in an automatic fashion (Haenggi & Perfetti, 1994; Kintsch, 1994).

Thus, the complex structures, distinct reader goals, and unfamiliar information of expository text might be posited to impede inference processing. Kieras (1985) proposed,
however, that readers have robust procedures to derive inferences from unfamiliar text. These procedures include the construction of the idea units, or propositions, of the text; and the assembly of those propositions into higher level representations, such as macrostructures (Kintsch & van Dijk, 1978). Kieras presented evidence that readers could inferentially extract generalizations and deductions from unfamiliar text information.

Our investigation was guided by the validation model of inference processing (Singer, Halldorson, Lear, & Andrusiak, 1992; Singer, Revlin, & Halldorson, 1990; see also Noordman, Vonk, & Kempff, 1992; Revlin & Hegarty, 1999). The model can be explained in terms of sequence (1):

(1) a. Dorothy poured the bucket of water on the bonfire.
   b. The fire went out.

A complete understanding of sequence (1) requires the bridging inference (Haviland & Clark, 1974; Singer, 1980) that pouring water on the fire caused it to go out. The validation analysis states that tentative bridging inferences must be validated with reference to world knowledge before they are accepted by the understander. First, the candidate cause of a text outcome is combined with the outcome to form a mediating idea. For the present example, the mediating idea might take the form, "Water extinguishes fire." The mediating idea is compared with relevant knowledge and if it is found to be consistent, then the inference has been validated. Consistent with this analysis, people take less time to verify familiar facts such as Water extinguishes fire after reading causal sequences posited to require their involvement, such as (1); than after control, temporal sequences, such as Dorothy PLACED the bucket of water BY the bonfire, The fire went out (Singer & Halldorson, 1996; Singer et al., 1992). The mediating idea that relates the text outcome with the candidate cause is by no means always consistent with general knowledge. The contrasting sequence, Dorothy poured the GASOLINE on the bonfire, The fire went out, might result in the construction of the mediating idea, "Gasoline extinguishes fire." Readers readily detect the contradiction between this fact and their general knowledge.
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(Singer, 1993).

In the context of this analysis, we examined readers' expository text inference processes with reference to sentences such as (2) in the present study:

(2) Some fireworks emit crimson flames because they contain calcium salt.

The conjunction *because* signals that the subordinate clause identifies the cause of the idea conveyed by the main clause. According to the validation analysis, the reader will construct a mediating idea such as "calcium salts burn with a red colour." The typical reader has no knowledge with which to evaluate this mediating idea, in contrast with the situation for Dorothy poured the bucket of water on the bonfire. The fire went out. Nevertheless, the reader can accept the mediating idea, on the premise that the writer is being cooperative (Grice, 1975).

Singer, Harkness, and Stewart (1997) examined the reader's validation of causal bridging inferences using a paradigm introduced by Noordman et al. (1992) and illustrated in Table 1. In the implicit condition of this paradigm, the reader encounters the target sentence (b) embedded in a passage. In the explicit condition, in contrast, target sentence (b) is preceded by explicit sentence (a). Sentence (a) directly expresses an idea which, according to the validation analysis, mediates the clauses of the target sentence. Singer et al. reported that answer time for a question that queried the mediating idea, such as *Do calcium salts emit crimson flames?*, was about equal after passages in the explicit and implicit conditions. Following the logic of Noordman et al. (1992), they concluded that, upon reading sentence (b) in the implicit condition, the readers engaged in inference validation. Other, more difficult, sequences of this sort appear to prohibit such inferences (Noordman et al., 1992).

Insert Table 1 about here

There is other, converging evidence that readers derive causal inferences during expository comprehension. Examining sequences similar to those of Table 1, Singer and Gagnon (1999) reported that, during reading, people detected inconsistencies between explicit sentence (a) and the mediating idea posited to underlie target sentence (b). They concluded that the
readers must have inferred the mediating idea during reading, because the norms of Singer et al. (1997) indicated that people generally do not know the ideas that were examined. In another project, Graesser and his colleagues (Graesser & Bertus, 1998; Millis & Graesser, 1994) invoked the constructionist principle (Graesser, Singer, & Trabasso, 1994) that readers infer the explanations of text outcomes. As a result, they predicted that inferences about causal antecedents would accompany the comprehension of expositions. In contrast, the principle of explanation makes no prediction about readers' inferences about the consequences of text outcomes. Consistent with this analysis, lexical decision times revealed that text outcomes facilitated ideas that constituted causal antecedents but not the causal consequences of those outcomes (Millis & Graesser, 1994).

In the investigations antecedent to this one (Singer & Gagnon, 1999; Singer et al., 1997), the crucial experimental sequences were embedded in passages that were four sentences long (in the explicit condition). One goal of the present study to confirm that Singer et al.'s findings about expository text inference processes apply to longer passages. This is a matter of considerable importance. Singer et al. derived their materials from a science encyclopedia to ensure that they were natural, informative, and coherent (Magliano & Graesser, 1991). However, some researchers have questioned the generality of findings based on the study of short passages (Graesser & Bertus, 1998, p. 250; Graesser, Haberlandt, & Koizumi, 1987; Magliano & Graesser, 1991). In the domain of inference processes, Magliano and Graesser proposed that the sparse context of a short passage might contribute to processing patterns different from that of a long passage.

