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Causal and Semantic Relatedness in Discourse Understanding and Representation

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Processing time and memory for sentences were examined as a function of the degree of semantic and causal relatedness between sentences in short narratives. In Experiments 1–2B, semantic and causal relatedness between sentence pairs was independently manipulated. Causal relatedness was assessed through pretesting and semantic relatedness was assessed with Latent Semantic Analysis. Causal relatedness influenced processing time and memory. Semantic relatedness influenced memory, and influenced processing time when causality was not manipulated within an experiment and the situation described by the sentence pairs was somewhat difficult to construct. Experiment 3 utilized naturalistic texts. Semantic and causal relatedness between sentences influenced online judgments of fit and free recall. Results are discussed in terms of bottom-up and top-down theories of text processing.

A critical element of narrative comprehension is the establishment of a coherent mental representation of the situation being described by the narrative. Many prior studies have explored this process by examining the dimensions on which readers connect together information as they read (Graesser, Singer, & Trabasso, 1994; Kintsch, 1998; Lorch & O'Brien, 1995; van Oostendorp & Goldman, 1999; Zwaan & Radvansky, 1998). These processing dimensions include both "bottom-up" processes, which are thought to operate relatively automatically, and are often independent of the events being described in the narrative (Kintsch, 1998; Myers &

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O'Brien, 1998), and "top-down" processes, which are driven to a greater extent by the "scenario" being described in the narrative (Graesser et al., 1994; Zwaan & Radvansky, 1998). In our project, we are interested in the simultaneous influence of particular aspects of bottom-up and top-down processing—semantic and causal relatedness. We examine semantic and causal relatedness effects independently to assess the extent to which they represent separate or interacting influences on narrative processing time and memory.

MECHANISMS OF CONNECTIVITY BETWEEN SENTENCES

There are two mechanisms of connectivity between sentences that were investigated in this study. One is semantic relatedness, which refers to the general associations among concepts in prior semantic knowledge. These associations are assumed to be separate from the particular episodic representation that a reader forms while reading a narrative. Semantic relatedness effects in text processing have been widely studied at the word level (Gernsbacher & Faust, 1991; Swinney, 1979; Till, Mross, & Kintsch, 1988). Words that are semantically related to individual words, or to the theme of a sentence, are activated during reading. In the Construction-Integration (CI) model of Kintsch (1998, 2001), semantic associates of words are activated and connected to text elements during the construction of a mental representation of a sentence. This semantic activation makes relatively large amounts of related information available for active processing or integration into a mental representation. These activated associates may or may not remain activated once the constructed network is integrated into a coherent representation, but their initial activation seems to come at little to no cost in terms of processing capacity. Semantic relatedness effects at the level of units as large as sentences are less clear, however. For one thing, they have been difficult to study due to the difficulty of obtaining objective measures of relatedness for large segments of text on a wide range of topics. Furthermore, it is not theoretically clear whether sentence-level semantic relatedness effects actually take place. Finally, there is some question as to how the semantics of a sentence can be represented and compared to other sentences.

Kintsch (2001) developed a predication algorithm within the CI framework that addresses some of the issues related to semantic relatedness in comprehension and the semantic representation of sentences. In the predication algorithm, the Latent Semantic Analysis (LSA) model of knowledge representation (Landauer & Dumais, 1997; Landauer, Foltz, & Laham, 1998) is used as the semantic knowledge component of the CI framework. LSA is a computational model of human knowledge representation in which word meanings are acquired based on their contextual usage across large samples of written language. Words and larger text segments are represented as vectors in a high dimensional "semantic space" and the similarity of these vector representations provides estimates of semantic relatedness between words and texts. For our purposes, it is also important to note that the semantic relatedness estimates in LSA are not based on repetition of specific words, or even close synonyms, but rather are based on the general semantic relatedness between texts, much as human estimates would be. The predication algorithm is a method for simulating the meaning of a sentence in which one or more arguments modifies the specific meaning of a predicate in the context of a particular sentence. Kintsch showed how this algorithm can account for comprehension of simple sentences in which word order is important, such as in metaphor or similarity. Kintsch also argued that in the case of longer sentences, or connected discourse, the meaning of a sentence can be represented by the centroid, which is the vector average of the LSA vectors that comprise the words in a sentence. The centroid is not sensitive to word order within a sentence, and thus will miss any subtleties in meaning that are carried by word order. In our work, however, we are concerned with general semantic relatedness between sentences, and our sentences are not constructed so that their meaning will depend critically on word order. Thus, we represent sentences in LSA in terms of their centroid.

Using LSA to represent the meaning of sentences and the semantic similarity of sentences to each other, however, does not address whether we will, or should, find sentence level effects on discourse processing or representation. On this point, our work should be considered somewhat exploratory. In addition, although LSA calculates similarity at the sentence level, it is not clear to what extent specific word–word relations may drive overall relatedness effects across sentences. There are, however, a few well-established lines of research that indicate that semantic relatedness between sentences may influence processing and representation and are worth exploring. First, research has shown that text coherence can be established when arguments are shared across sentences of a narrative (Kintsch & van Dijk, 1978). The original text processing theory of Kintsch and van Dijk proposed that argument overlap is a primary means by which readers connect sentences together to form a mental representation of them. Argument overlap also serves as a means of reinstating information from earlier in a text to establish coherence across sentences of a text. Memory for text information was greater for text propositions that were connected to more other propositions via argument overlap than for propositions that had fewer connections (Kintsch, 1974). Argument overlap may be seen as a kind of approximation of more general semantic relatedness. However, LSA assessments of semantic relatedness may differ from argument overlap in at least two ways. First, sentences or other textual units can vary on semantic relatedness while not varying on argument overlap, because the argument overlap criterion are not sensitive to the subtle ways in which information can be more or less related without actually sharing any of the same concepts. Second, repetition of arguments across sentences of a narrative may trigger specific processing strategies to establish coherence that are not triggered by more general semantic relatedness.

