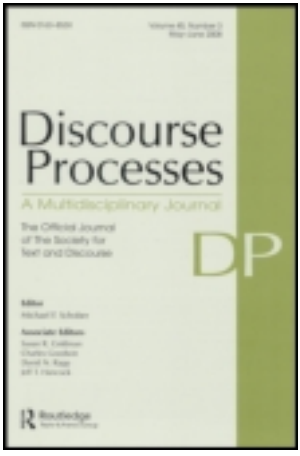

Discourse Processes
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hdsp20

Memory-based processing in understanding causal information

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Version of record first published: 11 Nov 2009.

To cite this article: Leo G. M. Noordman & Wietske Vonk (1998): Memory-based processing in understanding causal information, Discourse Processes, 26:2-3, 191-212

To link to this article: http://dx.doi.org/10.1080/01638539809545044

DISCOURSE PROCESSES, 26(2&3), 191–212

Memory-Based Processing in Understanding Causal Information

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The reading process depends both on the text and on the reader. When we read a text, propositions in the current input are matched to propositions in the memory representation of the previous discourse but also to knowledge structures in long-term memory. Therefore, memory-based text processing refers both to the bottom-up processing of the text and to the top-down activation of the reader's knowledge. In this article, we focus on the role of cognitive structures in the reader's knowledge. We argue that causality is an important category in structuring human knowledge and that this property has consequences for text processing. Some research is discussed that illustrates that the more the information in the text reflects causal categories, the more easily the information is processed.

Reading is a process that depends on the reader and on the text. Current theories of the reading process differ in the emphasis they put on the role of the text or on the role of the reader. The constructionist models (Graesser, Singer, & Trabasso, 1994) emphasize the role of the reader as a problem solver. The reading process is characterized as a search after meaning, in which the reader actively seeks to link events to their causes (Trabasso, Secco, & van den Broek, 1984; van den Broek, 1990). In other theories, henceforth labeled *integration theories*, the emphasis is on the bottom-up processes by which propositions in the text are

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related to each other (Albrecht & Myers, 1995; Kintsch, 1988; McKoon, Gerrig, & Greene, 1996; Myers & O'Brien, 1998/this issue). Reading is considered a pattern-matching process, in which concepts and propositions in the sentence currently being processed make contact with other concepts and propositions from the previous discourse. The concepts and propositions from the previous discourse resonate to the current input "as a function of their strength and their degree of match to the input" (Albrecht & Myers, 1995, p. 1460).

In this article, we propose that these two views represent two complementary aspects of memory-based text processing. We consider the reading process as a pattern-matching process. Propositions in the current input are matched to propositions in the memory representation of the previous discourse but also to knowledge structures in long-term memory. Not only do the text propositions resonate in a bottom-up fashion with the current input but the knowledge structures of the reader also resonate in a top-down fashion. In this article, we focus on the role of the reader's knowledge in this resonance process. The reading process itself is the processing of information in the text, but the nature of this process depends on the reader, and in particular, on the reader's knowledge. On the one hand, words in the text activate knowledge and knowledge structures in long-term memory; on the other hand, this knowledge will determine how the processing of the information takes place. The way in which our knowledge is structured influences the way we understand the information in a text. It is in this sense that we conceive of memory-based text processing. The aim of this article is to illustrate how the structure of knowledge in the human memory affects text processing. This claim is consistent with the adage that is attributed to Aristotle's epistemological theory: "Quicquid recipitur ab alio recipitur per modum rei accipientis et non receptae" (Hamesse, 1974, p. 232), that is, what is received, is received in the way of the receiver. The way in which we perceive and understand information depends on the knowledge structure of the processor.

We focus on one aspect of a reader's knowledge structure: causal relations. Our goal is to demonstrate that causal relations form a basic organizing principle in human knowledge and that this organization has consequences for text processing. In particular, we give some illustrations of the fact that the more sentences in their surface form correspond to a causal relation, the more easily the sentences will be processed.