These concerns converge with the results of Noordman et al. (1992), which denied the on-line validation of bridging inferences. Those data were derived from the inspection of passages of mean length 7.6 sentences, about double that of the passages of Singer et al. (1997). It is noteworthy that readers failed to derive these inferences even when Noordman et al.'s texts were presented in a shortened form (Singer et al., 1997). Nevertheless, the data profile that
supports the on-line derivation of these inferences had been observed only with very short passages. Therefore, it was considered important to examine these processes with reference to longer texts.

The relation of text length to inference construction has several theoretical bases. First, in a short passage, experimental sequences such as the ones under consideration are located, by necessity, at or near the outset of the passage. They therefore have enhanced thematic status. In this regard, concepts that are mentioned toward the outset of an expository passage are judged to be the main idea more than comparable concepts that are introduced later (Kieras, 1980). Likewise, concepts that are mentioned early in a text function as more effective recall cues than do later concepts (Kieras, 1981). The impact of position of mention on the thematic status of a text idea is important for the present purposes because inference processes have been shown to favor thematic ideas in text comprehension (Cirilo, 1981; Goetz, 1979; Walker & Meyer, 1980).

Second, the volume of ideas of a long passage would place high demands on the cognitive resources of the reader, which in turn might impede inference processing. For example, assigning participants the highly demanding task of proofreading a text abolished a pattern of inference processing that appeared in other reading conditions (Singer & Halldorson, 1996, Experiment 4). In a more direct demonstration of this sort, Daneman and Carpenter (1980) showed that readers' ability to inferentially resolve text anaphors decreased with the number of sentences intervening between the anaphor and its antecedent. However, readers high in working memory resources were immune to these effects for the inspected range of two to seven intervening sentences. The impact of the length of an expository text on processing load would be compounded by the unfamiliarity of the words and concepts it presented (Just & Carpenter, 1992; Kintsch, 1994; Rukavina & Daneman, 1996; Wineburg, 1998).

These theoretical considerations raise the possibility that text length will interact with variables that influence inference processing. That is, inferences might accompany reading in favorable conditions (e.g., high thematic status, low cognitive load) only in shorter texts.
evidence that bears on this problem is mixed. On the dependent variable of text recall, which is not a highly inferential measure, text length has been observed to interact with text difficulty (Browne, 1989) and position of the text subunit (Rothkopf & Billington, 1983). Hartley (1993), in contrast, measured no Length x Age interaction in text recall, contrary to the expectation that the detrimental impact of text length would increase with age. Likewise, length did not interact with vocabulary difficulty in readers' ability to infer word meaning (Browne, 1989) nor with the number of new text concepts on the measure of reading time per text idea recalled (Kintsch, Kozminsky, Streby, McKoon, & Keenan, 1975).

The possible interaction of text length with inferential status was of central concern in the first experiment. Experimental expository passages were cycled across the four conditions obtained by crossing passage length and relation (explicit, implicit -- see Table 1). The main predictions focused on the answer time for the questions that probed the posited mediating ideas. For the short passages, approximately equal explicit and implicit answer times were expected, in view of Singer et al.'s (1997) previous findings. The validation model (Singer et al., 1992), considered earlier, suggests the same outcome for the long passages, by virtue of the contribution of validation processes to the coherence of the text representation. In contrast, some of the methodological, theoretical, and empirical considerations examined earlier suggest that answer time might be greater in the implicit condition than the explicit condition; reflecting the readers' failure to derive the inferences in the implicit condition of long passages.

These hypotheses were complemented by reading time predictions. Noordman et al. (1992) reasoned that if readers derive the critical inferences from the target sentences, then target reading time should be longer in the implicit condition than the explicit condition. This is because the appearance of the explicit sentence in the explicit condition (see Table 1) makes it unnecessary for the reader to extract the critical inference from the target sentence. In summary, according to Noordman et al.'s analysis, on-line inferences of this sort are diagnosed by the observation of longer implicit than explicit target reading times coupled with equal implicit and
explicit answer-times.

**Experiment 1**

**Method**

**Participants**

The participants were 75 male and female native-English-speaking students of introductory psychology at the University of Manitoba. They participated in partial fulfillment of a course requirement.

**Materials**

The materials were short and long texts based on 20 passages that were studied by Singer et al. (1997). Those authors chose their texts from a pool of 35 passages that they derived from the McGraw-Hill encyclopedia of science and technology (1992). We randomly assigned 12 of the 20 passages to act as experimental items and 8 to be fillers. Central to each passage was a sequence illustrated by set (3) in Table 2:

**Insert Table 2 about here**

For each passage, Singer et al. (1997) constructed target sentences (unless the original Encyclopedia entries included a suitable target) and corresponding explicit sentences. In each target sentence, the conjunction because signaled that the subordinate clause identified the cause of the main clause idea. As described earlier with reference to Table 1, a passage represented the explicit condition when it included the explicit sentence, and the implicit condition when it excluded the explicit sentence.