A second relevant line of research involves the memory-based model of McKoon and colleagues (Gerrig & McKoon, 1998; McKoon, Gerrig, & Greene, 1996), as well the resonance model of Myers, O'Brien, and colleagues (Myers & O'Brien, 1998; Myers, O'Brien, Albrecht, & Mason, 1994; O'Brien & Albrecht, 1991; O'Brien, Albrecht, Hakala, & Rizzella, 1995; O'Brien & Myers, 1999). These models describe the processes by which prior world knowledge and backgrounded episodic information are reinstated in the current discourse focus. According to these models, information in the current discourse focus sends out signals to both the current episodic memory representation, as well as to all of long-term memory. These signals resonate with information that is related semantically or contextually based on the overlap of features with the current discourse focus. Information with a high degree of resonance is made available during processing. This resonance is "dumb" in that the relevance of the information to the situation being described is not considered. Several studies have demonstrated that semantic relatedness (featural overlap) between concepts in the current discourse focus and backgrounded text information determines what information is reinstated in working memory during processing (O'Brien et al., 1995; O'Brien, Rizzella, Albrecht, & Halleran, 1998). In these studies, reinstatement is typically established through a reference to a portion of earlier text information that has been backgrounded. These references can take the form of literally repeating a portion of earlier text, or of mentioning a characteristic or action of a person that is related to something that had been stated earlier (e.g., being a vegetarian or ordering a hamburger). The resonance model accounts for findings that the information that is made available for processing is not only the information that has been directly reinstated, but also other information related to the reinstated context. One advantage of LSA is that semantic relatedness is characterized as a general property, rather than as overlap of specific features. As a result, the influence of semantic relatedness on processing and memory can be assessed without the need to reinstate specific information into the discourse focus, and without the need to define what features may be relevant at any given moment.

Finally, general semantic relatedness between sentences has been shown to influence subject ratings of textual coherence. Foltz, Kintsch, and Landauer (1998) used LSA to assess the semantic relatedness of sentence pairs n.n + 1 across a text. Computationally, semantic relatedness was calculated as the cosine of the vector representing Sentence 1 to Sentence 2, Sentence 2 to 3, and so on. These data represent semantic coherence at the local level and were highly predictive of human ratings of text coherence. These coherence results suggest that LSA may also be able to capture potential semantic relatedness effects on processing and memory.

Although our work with semantic relatedness is somewhat exploratory, we envision three possible patterns of effects for semantic relatedness on processing time and memory for text. First, semantic relatedness could have no effect. This pattern would be consistent with the idea that semantic relatedness is a relatively automatic means for making information available for processing, as predicted by the resonance model, but that it does not play a role in the actual integration of information into a discourse representation. Second, semantic relatedness could consistently influence processing and memory. This pattern would involve semantic relatedness playing a role similar to other dimensions of situation model construction such as causal or temporal relatedness (Zwaan & Radvansky, 1998). Finally, semantic relatedness could influence processing or memory in an interactive manner, or only under certain circumstances. It is conceivable that semantic relatedness is a factor that can aid in construction of a discourse representation, but that it's effects are subtle and potentially overwhelmed by more "prominent" measures of connectivity, such as causal relatedness.

A second mechanism of connectivity is causal relatedness. A plethora of studies have established the importance of causality in narrative comprehension (e.g., Klin, 1995; Langston & Trabasso, 1999; Myers, Shinjo, & Duffy, 1987; Trabasso & Suh, 1993; Trabasso & van den Broek, 1985; van den Broek, 1988). Narrative information is better recalled and processed faster if it is on the causal chain that is established by the story than if it is not on the causal chain (Trabasso & van den Broek, 1985). Information is also processed faster if it is causally close to earlier information. For example, Myers et al. presented participants with pairs of sentences that were causally related to each other, but varied in the extent to which the causal relations were close or distant. Participants read target sentences that were the same across conditions, with prime sentences that varied in causal relatedness to the targets. Reading times of the target sentences indicated that causally close sentences were processed faster than causally distant sentences. Memory for the target sentences was also better when they were preceded by causally close prime sentences. This experiment (see also Keenan, Baillet, & Brown, 1984) indicates that the causal relatedness of sentences pairs influences both processing time and memory for target sentences. Our experiments utilize a similar experimental paradigm as Myers et al.

It can be argued that the construction of a coherent situation model is, in part, a constructive and conscious process (Gernsbacher, 1990; Graesser et al., 1994; Long & Lea, in press; Magliano & Radvansky, 2001; van den Broek, Risden, & Husebye-Hartmann, 1995; Zwaan & Radvansky, 1998). Most certainly, the building blocks for this construction are made available through bottom-up mechanisms in which the words and ideas in a text resonate with concepts in semantic and episodic memory (Myers & O'Brien, 1998; O'Brien & Myers, 1999). Furthermore, this construction may be facilitated when activated knowledge can be readily integrated in memory (Kintsch, 1998). In some cases with very simple sentences, it is likely that the causal knowledge needed to establish coherence can be directly activated in long-term memory (Kintsch, 2001). In such cases, causal reasoning can be accounted for by an activation and constraint satisfaction process, and may be relatively passive (see Long & Lea, in press, for a discussion of this issue). However, in the cases of more complex sentences and in extended discourse, it is unlikely that specific knowledge can simply be activated; it must be constructed during comprehension. The reader must assess the extent to which activated information provides the necessary and sufficient conditions to causally connect the current sentence with the prior discourse (Trabasso et al., 1989; van den Broek, 1990). When the activated knowledge does not provide the conditions required to establish coherence, readers must construct the inference required to establish those relations (Millis, Golding, & Barker, 1995; Myers et al., 1987). This constructive process is marked by increases in reading times when there are breaks in causal coherence and constitutes a top-down influence on comprehension (e.g., Long & Lea, in press; Magliano, Trabasso, & Graesser, 1999; Myers et al., 1987; Zwaan, Magliano, & Graesser, 1995).