CAUSALITY AND THE STRUCTURE OF KNOWLEDGE

The notion of causality is inherent in the very nature of human cognition. Knowledge about events implies, among other things, the belief that all events have causes. It is a human propensity to try and determine, for the events we perceive, that they are the consequences of particular causes (Miller & Johnson-Laird, 1976). The ability to predict the consequences of one's own behavior as well as to anticipate the consequences of the behavior of others is a fundamental aspect

of intelligent and adaptive behavior. Causal relations play an important role in prediction. "Causal relation means predictability" (Carnap, 1966, p. 192). Searle (1983) argued that causality originates in our experiences in the interaction with the world: It originates in our actions in the world and in our perceptions of the world. Every experience of perceiving and acting is an experience of what Searle called *intentional causation.* As an example in the domain of action, Searle discussed the following experience: "Suppose I am thirsty and I take a drink of water. If someone asks me why I took a drink of water, I know the answer without any further observation: I was thirsty" (p. 118). If the speaker had not been thirsty in those circumstances, he would not have taken a drink of water. So, he knows the causal explanation of the action. He knows the truth of the causal statement and the counterfactual statement. The experience of this action is an experience of causation. The important observation in the present context is that intentional causation is not the object but the content of the experience of perception and the experience of action: Causation is experienced in perceiving and acting. The importance of the notion of causation was made clear by Searle when he pointed at an asymmetry between causation and other perceptual content:

> Redness is not a feature of my visual experience . . . ; the experience is of something red, but is not itself a red experience. But causation is part of the content of my experience. . . . The concept of reality is a causal concept. Part of our notion of the way the world really is, is that its being the way it is causes us to perceive it as being that way. Causes are part of reality and yet the concept of reality is itself a causal concept. (p. 131)

One may argue that causality is a prototypical category. Rosch's (1978) idea was that the categorization of the world is not arbitrary but corresponds to psychological principles. Categorization may be predicted and explained. Rosch discussed two principles underlying human categorization. The first principle is the principle of cognitive economy: "The task of category systems is to provide the maximum amount of information with the least cognitive effort" (p. 28). The second principle has to do with the structure of the information: "The perceived world comes as structured information rather than as arbitrary or unpredictable attributes" (p. 28). In this way, maximum information is given with the least effort. The principles that Rosch proposed for justifying human categorization argue for the basicality of the concept of causality in categorizing our experiences (without working out any technical claim about causality as a category prototype or basic level in a taxonomy of cognitive relations). The concept of causality corresponds to the way in which we perceive the world: When we perceive events in the world, we believe that these events are caused by other events. In addition, the category of causality is a very informative category, as explained earlier. It functions as an interpretation scheme for understanding the world. In a sense, concepts such as causality may be compared with the views of the Gestalts (Lakoff, 1977) because they both express the way in which we perceive the world.

It is also through perception that the notion of causality develops (Miller & Johnson-Laird, 1976). We learn to observe co-occurrences and relations between events and to discern what the reasons are for these co-occurrences. Ontogenetically, these experiences start in the sensorimotor domain (Piaget, 1961). The sensorimotor experience of how events in the real world are organized is the basis for the development of visual causality and the starting point for the further conceptual development of the notions of temporality and causality. That the notion of causality has a perceptual basis is also clear independent of the ontogenetic development: Michotte (1954) demonstrated how the precise timing between two events led the perceiver to a causal interpretation of two moving events. Research by Michotte as well as Piaget indicated that we do not just perceive regularities in the outside world but that we also perceive causal relations.

The Causal Organization of Knowledge: An Illustration

If causality is an important concept in structuring knowledge, degrees of expertise in a particular domain should be related to differences in causal knowledge. That the knowledge of experts is organized differently than the knowledge of nonexperts has been demonstrated in a number of domains (Adelson, 1984; Chase & Ericsson, 1981; Chase & Simon, 1973; Chi, Glaser, & Rees, 1982; Riesbeck, 1984). Knowledge of experts is organized in higher order knowledge structures, at a more abstract level, and according to general categories, principles, and laws.

To illustrate the kinds of relations that are characteristic of expertise in a particular domain, we discuss a study performed with experts and nonexperts in economics (Simons, 1993; Vonk & Noordman, 1992). The experts were 30 advanced doctoral students in economics; the nonexperts were 40 advanced doctoral students in disciplines not related to economics. On the basis of a survey in a quality Dutch newspaper, 80 well-known economic concepts were collected. These concepts were used in a free association task administered to both groups of participants. On the basis of the free associations, 100 pairs of frequently associated concepts were constructed. These concepts were presented to a new group of 20 experts and 20 nonexperts, along with the task of describing the relation between these concepts. These descriptions were analyzed to find out what kinds of relations are related to differences in expertise. Only those pairs that were described in an identical way by 75% of the experts and by 75% of the nonexperts, respectively, were analyzed.