The explicit sentences were constructed to express the idea that mediated the cause and effect of target sentences such as (3b): that is, the idea that explains why the cause in sentence (3b) brings about the effect. Singer et al. (1997) derived the explicit sentences from the ideas that four expert respondents identified as mediating the main and subordinate clauses of the target sentences. The explicit sentences differed from their corresponding targets by several synonyms. For example, sentence (3a) used inclined and unusual whereas (3b) used tilted and
peculiar. The impact of this feature of the materials will be explained later.

The passages of Singer et al. (1997) were four sentences long (in the explicit condition), and constituted the short texts of the present study. The present long texts ($M = 9.25$ sentences, $SD = 1.14$) were based on the short passages but preserved much more of their respective encyclopedia entries. The long texts differed from the encyclopedia entries in some ways. First, some of the original sentences were altered to maintain passage coherence, to eliminate especially technical terms, or to achieve a reduction in sentence length. Second, sentences from the original entry were sometimes moved to prevent the experimental sequence from appearing at the beginning or the end of the passage. Aside from the latter consideration, the position of the experimental sequence in the passage was not manipulated. As a result, the target sentences could appear in positions ranging from 7th-last to 2nd-last in their passages. Table 2 presents the short and long versions of one passage.

For each experimental passage, there were two questions. The experimental question queried the fact that was posited to mediate the cause and the effect of the target sentence and that was stated directly in the explicit sentence. The experimental question for the materials of Table 2, shown at the bottom of the table, was Do tilted planetary axes produce peculiar seasons? It was explained earlier that the explicit and target sentences differed by several synonyms. The experimental question used the distinctive synonyms of the target sentence, because the target sentence appeared in both the explicit and implicit conditions.

The second question of each experimental passage queried one of its details. An example appears at the end of Table 2. These questions were included to discourage the participants from focusing exclusively on background knowledge pertinent to the texts. Half of the detail questions had the correct answer "yes."

The filler passages were similar to the experimental passages except that their question about inference-relevant knowledge had the correct answer "no." This was intended to prevent the participants from thoughtlessly answering "yes" to all general knowledge questions. Each of
the four Relation x Length conditions were mimicked by two different filler passages. Each filler passage was also followed by a detail question, half of which had the correct answer, "yes."

From these materials, four experimental lists were constructed. For the first list, the 12 experimental passages were randomly assigned, in equal numbers, to the four conditions. The passages were then randomly assigned to one of 20 available list positions, subject to the restrictions that at least one passage in each condition appear in each half of the list and that no two consecutive items in the list represent the same condition. The filler passages were randomly assigned to the remaining list positions, with the constraint that one filler passage mimicking each condition be assigned to each half of the list.

The remaining three lists were obtained by cycling the experimental items across the four conditions, following a Latin-square design. As a result, each list included an equal number of passages in each condition; and, across the four lists, each experimental item appeared once in each condition. The filler items were constant in form across the lists. Each list was preceded by one practice passage.

Procedure

The sessions were conducted with groups of one to four participants. Each participant was tested in a closed room, at a station that consisted of a personal computer, a video monitor, and a keyboard.

At the start of each trial, a message indicated that the participant could press a ready button (the keyboard space bar) to view the passage. When the ready button was pressed, the first sentence of the passage was displayed, left-adjusted, on line 5 of the monitor. The participant was instructed to read each sentence and to press "ready" again as soon as the sentence was understood. Each press of the ready button resulted in the display of the next sentence, while the prior sentences remained on the screen (Noordman et al., 1992, Experiment 1; Singer et al., 1997). Sentence reading time was measured as the time between button presses and was recorded to centisecond accuracy. If the participant did not reply to a sentence within 10
s, the next sentence automatically appeared. After the participant had responded to the last sentence of the passage, the screen went blank.

Then, 2.5 s later, an "X," serving as a fixation point, appeared for .5 s in column 1 of row 5. Then, the first question was displayed there. The participant answered the question "yes" or "no," using the "." and "x" keys, respectively. The question was removed when the participant replied; and 2.5 s later, the fixation point appeared again, followed by the second question. The order of the experimental and detail questions was random. There was an answer time limit of 6 s, after which the question disappeared and an error was credited. Answer time was automatically measured as the interval between the onset of the question and the participant's response.

At the end of any trial for which the participant had taken the full 10 s to read any of the passage sentences, a message discouraged this for 3.0 s. There was an intertrial interval of 3.0 s.

Results

The data were submitted to analysis of variance (ANOVA), alternately treating participants (F1) and items (F2) as the random variable. A significance criterion of $\alpha = .05$ was used except where otherwise indicated.

In all participants-random ANOVAs, list (the lists constructed for the purposes of counterbalancing) was a between-participants variable. The effects involving this variable had no theoretical significance, because no attempt was made to control, between the lists, factors such as sentence length and word frequency. What is important is that, across lists, each item served as its own control. Therefore, effects involving the list variable are not reported.