In this study, we examined the co-influence of semantic and causal relatedness between discourse constituents on online (e.g., reading times) and offline (e.g., recall performance) behaviors. Doing so provides an opportunity to assess the co-influence of bottom-up and top-down processing during and after reading. Although many studies have examined semantic and causal influences on processing and memory separately, relatively few have examined these two factors simultaneously. To develop a more complete understanding of the influences of these processes, it is necessary to understand the extent to which they operate independently or interact with each other. This issue is important because semantic and causal relatedness are often confounded with each other in typical narratives. Narrative elements that are central to the causal chain of events in a story may also be central in terms of the structure of the text as assessed by argument overlap. However, Zwaan, Magliano, et al. (1995; Magliano, Zwaan, & Graesser, 1999) showed that argument overlap and casual relatedness are moderately correlated in naturalistic texts.

There are mixed results regarding the relative contribution of argument overlap and causal relatedness. Fletcher, Chrysler, van den Broek, Deaton, and Bloom (1995) examined memory for two-clause sentences that were connected either by a shared argument or by a shared argument and causally. Under normal processing conditions, memory results showed no advantage for the causal connection over and above the argument overlap connection. When the processing task involved explaining the relation between the clauses, however, then the causally related clauses showed a memory advantage. On the other hand, studies employing connected discourse showed that both contribute independent variance in online reading times (Magliano et al., 1999; Zwaan, Magliano, et al., 1995) and degree of relatedness of sentences in memory (Trabasso & van den Broek, 1985; Zwaan, Langston, & Graesser, 1995).

In Experiments 1 and 2, we independently manipulate causal and semantic relatedness in pairs of sentences. Importantly, the semantic manipulation does not involve a manipulation of shared arguments, but rather is at a general semantic level. Thus, we cannot only examine the independent effects of causal and semantic relatedness on processing time and memory, but we can also examine potential interactions between these two factors. In Experiment 3, we utilize naturalistic narrative texts in a correlational design and examine the extent to which semantic and causal relatedness among sentences each predict processing and memory after factoring out the effects of the other.

EXPERIMENT 1

In Experiment 1, participants read a series of two-sentence stories in which the relation between a prime sentence and a target sentence varies along the dimensions of semantic and causal relatedness. The design and dependent measures were modeled after Myers et al. (1987). For any particular target sentence, four different prime sentences were constructed to independently manipulate semantic relatedness and causality. Reading times for the target sentences provide an indication of the extent to which it is easy or difficult to construct a mental representation of the situation being described by the sentence pairs. If semantic and causal relatedness are dimensions on which readers process narratives, then target sentences that are highly related to the prime sentences should be read faster than sentences that are not highly related. After reading all sentence pairs, participants also performed a cued recall test in which the prime sentences were given as cues and participants recalled the target sentences. If semantic and causal relatedness are factors on which memory for narratives is based, then target sentences that are highly related to their prime sentences should be better recalled than sentences that are not highly related to their primes.

Method

Participants. Fifty-two students from Northern Illinois University who were enrolled in Introductory Psychology participated and received course credit.

Design. A 2 × 2 (Causal Relatedness × Semantic Relatedness) within-participants design was employed. Sentence reading times and cued recall performance for the target sentences were the dependent measures.

Materials. A total of 32 sets of sentence pairs were constructed. Each set contained four prime sentences and one target sentence (see Table 1 for an example set). The prime sentences described events that were antecedents of the target sentence. Within each set, there were two causal chains consisting of two sentences each. The causal chains were constructed by writing two-sentence stories, each

TABLE 1
Sample Sentence Pairs From Experiments 1 and 2

Condition[a]	*Prime Sentences*	*LSA Cosine*[b]
LC/HS	Malcolm was a doctor in family practice.	0.35
HC/HS	Malcolm collapsed while treating patients in his office.	0.48
LC/LS	Malcolm had a great seat for the baseball game.	0.02
HC/LS	Malcolm was hit in the head with a stray baseball.	0.07
Experiment	*Target Sentence*	
1	He was carried unconscious to a hospital.	
2A and 2B	Malcolm/Jim was carried unconscious to a hospital.	

Note. LSA = Latent Semantic Analysis; LC = low causal relatedness; HC = high causal relatedness; HS = high semantic relatedness; LS = low semantic relatedness.

[a]For Experiment 2A, only LC prime sentences were used. For Experiment 2B, only HC sentences were used. [b]LSA cosines between prime sentence and target sentence.

concluding with the target sentence (Myers et al., 1987). The first sentence of a chain described an event that was low in causal relatedness with the target sentence and the second sentence described an event that was high in causal relatedness with the target sentence. Causal relatedness was based on experimenter intuition, but validated in a pilot study. In this pilot study, participants made goodness of answer judgments in which the target sentence was posed as a why question (e.g., Why was Malcolm carried unconscious to the hospital?) and one of the prime sentences was posed as the answer to the question (e.g., Because he was a doctor in a family practice, because he collapsed while treating patients in his office, because he had great seat for the baseball game, or because he was hit in the head with a stray baseball). Participants made their judgments on a 6-point Likert scale ranging from 1 (*very bad answer*) to 6 (*very good answer*). The prime sentences were assigned to a counterbalancing scheme with a 4 × 4 Latin square. Across all sentence pairs, sentences high in causal relatedness were rated higher ($M = 4.84$), than sentences low in causal relatedness ($M = 2.53$), $F(1, 126) = 267.22$, $p < .0001$.