The descriptions were classified with a classification scheme that was independently developed in previous research. The analysis was performed by two independent judges. Seventy percent of the descriptions given by experts contained causal relations, whereas only 39% of the descriptions given by nonexperts contained causal relations. This difference indicates that the degree of knowledge in this knowledge domain is related to the amount of causal relations. The fact that nonexperts produced a considerable number of causal descriptions, despite

the fact that they did not have much knowledge of this domain, also illustrates the importance of causal interpretation.

Causality Expressed in Language

Because causality is a fundamental category of human knowledge and because language is an expression of human knowledge, one may expect to find many ways in which causality is expressed in language. The semantic analysis of verbs testifies for this. Many verbs express causality (e.g., *kill, lengthen,* and *allow*). More fundamentally, causality is an important category in the classification of verbs. Verbs can be classified as states or events. Events can be differentiated into agentives and nonagentives. Agentive verbs can be further classified into causative and noncausative verbs. Miller and Johnson-Laird (1976) showed that these distinctions are made on the basis of the concepts *happen, do, cause,* and *intend.* These concepts "are sufficiently basic to qualify as psychological universals" (p. 483). Talmy (1988) discussed in more detail the linguistic expression of causality under the more general notion of *force dynamics.*

Causality is also expressed at the discourse level, as exemplified in the way in which stories are described (Mandler & Johnson, 1977; Rumelhart, 1975; Schank & Abelson, 1977; Thorndyke, 1977; Trabasso et al., 1984; Trabasso & van den Broek, 1985). In addition, in theories that describe discourse in terms of discourse relations, causality is one of the basic categories (Mann & Thompson, 1986; Sanders, Spooren, & Noordman, 1992).

UNDERSTANDING AS A KNOWLEDGE-BASED EXPLANATION PROCESS

In this section, we characterize text understanding as a process of explanation. The dominant view in psycholinguistics is that understanding is the process of constructing a coherent representation of the text. Connections are made between the sentences so as to integrate them. Important linguistic devices that indicate how sentences are related to each other are anaphoric expressions and conjunctions. In processing anaphoric expressions, readers identify addresses in the representation and attribute predicates to these addresses (Seuren, 1985). This aspect deals with the textual relations and their cognitive correlates. The representation from this point of view expresses how the current input is related to the previous representation. At each moment, the representation is incrementally constructed. However, there is another aspect of the representation: The representation is a representation of something. Apart from the relations that text segments have with each other, there are relations between the text segments and (a model of) the world. This distinction has been made in linguistics, for example, by Guenthner (1989) in terms of discourse relations and truth relations.

The distinction made by psychologists between propositional representation and mental models or situation models (Johnson-Laird, 1983; van Dijk & Kintsch, 1983) reflects the same distinction. The propositional representation expresses the propositions in the text and forms the so-called text base. A mental model expresses the situation in the world described by the text. Such a mental model is constructed on the basis of world knowledge and is integrated with world knowledge. In understanding, we match what we read with what we know about the world. We implicitly ask ourselves whether the text is true, plausible, or possible. We implicitly test the truth, plausibility, or possibility of the text. Understanding a text is explaining why the information conveyed by the text is true, plausible, or possible. Understanding actions and events implies that one can explain them: that one can specify reasons, motivations, and causal antecedents for the events and actions (Craik, 1943; Schank, 1986). These explanations depend on the knowledge of the reader (Graesser et al., 1994; Singer, Halldorson, Lear, & Andrusiak, 1992). Understanding a text is justifying it on the basis of our knowledge. Several researchers have expressed this by the term *abduction* (Hobbs, Stickel, Appelt, & Martin, 1993; Pierce, 1955). Understanding is "to prove that what one is told must be true on the basis of what one already knows" (Charniak, 1986, p. 585). This is not to say that everything is already known to the reader; of course, each sentence and each text contains new information. However, the claim is that one has to prove and to explain the information in the text as much as possible. Those parts of the text that cannot be proved have to be assumed and constitute the new information (Hobbs et al., 1993). This conception of understanding as a knowledge-based explanation process is discussed for the understanding of causal relations.