Reading Times

The mean reading times of the target sentences are shown in Table 3. In ANOVA treating participants as the random variable, relation and length were within-participants effects and list was a between-participants effect. With items random, both relation and length were within-items effects. Only the relation main effect reached significance, with mean reading times
of 463 cs and 489 cs in the explicit and implicit conditions, respectively, $F_1(1,67) = 11.27$, $\text{MSE} = 4,946$, $F_2(1,11) = 7.18$, $\text{MSE} = 1,212$.

Insert Table 3 about here

**Answer Times and Errors**

The mean correct answer times and error rates are displayed in Table 3. The participants-and items-random ANOVAs had the same designs as the respective reading time analyses. Table 3 reveals that the answer times in all four conditions were similar, ranging only from 2771 ms to 2849 ms. Consistent with this difference, the answer time ANOVAs revealed no effects of theoretical significance. Error rates of .09 and .14 were observed in the explicit and implicit conditions, respectively, $F_1(1,67) = 5.59$, $\text{MSE} = 0.20$, $F_2(1,11) = 8.41$, $\text{MSE} = 0.04$. No other error effects were significant.

**Discussion**

Similar answer times were observed in the explicit and implicit condition, whereas reading time was greater in the implicit condition than the explicit condition. This is precisely the pattern that, according to Noordman et al.'s (1992) analysis, diagnoses that the crucial ideas were inferred during reading in the implicit condition. It is noteworthy that this pattern was observed both for the short and the long passages. This is the first time in the application of this paradigm (Noordman et al., 1992; Singer & Gagnon, 1999; Singer et al., 1997) that, using passages of almost ten sentences in length, the evidence favored the on-line construction of the inspected inferences. Thus, the appearance of the present experimental sequences in lengthy texts derived from an original source does not prohibit the reader from inferring the crucial ideas.

The error rates were higher in the implicit condition than the explicit condition, an outcome that tends to weigh against our main conclusion. Therefore, we monitored this feature of the results in the remaining experiments and will address this point in the context of Experiment 2.
The conclusion that the scrutinized inferences accompanied comprehension derived in part from a null outcome among the answer times. Therefore, it was considered necessary, in Experiment 2, to address the null answer time result. The basic plan was to identify a condition that would hinder the readers' computation of the critical inferences. We predicted higher implicit than explicit answer times in circumstances posited to hinder inference processing.

**Experiment 2**

The target sentences of Experiment 1 were expressed in the form of sentence (4b), in Table 2 (identical to 3b). Notwithstanding the very complex structure of (4b), Experiment 1 and our previous studies indicated that readers can construct and validate its underlying causal bridging inferences. To deny uninteresting interpretations of the null answer time effects of Experiment 1, we sought a construction for the ideas of sentence (4b) that would impede the readers' inference computations. First, we deleted the conjunction. There is evidence that when text ideas are related in complex ways, the use of proper conjunctions is central to the reader's ability to extract the correct interpretation (e.g., Caron, 1988; Millis, Golding, & Barker, 1995; Millis & Just, 1994; Millis & Magliano, 1999; Mouchon, Ehrlich, & Loridant, 1999; Traxler, Bybee, & Pickering, 1997). Causal conjunctions such as *because* are particularly important in this regard.

Second, the removal of the conjunction prompted, if not required, that we express the ideas in two sentences. When a sentence introduces a new topic, there are cognitive costs associated with encoding new concepts and situational elements (Gernsbacher, 1990; Gernsbacher, Hargreaves, & Beeman, 1989; Haberlandt & Graesser, 1985; Kintsch et al., 1975; Zwaan, Magliano, & Graesser, 1995). In the present instance, the second sentence of the target sequences did not change the topic. However, we posited that determining this would impose a high cognitive cost on the reader; particularly because of the absence of an appropriate conjunction, and augmented by the complexity and unfamiliarity of the text.

The result of these two changes were target sequences such as (4c) in Table 2. In
Experiment 2a, the passages appeared in the explicit or implicit condition; and the target sequences were expressed either as (4b) or as (4c). We hypothesized that it would be difficult for a reader to derive, from (4c), the inference that tilted planetary axes produce peculiar seasons. As a result we predicted that implicit answer times would exceed explicit ones for passages with targets like (4c) but not (4b).

We were aware that, if this prediction were supported, we could not conclusively assign inference computation difficulty either to the deletion of the conjunction or to the partition of the target sentence. Therefore, in Experiment 2b, the targets in both the connective and no-connective conditions were expressed in two sentences, and differed only in terms of whether they included a conjunction. These connective and no-connective targets are shown in Table 2 as (5b) and (5c), respectively.

The main prediction, and its underlying logic, for Experiment 2b was the same as for Experiment 2a. However, because the connective and no-connective targets of Experiment 2b differed by only one of the Experiment 2a manipulations (presence or absence of That's because), we considered the possibility that Experiment 2b would reveal weaker effects than Experiment 2a.

**Method**

**Participants**

The participants were naive individuals sampled from the same participant pool that was used in Experiment 1. There were 68 participants in Experiment 2a and 64 participants in Experiment 2b.