Within each set of sentences, one chain had high semantic relatedness with the target sentence and the other chain had low semantic relatedness. Semantic relatedness between the chain and the target sentences was based on the intuition of the experimenters, but verified using LSA (Landauer & Dumais, 1997) to assess the overall semantic relatedness (cosine) between prime and target sentences. LSA similarity scores were generated using the University of Colorado Web site (http://lsa.colorado.edu). All similarity scores were computed using the semantic space "General reading up to first year college" with 300 dimensions. The protagonist name in the prime sentence and the pronomial reference in the target sentence were not used in computing semantic relatedness because the choice of name for a sentence pair was arbitrary. All other words of the sentences were included in the similarity computations. Across all sentence pairs, high semantically related sentence pairs have higher cosines (*M* = .32), than low semantically related sentence pairs (*M* = .04), $F(1, 31) = 161.17$, $p < .0001$. LSA cosines did not vary as a function of causal relatedness, nor was there an interaction between causal and semantic relatedness (both $p > .25$). As such, semantic relatedness as determined by LSA cosines was orthogonal to causal relatedness within these sentence pairs.

For all sentence pair sets, the prime sentence begins with the name of the protagonist. For the target sentences, 30 of the 32 sentences begin with a pronoun that refers to the protagonist. The other two target sentences do not contain a pronoun. There are no other referential connections between the sentence pairs and no arguments (concepts) overlapped between prime and target sentences. Thus, the semantic and causal manipulations exist at the sentence level and are not driven by individual argument or word overlap.

Procedure

The experiment was run on PCs with E-Prime. Participants were tested in groups of up to eight in individual rooms. There were two phases to the experiment. During the first phase, participants read the 32 sentence pairs. Participants were instructed to read a series of short, two-sentence stories. They were told to read the stories to comprehend them and that they would be asked questions about them later. They were not given any indication of a memory test, but rather were instructed that the questions would tap their understanding of the stories. The sentence pairs were presented one sentence at a time. Participants pressed the space bar to advance to the next sentence and kept a hand on the space bar at all times. Sentence reading time was defined as the time between the onset of a sentence on the screen and the pressing of the space bar, which was recorded with millisecond accuracy. A screen appeared between each sentence pair that stated "Prepare to read the next story." The prime sentences for the stimulus sets were assigned to the conditions with a with a 4 × 4 Latin square, which yielded four counterbalancing schemes. The sentence pairs were randomly presented to the participants. The second phase of the experiment involved a cued recall task. Prime sentences were presented one sentence at a time on the computer screen. Participants were provided sheets of paper and were told to write the sentences associated with the ones presented on the computer screen. Prime sentences were presented to the participants randomly, and the order of presentation of the sentences was recorded by the computer. Participants solved three-digit addition and subtraction problems for 5 min in between Phases 1 and 2.

Results and Discussion

There were two, 2 × 2 (Causal Relatedness × Semantic Relatedness) analyses of variance (ANOVAs) that were conducted. The first analysis was conducted on the sentence reading times for the target sentences, which were divided by the number of syllables to control for sentence length. The second analysis was conducted on cued recall performance, which was assessed by the number of sentences recalled. A target sentence was judged to be recalled if participants either reproduced it verbatim or paraphrased it. Inter-rater reliability was high for these judgments (Cohen's $\kappa = .91$). The proportion of target sentences that were recalled per condition was calculated for each participant. The participant analyses are referred to as *F1* and the item analyses are referred to as *F2*.

Reading times per syllable are presented in Table 2. Sentences that had high causal relatedness ($M = 384$), were read faster than sentences that had low causal relatedness ($M = 479$), $F1(1, 51) = 44.12$, $MSE = 43797.10$, $p < .0001$; $F2(1, 31) = 9.24$, $MSE = 134468.16$, $p = .005$. Reading times do not differ reliably as a function of semantic relatedness, nor was the interaction reliable (both *F*s < 1).

The mean proportion of target sentences recalled are also presented in Table 2. Target sentences that had high causal relatedness with the prime ($M = .81$), were recalled better than those that had low causal relatedness ($M = .70$), $F1(1, 51) = 32.01$, $MSE = .018$, $p < .01$; $F2(1, 31) = 11.66$, $MSE = .105$, $p = .002$). Target sentences that had high semantic relatedness with the prime sentences ($M = .81$), were recalled better than those that had low semantic relatedness ($M = .70$), $F1(1, 51) = 22.05$, $MSE = .029$, $p < .01$; $F2(1, 31) = 14.91$, $MSE = .106$, $p = .001$. These main effects were qualified by a significant Causal Relatedness × Semantic Relatedness interaction, $F1(51) = 19.60$, $MSE = .025$, $p < .01$; $F2(1, 31) = 12.60$, $MSE = .08$, $p = .001$. As can be seen in Table 2, recall of the target sentences appears to be low when the prime sentences are low in both causal and semantic relatedness.

These results indicate semantic and causal relatedness had differential impacts on reading times and cued recall performance. Specifically, causal relatedness between sentences had an influence on ease of integration (as measured by reading

TABLE 2
Reading Times per Syllable (in Milliseconds) and Proportion of Target Sentences Recalled as a Function of Causal and Semantic Relatedness

	Causal Relatedness		
	High	*Low*	*M*
Reading times			
Semantic relatedness			
High	376	476	426
Low	391	483	437
M	384	479	
Recall			
Semantic relatedness			
High	.81	.80	.81
Low	.80	.59	.70
M	.81	.70	

times), whereas semantic relatedness did not. We believe this suggests that reading times are more heavily influenced by top-down constructive processes than bottom-up processes in the context of this experiment. We view reading times to be heavily influenced by a process of evaluation in which readers assess the extent to which a coherent representation can be readily constructed (Long & Lea, in press). We do not know if readers are actually constructing a causal bridge between the causally distant sentences or if they are simply slowing down in recognition that these sentences are causally distant. Based on prior research, we do suspect that participants were constructing knowledge-based explanations to bridge sentences that activate sufficient knowledge necessary to construct these inferences (Millis et al., 1995). However, this study provides no direct evidence of the construction of these inferences. It is important to know that semantic relatedness with the prior discourse has an impact on ease of processing and reading times for longer discourse (Myers & O'Brien, 1998). On the other hand, both causal and semantic relatedness appear to provide links to aid in the cued recall task. For semantic relatedness, the results are consistent with the view that semantic associations can be established at the level of sentences, and that these associations are not merely activated, but can become part of the discourse representation.