Knowledge-Based Understanding of Causal Relations

Understanding a causal relation can be conceived of as follows: A causal scheme is activated by the text. This may occur in different ways: just on the basis of the propositions in the text or on the basis of a causal conjunction that explicitly expresses the causal relation. In the first case, readers may activate their knowledge and detect that there is a causal relation in their knowledge representation corresponding to the situations or events expressed in the text. In the second case, it is the causal conjunction that triggers a causal scheme. A causal scheme can be represented as the complex concept as proposed by, for example, Miller and Johnson-Laird (1976). They specified a causal relation in terms of a decision table—that is, in terms of the conditions that have to be fulfilled in order to decide that there is causality involved. Meaning is expressed in a procedural way as condition–action pairs: If the following conditions concerning two events (e1 and e2) are fulfilled—possible (e1 & e2), not possible (e1 & not e2), possible (not e1 & e2), and possible (not e1 & not e2)—then interpret cause (e1, e2). According to this conception, a causal interpretation of a sentence is obtained

by activating knowledge in two steps. First, the causal scheme that specifies the conditions that have to be fulfilled for an appropriate application of the causal relation is activated. Second, it has to be decided whether the conditions are fulfilled by checking the conditions with respect to the reader's knowledge base. If the conditions are indeed fulfilled, the reader decides that the causal relation expressed in the text conforms to the situation in the world. Establishing this is understanding the causal relation in the text.

Given this characterization of understanding a causal sentence, understanding a causal relation depends on the reader's knowledge base. Suppose a reader who is familiar with the qualities of the material Kevlar reads the following sentence: "Connors used Kevlar sails because he expected little wind" (Noordman & Vonk, 1992). Understanding this sentence implies that the reader checks the conditions for a causal relation, in particular the conditions that expecting little wind goes together with using Kevlar sails and that expecting little wind does not go together with not using Kevlar sails. Testing these conditions against the reader's world knowledge means that the reader tries to give an explanation for the use of *because*. The explanation in this case is the general premise that it is advantageous to use Kevlar sails when there is little wind. For a reader who is familiar with the qualities of Kevlar, testing the conditions and deriving the general premise is not problematic. The sentence is easily understood. The inference that the writer assumed the reader to make ("Kevlar is advantageous when there is not much wind") is easily made because it is familiar knowledge for the reader. This is different for readers who are not familiar with Kevlar. These readers cannot explain the correctness of the *because* sentence and cannot prove that the sentence is true on the basis of what they already know. In this case, the major premise has to be constructed as new information: "Apparently, Kevlar is advantageous if there is not much wind." This inference is of quite a different nature than the inference made by a high-knowledge reader. It is the derivation of new information and not the activation of available knowledge. So, there are two kinds of inferences. Which inference takes place depends on the reader's knowledge. The first kind of inference is actually the activation of available knowledge. It is an inference in the sense that the information is not explicitly expressed by the text, but, in terms of reasoning as abduction, it is not new information. The second inference, on the other hand, is the derivation of new information. In the psychological literature, this distinction is hardly ever made. Most inferences in the literature are of the first type. For example, most of the anaphoric inferences are of this type.

Experimental Evidence for Knowledge-Based Causal Inferences

Do readers, who are not familiar with the inferential information, make the causal inference? Or do only high-knowledge readers make the inference? This was expected on the basis of an earlier study (Vonk & Noordman, 1990). To find

out how the inference process depends on the reader's knowledge, we used an expert–novice reading paradigm with experts and nonexperts in the domain of economics (Noordman & Vonk, 1992; Simons, 1993). The knowledge structures of experts and nonexperts were obtained by the elicitation experiments described in the preceding section. These knowledge structures were represented as networks. In these networks, triplets of concepts were identified that were causally related for the experts but not related for the nonexperts. On the basis of these triplets, sentences were constructed that were used in a reading time experiment—for example, "American exports have been suffering a decline, because rising inflation has produced a harmful effect on the competitive position of the U.S.A." This sentence requires the inference that deterioration of the competitive position leads to a decline in the exports. The construction of the materials had ensured that this relation was known by the experts but not by the nonexperts. The target sentences containing *because* were embedded in larger texts. The participants were instructed to read the texts carefully and were requested to make verifications after reading the texts. The texts were presented in two conditions. In the explicit condition, the target sentence was preceded by a sentence that expressed (part of) the inference, for example, "Generally speaking, the competitive position of a country has a strong influence on the volume of its exports." If, according to the hypothesis, the experts make the inference immediately when reading the target sentence, the inference should be facilitated by the explicit information, leading to a shorter reading time. The role of the explicit information is to activate the relation between the concepts in the reader's memory so as to facilitate the inference process. This should be effective for the experts because the relation is available to them. Therefore, it is expected that the reading times for the target sentence in the explicit condition will be shorter than in the implicit condition for the experts. No such difference is expected for the nonexperts because the relation between the concepts is not familiar to them and, consequently, cannot be activated by the explicit information sentence. The reading times were exactly as predicted. This indicates that the online inference process depends on the reader's knowledge. More precisely, inferences that are derivations of new information are not made spontaneously during reading. Inferences that are activations of available knowledge are made during reading.