**Materials**

The materials were derived from those of Experiment 1. The short-passage results of Experiment 1 replicated the findings of Singer et al. (1997), so Experiment 2 was performed with only the long versions of the passages.

As discussed earlier, the manipulations of Experiment 2a are illustrated by set (4) in
Table 2. The experimental sequences in the explicit connective, implicit connective, explicit no-connective, and implicit no-connective conditions respectively took the following forms: (4a)-(4b), (4b) only, (4a)-(4c), and (4c) only. From the 12 experimental passages and 8 filler passages, four counterbalanced lists were constructed in the manner of Experiment 1. Each of the experimental conditions was mimicked by two of the eight filler passages.

The materials of Experiment 2b were identical except that the experimental sequences were derived from set (5) rather than set (4) of Table 2. In all other respects, the materials of Experiment 2 were identical to those of Experiment 1.

**Procedure**

The procedure was identical to that of Experiment 1. When the target sequence consisted of two sentences (e.g., 4c), those sentences were presented separately during reading.

**Results**

**Experiment 2a**

**Target reading times.** The mean target reading times are displayed in Table 4. Reading times are reported for the sentence at which the participant had the opportunity to draw the crucial inference. This was the usual target, (4b), in the connective condition; but only the second sentence of (4c) (Its axis ...) in the no-connective condition. The resulting reading times were, therefore, of different magnitudes in the connective and no-connective condition. This was not of major concern because the main focus was the measurement of the relation effect.

The reading time ANOVAs revealed a main effect of connective, $F_1(1,64) = 292.9$, $MSE = 8,416$, $F_2(1,11) = 147.0$, $MSE = 2,930$, due to the fact that reading time was measured for a shorter sentence in the no-connective condition. The Relation x Connective interaction was significant, but only in the participants-random ANOVA, $F_1(1,64) = 4.14$, $MSE = 3,077$. As conveyed by Table 4, this interaction reflects the fact that implicit reading times exceeded explicit reading times in the connective condition only. Finally, there was a marginally
significant main effect of relation in the participants-random ANOVA, $F_{1}(1,64) = 3.01$, $MSE = 4,342$, $p = .09$.

**Answer times and errors.** The mean correct answer times and error rates of Experiment 2a are shown in Table 5. In view of the importance, for our hypotheses, of the answer-time relation effect at the different levels of connective, we performed planned comparisons to probe this effect (Boik, 1993; Kirk, 1982). The planned comparisons were complemented with full ANOVAs. The relation effect was not significant in the connective condition, $F$s < 1. In the no-connective condition, the relation effect was significant by participants and marginally significant by items, $F_{1}(1,64) = 12.08$, $MSE = 226,313$, $F_{2}(1,11) = 2.66$, $MSE = 77,930$, $p = .065$, one-tailed. Full ANOVA revealed the corresponding Relation x Connective interaction to be marginally significant, $F_{1}(1,64) = 5.13$, $MSE = 251,639$, $F_{2}(1,11) = 2.73$, $MSE = 54,828$, $p = .13$. The relation effect approached significance: explicit answer time was 112 ms shorter than implicit answer time, $F_{1}(1,64) = 9.63$, $MSE = 149,900$, $F_{2}(1,11) = 2.73$, $MSE = 54,828$, $p = .063$, one-tailed. Finally, the connective effect was not significant.

ANOVA applied to the error rates revealed only a marginally significant relation effect in the participants-random analysis, $F_{1}(1,64) = 3.46$, $MSE = 301$, $p = .07$. This outcome reflected error rates of .11 and .15 in the explicit and implicit conditions, respectively.

**Experiment 2b**

**Reading times.** The reading times of Experiment 2b are displayed in Table 4. By virtue of the design of this experiment, the connective target sentences exceeded the no-connective targets by the phrase *That's because*. Consistent with this observation, reading time was 19 cs longer in the connective condition than the no-connective condition, $F_{1}(1,60) = 6.83$, $MSE = 3,242$, $F_{2}(1,11) = 4.13$, $MSE = 1,002$, $p = .07$. Reading time was also 11 cs longer in the implicit than the explicit condition, an effect that was marginally significant by participants only, $F_{1}(1,60) = 2.36$, $MSE = 3,423$, $p = .13$. No other effects of theoretical relevance were
significant.

**Answer times and error rates.** The mean correct answer times of Experiment 2b appear in Table 5. Planned comparisons showed that the relation effect was not significant in the connective condition, $F_s < 1$, but that it was in the no-connective condition, $F_{1}(1, 60) = 12.62, \text{MSE} = 259,948, F_{2}(1, 11) = 6.18, \text{MSE} = 64,713$. Full ANOVA revealed that the corresponding Relation x Connective interaction approached significance, $F_{1}(1,60) = 6.68, \text{MSE} = 215,676, F_{2}(1,11) = 2.81; \text{MSE} = 57,352, p = .12$. The relation main effect was significant, with mean answer times 142 ms longer in the implicit condition than the explicit condition, $F_{1}(1,60) = 7.95, \text{MSE} = 233,051, F_{2}(1,11) = 3.70; \text{MSE} = 65,765, p = .04$, one-tailed. The connective main effect was not significant.