The lack of a processing time effect for semantic relatedness has two potential interpretations. First, it may be that semantic relatedness does not influence processing time. This conclusion would be consistent with the claim that semantic resonance is a relatively automatic process. Another possible interpretation is that semantic relatedness may influence processing time, but not in the context of this experiment. If the causal manipulation across sentence pairs was a very salient attribute of the materials, then the processing focus of the reader may have been on the causal relatedness between the sentences. Semantic relatedness may be a more subtle manipulation, whose effects on processing time may have been overwhelmed by the causal reasoning of the Participants. We examine this interpretation in Experiments 2A and 2B.

EXPERIMENTS 2A AND 2B

In Experiments 2A and 2B, a more "pure" examination of semantic relatedness effects on processing and memory was undertaken by eliminating the causal manipulation of sentence pairs within each participant. All participants received sentence pairs that were either consistently low in their causal relatedness (Experiment 2A), or consistently high in their causal relatedness (Experiment 2B). Semantic relatedness was manipulated as in Experiment 1. As an additional manipulation, sentence pairs were constructed such that the two sentences in each pair were either part of the same situation or different situations. This manipulation was created by having the protagonist in the prime and target sentences either be the same or different. By having the prime and target sentences in a pair refer to different situations, this was reasoned to provide a particularly strong test of the possibility that semantic relatedness could influence processing times under certain conditions. Essentially, the goal was to create sentence pairs in which the semantic relatedness manipulation was primary by making it difficult to establish situational links between sentences.

Method

Participants. A total of 43 and 51 participants, respectively, participated in Experiments 2A and 2B. All participants were students at Northern Illinois University, were enrolled in Introductory Psychology, and received course credit.

Materials. The materials used in Experiment 1 were modified slightly for Experiments 2A and 2B. For each sentence pair, two versions were created such that the prime and target sentence either contained the same protagonist (same "situation") or different protagonists (different "situations"). When the protagonists were the same, the name was repeated in the target sentence, rather than the pronoun used in Experiment 1. The semantic relatedness manipulation was identical to Experiment 1, and as a result the LSA similarity scores were identical. These variables were crossed to create a 2 × 2 design. Causal relatedness was constant within each experiment. Experiment 2A contained only causally distant sentences and Experiment 2B contained only causally close sentences. Table 1 shows sample sentence pairs.

Procedure. The manipulation of the protagonist (same/different) was a between-participants variable in these experiments. Otherwise, the procedure for Experiments 2A and 2B was identical to Experiment 1.

Results and Discussion

Analyses were conducted separately for Experiments 2A and 2B. Cued recall was scored as in Experiment 1. For each experiment, two mixed ANOVAs were conducted with semantic relatedness as a within participants factor, and the same or different protagonist as a between participants factor.

Results for Experiments 2A and 2B are presented in Table 3. For the sentences low in causal relatedness (2A), highly semantically related sentences ($M = 418$), were read faster than sentences with low semantic relatedness ($M = 468$); $F1(1, 41) = 5.15$, $MSE = 6961.93$, $p < .05$; $F2(1, 19) = 5.15$, $MSE = 4664.92$, $p < .05$. The target sentences were read slower when they contained the same protagonist as the prime ($M = 468$), than when they did not ($M = 410$), but this effect was significant in an item, $F2(1, 19) = 12.62$, $MSE = 4664.92$, $p < .05$, but not in a participant analysis ($p > .10$). Recall was greater when semantic relatedness was high ($M = .62$), than when it was low ($M = .44$); $F1(1, 41) = 72.25$, $MSE = .0135$, $p < .01$; $F2(1, 19)$

TABLE 3
Reading Times per Syllable (in Milliseconds) and Proportion of Target Sentences Recalled as a Function of Protagonist and Semantic Relatedness for Low Causal Relatedness Sentence Pairs (Experiment 2A) and High Causal Relatedness Sentence Pairs (Experiment 2B)

	Low Causal Relatedness			*High Causal Relatedness*		
	Same Protagonist	*Different Protagonist*	*M*	*Same Protagonist*	*Different Protagonist*	*M*
Reading time						
Semantic relatedness						
High	445	392	419	368	426	397
Low	492	428	460	388	417	403
M	469	410		378	422	
Recall						
Semantic relatedness						
High	.77	.47	.62	.85	.69	.77
Low	.61	.26	.44	.83	.49	.66
M	.69	.37		.84	.59	

= 13.45, *MSE* = .05113, $p < .05$. Recall was greater when the target sentences had the same protagonist ($M = .69$), than when they did not ($M = .37$), $F1(1, 41) = 22.65$, *MSE* = .09975, $p < .0001$; $F2(1, 19) = 53.04$, *MSE* = .05113, $p < .05$. The interaction was not significant (both $p > .10$).