The next question was whether nonexpert readers apply the causal scheme. Although they do not make the inference spontaneously, are they able to make the inference if they are requested to do so? After all, the conjunction *because* in the sentence suggests the inference. One of the verification statements presented after the reading task expressed the inference. The nonexpert participants were indeed able to make the inference after reading the text, as was suggested by the percentage of correct verifications they made. Additional support for this conclusion came from the verification latencies. These latencies were shorter in the explicit condition than in the implicit condition. So, the inferences were made during the verification task and not during the reading of the target sentence.

These verification data also rule out the possibility that the nonexperts followed a strategy of suspending comprehension a bit so as to make the inference during the reading of the next sentence. Moreover, this strategy is rather unlikely in the light of an earlier study (Noordman, Vonk, & Kempff, 1992), in which no difference in reading time for the posttarget sentence was obtained. That study gave further support for the conclusion that nonexpert readers are able to make the causal inference, even though they do not make it spontaneously. Manipulations of the reading task were effective in stimulating readers to make the inferences even during reading. If participants were required to read a text so as to be able to answer a particular question, and if that question related to the inference, readers made the inference during reading, even though that inference was not familiar to them.

Causality and Informativeness

If causality is such a fundamental category of human cognition, readers should have a preference to interpret a sequence of sentences in a causal way unless there is evidence against it. In this sense, readers should strive for a rich representation. The alternative is that readers make a causal interpretation only if it is explicitly indicated.

The principle of informativeness (Atlas & Levinson, 1981; Levinson, 1983) is relevant to this issue. This principle states: Read into an utterance more information than it actually contains. Levinson discussed the following example: "He turned on the switch and the motor started." He said:

> We read this in a way that is as "strong" (informationally rich) as the world allows and thus read in the following relations between two conjoined clauses whenever possible:
>
> Given p and q, try interpreting it as:
> (i) "p and then q"; if successful try:
> (ii) "p and therefore q"; if successful try also:
> (iii) "p, and p is the cause of q." (p. 146)

The informativeness principle contrasts with the maxim of quantity, which states that, if a weaker statement is made in a situation in which a stronger statement would have been relevant, the speaker was not in the position to make the stronger statement and that, consequently, no stronger interpretation can be made. According to the maxim of quantity, interpretation (iii) is excluded because if it was appropriate, the speaker would have said so. But (iii) is the most obvious interpretation. This illustrates the principle of informativeness. Interestingly, Levinson presented the interpretations as a process model. The listener goes through a decision process from (i), the least informative interpretation, to (iii), the most informative interpretation. This order predicts that a causal interpretation

(ii, iii) requires more decisions (and more time) than a temporal interpretation (i) and, a fortiori, than an additive ("p and q") interpretation. (It should be noted that (i) is a temporal inference and that it is more informative than a purely additive interpretation.)

According to the informativeness principle, there is a trade-off between the speaker's tendency to be parsimonious and the listener's tendency to make an informationally rich interpretation. Cooperation between the speaker and listener leads the listener to select the most informative interpretation. The principle of informativeness demands that "the contribution is as informative as required and presupposes that more will be read in" (Traugott & König, 1991, p. 192). In this way, the greatest effect in cooperative communication is achieved by the least effort. This principle is central in relevance theory (Sperber & Wilson, 1986).

Traugott and König (1991) described the informativeness principle at work in the way in which the meaning of conjunctions develops in language. They showed that, in the evolution of language, speakers tend to become "more and more specific through grammatical encoding" (p. 192), and listeners tend to "select the most informative interpretation" (p. 192). They also showed how pragmatic meanings are grammaticalized later than nonpragmatic, propositional meanings. For example, the concessive meaning of *while* develops on the basis of the temporal meaning. What originally are conversational inferences become conventionalized. Traugott and König argued that, in language change, there is a "shift from what is said to what is meant" (p. 193): The concessive meaning of *while* does not precede the temporal meaning but develops later. The development goes in the direction of greater specificity and informativity. This development is also visible for causal conjunctions. Expressions that originally had temporal meanings acquire causal meanings (e.g., *since*). The polysemous interpretation of *since* originates from the conventionalization of earlier conversational inferences. There is a historical development toward more informative and more specific meanings (from temporal to causal and from temporal to concessive).