Table 5 also shows the error rates of Experiment 2b. Error proportions of .09 and .15 were measured in the explicit and implicit conditions, respectively, $F_{1}(1,60) = 7.48, \text{MSE} = .26, F_{2}(1,11) = 11.47, \text{MSE} = 33$.

**Experiments 2a and 2b: Combined Analyses**

According to our analysis, relation effects were expected in the no-connective conditions of Experiments 2a and 2b but not in the connective conditions. Planned comparisons corroborated this prediction but the corresponding Relation x Connective did not invariably attain conventional levels of significance. On the justification that Experiments 2a and 2b were highly similar in their designs, we next merge their answering data. The combined mean correct answer times and error rates of Experiments 2a and 2b are presented in Table 5. In ANOVAs treating participants as the random variable, list and experiment (2a, 2b) were between-participants variables, and relation and connective were within-participants variable. With items-random, relation, connective, and experiment were all within-items variables. Planned comparisons revealed that the relation effect was not significant in the connective condition, $F_s < 1$, but that it was in the no-connective condition, $F_{1}(1, 124) = 24.78, \text{MSE} = 242,588, F_{2}(1, 11) = 6.10, \text{MSE} = 99,507$. Full ANOVA yielded a main effect of relation, $F_{1}(1,124) = 17.31, \text{MSE} = 233,051, F_{2}(1,11) = 3.70; \text{MSE} = 65,765, p = .04$, one-tailed. The connective main effect was not significant.
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190,134, $F_2(1,11) = 4.01$, $\text{MSE} = 102,670$, $p = 0.04$, one-tailed; and a Relation x Connective interaction, $F_1(1,124) = 11.67$, $\text{MSE} = 234,237$, $F_2(1,11) = 8.90$, $\text{MSE} = 23,821$. Analysis of the error rates revealed only a main effect of relation, $F_1(1,124) = 10.64$, $\text{MSE} = 295$, $F_2(1,11) = 7.29$, $\text{MSE} = 63$.

Discussion

In Experiment 1, explicit and implicit answer times were approximately equal to one another both for the short and long expository texts. Experiments 2a and 2b were designed to discount uninteresting interpretations of the null explicit versus implicit (relation) effect on the answer time measure. Therefore, in Experiment 2, conditions were created to impede the inference processes of interest. In Experiment 2, connective targets were expressed in one sentence whereas no-connective targets were expressed in two sentences (Experiment 2a); or all targets were expressed in two sentences, but some included a connective and others did not (Experiment 2b). The most important result was that answer time was appreciably higher in the implicit condition than the explicit condition only in the absence of the connective. We interpret this outcome to indicate that, in the implicit no-connective condition, the crucial inferences had to be computed, at least in part, when the experimental question was presented. We propose, conversely, that in the other conditions, the critical idea was encoded during comprehension either because it was directly presented (the explicit conditions) or because the reader had successfully inferred it during reading.

Ideally, the target reading times of this paradigm complement the answer times. Following the logic of Noordman et al. (1992), when the inferences in question accompany comprehension, implicit reading times ought to exceed explicit ones, reflecting the cognitive processes that contribute to those inferences. Consistent with this proposal, in those conditions in which the answer times favored on-line inference processing (Experiment 1 plus the connective conditions of Experiments 2a and 2b), implicit reading time exceeded explicit reading time, with a range of 14 to 31 cs. In the no-connective conditions of Experiments 2a and 2b, in
contrast, the comparable differences were -1 and 7 cs. The joint answer time and reading time profile is highly consistent with the computation of the critical inferences during reading in all conditions except the no-connective ones.

Across Experiments 1 and 2, the implicit error rates exceeded the explicit ones by a generally consistent and usually significant margin of 5%. This outcome might be argued to deny that, in the implicit condition, the readers were constructing and validating the critical bridging inference. However, we offer a somewhat different interpretation. In the present experiments, after passages in which the readers exceeded the 10-s reading time limit for at least one sentence, we urged them to read more quickly. This procedure was used only once before in this project (Singer et al., 1997, Experiment 3). We propose that in conditions such as these, the readers engage in inference validation but derive the wrong inference somewhat more often in the implicit condition than the explicit condition.

To evaluate this claim, it is useful to consider these error rates in the context of the unfamiliarity of the critical ideas. A norming procedure of Singer et al. (1997) revealed a mean error proportion of .35 for these ideas, in contrast with .12 for 52 easy science questions (e.g., do fish use gills to breathe?).1 Across Experiment 1 and the connective conditions of Experiment 2, the mean implicit error rate was .14; a value hardly different from the easy-question norming score of .12. This relatively high performance could result only if the readers were inferring useful information from the implicit targets.