For the sentences high in causal relatedness (Experiment 2B), the target sentence was read faster when it contained the same protagonist as the prime ($M = 378$), than when it did not ($M = 422$), but this effect was significant in an item, $F2(1, 19) = 5.538$, *MSE* = 6704.70, $p < .05$, but not in a participant analysis ($p > .10$). No other reading time effects were significant in either analysis (all $p > .10$). Recall of the target sentences was greater for the high semantically related sentences ($M = .77$), than for sentences with low relatedness ($M = .66$), $F1(1, 49) = 22.42$, *MSE* = .01414, $p < .01$; $F2(1, 19) = 13.70$, *MSE* = .0258, $p < .05$. Recall was also greater when the sentences contained the same protagonist ($M = .84$), compared to when they were different ($M = 59$); $F1(1, 49) = 22.06$, *MSE* = .0702, $p < .01$; $F2(1, 19) = 76.83$, *MSE* = .01586, $p < .05$. These main effects were qualified by a significant Semantic Relatedness × Protagonist interaction, $F1(1, 49) = 14.10$, *MSE* = .01414, $p < .01$; $F2(1, 19) = 7.17$, *MSE* = .0706, $p < .05$. Specifically, there was an increase in recall as a function of semantic relatedness when the two sentences were part of different situations (i.e., had different characters), but there was not an increase as a function of semantic relatedness when the sentences were part of the same situation.

The results of these experiments are consistent with the reading time data from Experiment 1 and suggest that situational relatedness between sentence pairs has a greater impact on online processing than semantic relatedness. Semantic relatedness can influence reading times, however this occurred only when causal relatedness was low (in Experiment 2A), and not manipulated within subjects. When there was a strong causal relation between the two sentences (in Experiment 2B), semantic relatedness did not have an impact on reading times.

There was also an interesting difference in the pattern of reading times as a function of the protagonist across the two experiments. When causal relatedness was low, sentences containing the same protagonist were read more slowly than those that did not contain the same protagonist, whereas when causal relatedness was high, sentences containing the same protagonist were read more quickly than those that did not contain the same protagonist. Continuity in the protagonist provided a cue that the sentences could be integrated in the same situation, whereas discontinuity provided a cue that the sentences could not be integrated. The ease of this integration was manipulated by the degree of causal relatedness between sentences. When causal relatedness was low, readers had to engage in additional processing to infer the necessary and sufficient conditions that would indicate how the two sentences could be integrated. When causal relatedness was low but the protagonists were different, this additional processing was not necessary. When causal relatedness was high, little additional processing was necessary to achieve integration, so reading times for the target sentence were fast. This pattern of results also represents an example of a situation in which argument overlap can provide specific processing cues, and thus can lead to processing strategies that are different than those accounted for by general semantic relatedness.

The cued recall data were consistent with Experiment 1, and indicate that both causal and semantic relatedness serve as sources of resonance in memory. However, the interaction found in Experiment 2B suggests that causal relatedness provides a stronger source of resonance than semantic relatedness. These results are consistent with research by Radvansky (1999) that suggests that situational relations have a stronger impact on integration in memory than relations in a semantic network.

EXPERIMENT 3

In Experiment 3, we examine semantic and causal influences on processing and memory for naturalistic narrative texts. Naturalistic texts differ from the sentence pairs used in Experiments 1 and 2 in at least two respects. First, semantic and causal relatedness may have an influence at either a local or global level. At the local level, a sentence that immediately precedes a target sentence may be analyzed in terms of semantic and causal relatedness, and this local level may influence processing and memory (Foltz et al., 1998; Zwaan, Magliano, et al., 1995). At the global level, each sentence is integrated not only with the immediately preceding sentence, but also with the discourse context up to the point that the sentence is encountered. As a result, we examined semantic and causal relatedness both with respect to the sentence that immediately precedes a target sentence, and with respect to all preceding sentences *except* the immediately preceding sentence. Prior research has shown that semantic relatedness between distant entities in a discourse does have an impact on the availability of the earlier concept (O'Brien et. al., 1995). Second, with naturalistic texts, semantic and causal relatedness will vary naturally across sentences, rather than being manipulated as in Experiments 1 and 2. As a result, we examine semantic and causal influences through multiple regression analyses in which processing and recall data are predicted by continuous measures of semantic and causal relatedness (Trabasso & van den Broek, 1985; Zwaan, Magliano, et al., 1995).

In this experiment, processing of the texts will be assessed using fit judgments (Magliano et al., 1999; Rinck & Weber, in press; Scott Rich & Taylor, 2000). For each sentence that is read, participants indicate the extent to which the sentence fits in with the story that is being read. These fit judgments may be influenced by either semantic or causal relatedness between the sentence and the story up to that point, and may be influenced at either a local or global level (Magliano et al., 1999). Memory for the texts will be assessed with free recall. These free recall data will be coded in terms of recall of sentence pairs. Any particular pair of sentences will have some degree of semantic and causal relatedness to each other. If these factors influence memory for text information, then it should be the case that sentences that are more related should be more likely to be recalled. That is, one sentence should serve as a memory prime for another sentence. For any particular subject, if the pairs of sentences they recall are driven by semantic or causal relatedness, then the relatedness of those sentence pairs should be higher than the relatedness of nonrecalled pairs.

As in Experiments 1 and 2, LSA was used to assess semantic relatedness between all sentence pairs, and between a sentence and the prior story context. Causal relatedness in Experiment 3 was assessed using a computational model of comprehension that relies on causal relations to simulate a mental representation of the text information (Langston & Trabasso, 1999; Langston, Trabasso, & Magliano, 1999; Trabasso & Bartolone, in press). This model can be accessed on the Internet (http://www.ccp.uchicago.edu/~tomt/textnet/entermatrix.html). To use this model, a causal network analysis is performed on a text (Trabasso, van den Broek, & Suh, 1989). The model takes as input the matrix of causal relations between all text sentences that is constructed based on this analysis. As text connections between sentences are added to the representation (simulating the sequential nature of text processing), activation is spread through the connectivity matrix. At the completion of any particular text sentence, connectivity strengths between all text sentences were computed (see Langston & Trabasso, 1999, for further details). We discuss how we used the LSA and causal connectivity matrices to predict fit judgments and recall performance later.