One difficulty with this interpretation is that, in those instances in which the reader makes the wrong inference, they should sometimes be able construct the correct inference at test time and so answer correctly. Answer time in this circumstance would exceed that in which the correct inference was derived during reading. As a result, the overall mean implicit answer time would represent an averaging of faster and slower answer times; and, consequently, exceed explicit answer times. Close scrutiny reveals that our results are generally consistent with this possibility. In every condition of Experiments 1 and 2 that used a connective, implicit answer
time slightly (and never significantly) exceeded explicit answer time; by a range of 27 to 71 ms. Therefore, we conclude that, when the connective is present, readers engage in the inference processes under inspection, but occasionally construct the wrong inference.

The main purpose of manipulating the connective in Experiment 2 was to create conditions that hampered inference construction. The present results, however, advance our understanding the role of the connective in text comprehension. First, most antecedent studies evaluated the impact of the connective in terms measures such as text memory and reading times, whereas the present investigation focused on inferential measures that reflected the reader's ability to integrate and synthesize the information from related sentences or clauses. Second, most antecedent studies have examined these processes with reference to narrative materials, and often in the context of brief materials constructed for the purpose of experimentation (see, however, @Spyridakis & Standal, 1987). Experiment 2, in contrast, inspected relatively long, naturalistic, expository texts. Therefore, the present results offer a significant generalization of the impact upon comprehension of the felicitous use of connectives.

**General Discussion**

This study continued our investigations of the inference processes that accompany the comprehension of expository text. The data revealed that text length did not affect the readers' construction and validation of causal bridging inferences. This is an important outcome if the present paradigm and others are to be used to evaluate the impact of the text and reader factors that guide inference processing in the comprehension of expositions. Until now, studies that inspected passages longer than four sentences tended to deny the on-line construction of these inferences (Noordman et al., 1992). In addition, both researchers' caveats (e.g., Graesser & Bertus, 1998; Magliano & Graesser, 1991) and the thematic structure, cognitive load, and unfamiliarity of expository texts raised doubts about whether these inferences might accompany the comprehension of longer expositions.

One factor that may have contributed to the on-line construction of these inferences is
that all of the component ideas appeared in the experimental sequences, which, in turn, did not exceed three sentences in length (e.g., explicit condition, Experiment 2b). As such, the inferences in question were relatively local. It is possible that inferences that, in the comprehension of expository text, require the recruitment of ideas from disparate portions of the text plus from general knowledge might not reliably accompany reading. It is noteworthy, however, that Singer and Gagnon (1999) presented evidence that favored on-line inference processing even when the present explicit and target sentences were separated by two intervening sentences, albeit in brief passages.

The second main finding was that the absence of appropriate connectives appreciably impaired the computation of the crucial inferences (Experiment 2). This outcome was important in the present context, in order to discount the possibility that the present methods did not have the power to distinguish among relevant conditions. In addition, this result complements previous findings that the comprehension of narratives is regulated by informative connectives (Caron, 1988; Millis et al., 1995; Millis & Just, 1994; Millis & Magliano, 1999; Mouchon et al., 1999; Traxler et al., 1997). The present effects of connective bear on the ideal form of expository texts. In this regard, Britton and Gulgoz (1991) used theoretical principles of coherence (Kintsch & van Dijk, 1978) as a guide for improving expository texts, including the addition of apt connectives. For example, they revised As frustration mounted over the inability of the ARVN to defeat the enemy . . . to The South Vietnamese army was losing the ground war against North Vietnam and this CAUSED frustrations among the American officials. Britton and Gulgoz found that free recall of their revised texts exceeded that of the originals. They also reported that the readers' representation of the revisions were more similar to the authors' intended text representations than were the readers' representation of the originals.

A complete theory of inference in reading gains from the scrutiny of expository text. Expositions differ from narratives particularly in their typical structure and the unfamiliarity and abstractness of the ideas that they present (Black, 1985; Miller, 1985). These qualities have the
capacity to impair inference processing. For example, the unfamiliarity of expository ideas may prevent the reader from detecting important relations among text ideas. On the other hand, to posit that nonexpert readers can derive no inferences from complex expositions would deny that people can learn from expositions (cf. Goldman, 1997; McNamara & Kintsch, 1996). In this regard, the analysis and evidence of Kieras (1985) indicated that general procedures of reading permit people to derive low and high levels of text structure (i.e., textbase, macrostructure, Kintsch & van Dijk, 1978) even from unfamiliar texts. These representations, in turn, provide the basis for at least some of the inferences fundamental to the representation of the text.