Method

Participants. Thirty students from Northern Illinois University who were enrolled in Introductory Psychology participated and received course credit.

Materials. Four short historical narrative texts were used. Each narrative told the story of an event in U.S. history. The texts (with the number of sentences in parentheses) were Christopher Columbus (17), "Paul Revere" (15), "The Wright Brothers" (19), and "The Moon" (16). These historical narratives were constructed based on information provided in encyclopedia articles (Wahlberg & Magliano, under review)

Procedure. Participants were run in groups of up to 20. Participants read four short narrative texts and the order of the texts was counterbalanced. These texts were presented in a booklet provided to the participants. Each text was presented on one page of the booklet. Each sentence was presented on one line and after each sentence was a space in which the participants made their fit judgments. Participants were told to read the text for comprehension. After reading each sentence of each text, participants rated the fit of the sentence into the context of the story up to that point. When making the ratings, they were told to consider how well a sentence fit into the text based on their understanding of it up to that point. Fit ratings were recorded on a 4-point Likert scale and were made by marking the judgment in a space next to the story sentence. Participants did not make a fit judgment for the first sentence of a text because there was no prior context. After reading all four texts, participants were asked to do a series of addition, subtraction, and multiplication math problems for 5 min. Next, participants recalled the texts. They were given a recall booklet, which contained the titles of each text and space below each title. They wrote down as much as they could remember from each text in any order that they chose.

Results and Discussion

A series of multiple regression analyses were performed on the sentence fit judgments and recall data to assess the role of semantic and causal relatedness during text processing and recall. In item analyses, variability among items served as the error term in the multiple regression analysis. For these analyses, average fit scores and proportion recalled were calculated for each item of analysis. In a subject analysis, a multiple regression analysis was performed on each participant's fit judgments or recall score and the beta-weights for the predictor variables were extracted. A series of single-sample *t* tests were conducted to determine whether the average beta-weights were significantly different from zero (Lorch & Myers, 1990).

To analyze the sentence fit judgments, causal and semantic relatedness scores for each sentence were calculated at both the local and global level. At the local level, semantic relatedness was defined as the cosine between the current sentence and the immediately preceding sentence. At the global level, semantic relatedness was defined as the cosine between the current sentence and all sentences in the story up to, but not including, the immediately preceding sentence. There were eight predictor variables in the regression equations to predict the fit scores: Three contrast-coded variables were added to partial out variance as a function of the four texts (Judd & McClelland, 1989); serial position of a sentence was an auxiliary variable; and the theoretically important predictor variables were local causal relatedness, global causal relatedness, local semantic relatedness, and global semantic relatedness. Both local causal connectivity and semantic relatedness did not significantly predict sentence fit judgments (all $p > .10$). Global causal relatedness was a significant predictor of fit judgments, $t1(29) = 4.358$, $M\ \beta = .12$, $p < .05$; $t2(54) = 2.11$, $\beta = .48$, $p < .05$. Global semantic relatedness was significant predictor of fit judgments in a subject analysis, $M\ \beta = .14$, $t(29) = 6.191$, $p < .05$, but not in an item analysis ($\beta = .22$, $p > .10$).

These data are consistent with Magliano et al. (1999) and indicate that global measures of relatedness predict fit judgments, whereas local measures do not. These data suggest that participants mapped the extent to which a sentence fits into the thematic structure of the text when making these judgments. However, these data indicate that relatedness at both situational and semantic levels facilitate this assessment. As we have argued earlier, mapping at a situational level in part involves a constructive and conscious process (Graesser et al., 1994). However, the contribution of semantic relatedness is most likely primarily due to low-level resonance between the concepts in the sentence being judged and those in the prior context (Myers & O'Brien, 1998).

For the recall analyses, sentences were counted as correctly recalled if they were recalled either verbatim or if the gist of the sentence was recalled. Inter-rater reliability was acceptable, with 92% agreement (Cohen's $\kappa = .81$). To assess the influence of semantic and causal relatedness on the recall data, we adopted an approach similar to that used by Zwaan, Langston, et al. (1995) for analyzing sorting data. Zwaan, Magliano, et al. (1995) had participants sort words that reflected story events into piles. Specifically, they calculated the probability that any two words were included into the same pile and used assessments of situational relatedness to predict these probabilities. For our recall data, the influence of semantic and causal relatedness on memory was assessed by predicting the likelihood of recalling all possible pairs of sentences within a protocol as a function of their semantic and causal relatedness. Thus, each pair of sentences represented a data point. For the item analysis, the criterion variable was the probability that a given pair of sentences were included in a recall protocol (i.e., the number of participants who included both sentences of a pair within a protocol divided by the total number of participants). In a subject analysis, the criterion variable was whether or not a given participant included a pair of sentences in a recall protocol. Note that because the data are pairs of sentences recalled, local and global analyses are not distinguished for recall data.

Semantic relatedness between sentence pairs was defined as the LSA cosine between two sentences, whereas the causal connectivity between sentence pairs was defined as the connectivity strength between two sentences in the final connectivity matrix yielded by the Langston and Trabasso (1999) model. The regression models predicting recall included three contrast codes to account for variance between texts, causal relatedness between sentence pairs, and semantic relatedness between sentence pairs. The degree of causal relatedness between sentence pairs was marginally predictive of recall at the subject level, $t1(29) = 1.85$, $M\ \beta = .03$, $p = .07$, and significantly predictive at the item level, $t2(526) = 2.54$, $\beta = .11$, $p = .01$. The degree of semantic relatedness between sentence pairs was predictive of their inclusion in the recall protocols, $t1(29) = 2.44$, $M\ \beta = .36$, $p = .02$; $t2(526) = 2.26$, $\beta = 1.28$, $p = .03$. Interactions among semantic and causal relatedness variables were also tested, but were not predictive of either fit judgments or recall in any of the analyses.

These results expand the conclusions of Experiments 1 and 2 to naturalistic narratives and suggest the simultaneous and independent influence of semantic and causal relatedness on memory. That is, both situational relatedness and semantic relatedness serve as sources of resonance during recall.

GENERAL DISCUSSION

The creation of a coherent mental representation of narrative texts is dependent on both bottom-up and top-down mechanisms during processing. In four experiments, we have shown that two of these mechanisms, semantic and causal relatedness, have both independent and interacting influences on narrative processing and recall. Consistent with prior research (Myers et al., 1987; Trabasso & Suh, 1993; Trabasso & van den Broek, 1985; van den Broek, 1988), the degree of causal relatedness between sentences influences both processing time and memory for narrative information. When a sentence had high causal relatedness to the prior discourse context, the sentence was read faster and remembered better than when the sentence had low causal relatedness to the discourse context. The degree of semantic relatedness between a sentence and the prior discourse context also consistently influenced memory, with higher semantic relatedness resulting in better memory for sentences. These results were obtained both for sentence pairs (Experiments 1–2B) and for naturalistic narratives (Experiment 3).

The effects of semantic relatedness interacted with the degree of causal relatedness in accounting for processing time. Across the first three experiments, target sentences with a high degree of semantic relatedness to the prime sentences were processed faster only under circumstances in which the two sentences had low causal relatedness and were not part of the same situation. In Experiment 3, sentences with a greater degree of semantic relatedness between the sentence and the entire discourse context up to that point were rated as fitting in better with the discourse context. These results suggest that semantic relatedness is a factor in the online processing of narratives, but that causal relatedness between sentences appears to have a greater influence on processing time than semantic relatedness. Reading times appear to be influenced by a conscious assessment of fit, which would be facilitated by information that is made available through memory-based mechanisms.

The pattern of results across these experiments is consistent with a view of bottom-up and top-down processes in narrative comprehension as operating simultaneously and interacting to create a coherent discourse representation (Kintsch, 1998). Creating a causally coherent representation of the events of a narrative involves effortful processing of the causal relations among events in the narrative, as evidenced by prior research and the processing time data in these experiments. There is a potentially very large amount of information that the reader must have available to reason with, however. This information can be made available to the reader through mechanisms such as semantic relatedness between concepts in the discourse. In many instances, however, it is likely that the exact content of a causal inference cannot be activated directly from semantic memory; it must be constructed as part of the episodic representation that explains the events of the narrative (Kintsch, 2001; Long & Lea, in press).

The semantic relatedness results on processing and memory are interesting for two reasons. First, they add potentially important points to the resonance model (McKoon et al., 1996; Myers & O'Brien, 1998; O'Brien & Myers, 1999). For one, these results suggest that semantic relatedness between sentences influences memory for narrative information. Past work on the resonance model has been primarily concerned with how resonance processes make information available during processing (McKoon et al., 1996; Myers et. al., 1994; O'Brien & Albrecht, 1991; O'Brien et al., 1995). In our experiments, we demonstrate that information made available through resonance is more memorable as assessed by both cued and free recall. Also, our results suggest that semantic relatedness between sentences at a general level can influence processing and memory. In prior research (Fletcher et al., 1995; Kintsch & van Dijk, 1978; Myers et al., 1994; O'Brien et al., 1995), a relation between contexts has been established by repeating a word or phrase, or by using a phrase with specific features that overlap with prior text information. In the Kintsch and van Dijk (1978) model, argument overlap was the primary means by which readers were assumed to establish coherence across sentences of a text. These studies show that semantic relatedness can influence processing and memory even in situations in which there are no arguments or phrases that overlap.

Finally, we believe that these data suggest that the LSA model (Landauer & Dumais, 1997) may serve as a proxy for assessing semantic relatedness between a sentence and the prior context. Therefore, LSA may provide a quantitative estimate of the strength of the resonance process as a function of semantic relatedness. This use of LSA appears to be consistent with the spirit of prior research assessing semantic relatedness as described by the resonance model (Myers & O'Brien, 1998). If LSA can be viewed as a candidate model for computationally assessing resonance based on semantic relatedness, then future research examining the resonance model could potentially also capitalize on LSA in this manner. It is also important to note, however, that LSA is not proposed as a complete model of the resonance process because there are other, nonsemantic sources of resonance. For example, referential distance and elaboration of concepts have been shown to influence the availability of concepts during processing (Myers & O'Brien, 1998), but these mechanisms would not be easily captured by LSA.

The second reason the semantic relatedness effects are interesting is because they raise questions for future research about both sentence-level relatedness effects on processing and memory and about the use of LSA to capture these effects. In this study, we represent the semantics of a sentence in terms of the LSA centroid, which is the vector average of the individual word vectors that make up a sentence. This representation does not allow us to examine the relative importance of either relatedness effects at the individual word level, or the importance of word order in determining the meaning of a sentence. For example, it is unclear to what extent syntactic parsing of a sentence influences the semantic representation of a sentence in humans. Several previous studies have successfully accounted for various aspects of discourse processing by using the centroid representations of sentences, however, including predicting textual coherence (Foltz et al., 1998) and evaluating the relation between text sentences and think-aloud statements generated in response to sentences (Magliano & Millis, 2003; Wolfe & Goldman, 2003). It is also unclear at what stage in the comprehension process these semantic relatedness effects may be acting. The resonance and construction integration models predict that semantic associations to text information are generated quickly and automatically (i.e., in a bottom-up fashion.) However, given these results with respect to memory performance, it is also possible that semantic relatedness between sentences influences later stages of processing, such as aiding in integration of sentences into an episodic representation. We believe these questions provide promising directions for future research.

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