The conclusion that we offer, therefore, is that the inferences processes that permitted our readers to exhibit relatively fast and accurate judgements about the present experimental questions stem from the comprehension procedures of the competent reader (e.g., university students). Although there are definite limits to the quality and quantity of inferences that accompany reading (see Singer, 1994, for a review), we consider our results to suggest that the competent reader possesses some robust general procedures for inferentially linking text ideas in expository text.
References


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Author Notes

This research was supported by Research Grant OGP9800 from the Natural Sciences and Engineering Research Council of Canada to the first author. Experiments 1 and 2a were presented at the meeting of the Canadian Society for Brain, Behavior, and Cognitive Science, Edmonton, June, 1999. We acknowledge the contribution of Susan Stewart, who compiled the long texts from which we derived the experimental materials. We are grateful to Karen McClure and Paula MacPherson for their assistance with the data collection and tabulation, and to Paula MacPherson for also providing us with feedback about the manuscript. Please address correspondence to Murray Singer, Department of Psychology, University of Manitoba, Winnipeg, Canada R3T 2N2.
Footnotes

1. After a correction for guessing, the experimental ideas had a mean familiarity score of .30 on a scale of -1 to +1, in contrast with .76 for the easy science questions (Singer et al., 1997).
Table 1

Materials Illustrating the Experimental Conditions

Explicit Condition
(a) Calcium salt produces a red flame. (explicit)
(b) Some fireworks emit crimson flames because they contain calcium salt. (target)

Implicit Condition
(b) Some fireworks emit crimson flames because they contain calcium salt. (target)

Question
Do calcium salts emit crimson flames?
Sample Materials of Experiments 1 and 2

**Experiment 1**

**Experimental Sequence**

(3)  
 a. An inclined planetary axis produces unusual seasons. (explicit)  
 b. The seasons on Uranus are very peculiar because its axis is tilted so that it is almost in the plane of its orbit. (target)

**Short Version**

Uranus was the first planet to be discovered with the telescope and is the seventh in order of distance from the sun.

An inclined planetary axis produces unusual seasons. (explicit)

The seasons on Uranus are very peculiar because its axis is tilted so that it is almost in the plane of its orbit. (target)

This means that 'day' and 'night' for an observer at the north or south pole of Uranus each last for more than forty years.

**Long Version**

Uranus was the first planet to be discovered with the telescope and is the seventh in order of distance from the sun.

This planet is just visible to the naked eye in a dark sky when its position among the stars is known.

An inclined planetary axis produces unusual seasons. (explicit)

The seasons on Uranus are very peculiar because its axis is tilted so that it is almost in the plane of its orbit. (target)
This means that 'day' and 'night' for an observer at the north or south pole of Uranus each last for more than forty years.

The mass of Uranus is almost 15 times that of the earth.

The temperature on Uranus is about -360 degrees Fahrenheit, according to calculations.

Through the telescope, Uranus appears as a small, slightly elliptical blue-green disk.

Uranus owes its characteristic aquamarine colour to the relatively high proportion of methane in its atmosphere.

**Experiment 2a**

(4) a. An inclined planetary axis produces unusual seasons. (explicit)

   b. The seasons on Uranus are very peculiar because its axis is tilted so that it is almost in the plane of its orbit. (connective target)

   c. The seasons on Uranus are very peculiar. Its axis is tilted so that it is almost in the plane of its orbit. (no-connective target)

**Experiment 2b**

(5) a. An inclined planetary axis produces unusual seasons. (explicit)

   b. The seasons on Uranus are very peculiar. That's because its axis is tilted so that it is almost in the plane of its orbit. (connective target)

   c. The seasons on Uranus are very peculiar. Its axis is tilted so that it is almost in the plane of its orbit. (no-connective target)

**Questions (All Experiments)**

Do tilted planetary axes produce peculiar seasons? (experimental question)

Does 'day' last for more than forty years at the south pole of Uranus? (detail question)
Table 3

Mean Target Reading Times (in centiseconds) and Answer Times (in milliseconds) in Experiment 1

<table>
<thead>
<tr>
<th>Relation</th>
<th>Passage</th>
<th>Measure</th>
<th>Length</th>
<th>Explicit</th>
<th>Implicit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reading time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Short</td>
<td>463</td>
<td>494</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>462</td>
<td>484</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Answer time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Short</td>
<td>2771 (.07)</td>
<td>2849 (.15)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>2815 (.10)</td>
<td>2846 (.13)</td>
<td></td>
</tr>
</tbody>
</table>

Note. Error rates in parentheses.
Table 4
Mean Target Reading Times (in centiseconds) in Experiment 2

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Connective</th>
<th>Explicit</th>
<th>Implicit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. 2a</td>
<td>Yes</td>
<td>468</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>292</td>
<td>291</td>
</tr>
<tr>
<td>Exp. 2b</td>
<td>Yes</td>
<td>275</td>
<td>289</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>260</td>
<td>267</td>
</tr>
</tbody>
</table>
Table 5

Mean Answer Times (in Milliseconds) in Experiment 2

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Connective</th>
<th>Explicit</th>
<th>Implicit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. 2a</td>
<td>Yes</td>
<td>3058 (.10)</td>
<td>3096 (.14)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3023 (.13)</td>
<td>3209 (.16)</td>
</tr>
<tr>
<td>Exp. 2b</td>
<td>Yes</td>
<td>3038 (.08)</td>
<td>3065 (.13)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2966 (.10)</td>
<td>3224 (.16)</td>
</tr>
<tr>
<td>Exps. 2a and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b Combined</td>
<td>Yes</td>
<td>3051 (.09)</td>
<td>3088 (.13)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2988 (.11)</td>
<td>3213 (.16)</td>
</tr>
</tbody>
</table>

Note. Error rates in parentheses.