The informativeness principle—select the most informative, specific interpretation—leads to the prediction that causal interpretations, if allowed, are preferred over noncausal interpretations. A causal relation is more informative than an additive relation. Indeed, "e1 causes e2" implies "e1 and e2" and, in general, "e1 precedes e2." What does this imply for processing causal information? Depending on the interpretation of the informativeness principle, one may suppose that processing causal information requires more time than processing additive information or that it requires less time. The first interpretation states that a causal relation is more informative than an additive relation and that, therefore, processing the causal relation should require more time than processing an additive relation. This is in line with the way Levinson (1983) described the informativeness principle. According to this conception, we first check the least informative interpretation, the additive interpretation. If this first step succeeds, then we try the second step: the temporal interpretation. If that succeeds, we try the causal

interpretation. In this conception of the reading process, the reader arrives at the most informative reading while minimizing effort. On the other hand, the informativeness principle can be interpreted as a principle implying that the reader tries initially the most informative interpretation, that is, the causal interpretation. The comprehension process can then be considered as maximizing informativeness. The reader strives initially toward maximal information instead of minimal effort.

Research by Singer et al. (1992) is in agreement with this tendency to maximize informativeness. They found that the reading time for the second sentence in a causal sequence was shorter than that in a temporal sequence. Sanders and Noordman (1998; Sanders, 1992) compared the processing of causal and additive information. They conducted reading experiments in which an identical target sentence in a text was related to the preceding context either by a causal relation or by an additive relation. An example of a target sentence is: "The construction of a subway in the center of Veendam will begin next year." In the causal condition, the preceding context discussed a problem of traffic accidents with pedestrians. The causality that is involved here is a problem-solution situation (Sanders et al., 1992). The problem is to get at the solution that is considered the goal in the problem-solution situation. In the additive condition, the preceding context dealt with various construction activities in that region. To be sure that the target sentence was equally easy to integrate with the preceding context in the two conditions, the given–new relations of the target sentence with the preceding context were similar in both conditions. Furthermore, the texts were deliberately constructed such that the specific contents of the target sentences were hard to predict on the basis of the preceding context in both conditions. The reading times for the target sentence in the causal condition were significantly shorter than those in the additive condition. Immediately after reading the text the participants had to verify statements, one of which was related to the target sentence. The number of correct verifications was larger for the causal condition than for the additive condition. Also, the recall of the text in the causal condition was superior to that in the additive condition, and the causal relation was reproduced more frequently than the additive relation. So, causal relations are encoded more quickly and are better retrieved than additive relations. Readers start out assuming that the relation between two consecutive sentences is a causal relation. Readers initially assume the most informative relation. This is contrary to what Levinson (1983) proposed. Presumably, the reader will give an additive interpretation only if no causal interpretation can be made.

Integration and Inference Processes in Understanding Causal Relations

In the Experimental Evidence for Knowledge-Based Causal Inferences subsection, inferences in understanding causal sentences were discussed. It was shown that inferences require extra processing time. In the preceding subsection, it was

demonstrated that causality speeds up processing: Causal relations are processed more quickly than additive relations. The speeding-up and slowing-down effects of causality are a paradox. In trying to solve this paradox, we make a distinction between integration processes and inference processes. To illustrate the difference between the integration process and the inference process, consider the sentence: "John selected his stranston shoes because he expected much mud." This sentence can be understood more or less deeply. When we understand it superficially, we simply accept that there is a reason for selecting his stranston shoes: There is much mud. We take that reason for granted, without bothering to determine what stranston is and what the relation between stranston and mud is. We accept the causal relation without checking it against our knowledge base. We also can understand the sentence in a less superficial way. In that case, we derive the conclusion that stranston is such a material that it is advantageous when there is much mud. If we already know what stranston is, we check the information against our knowledge base (this is what we earlier called *an inference as activation of knowledge*); if we do not yet know it, we add the information to our knowledge base (this is what we earlier called *an inference as the derivation of new information*). The process in the superficial understanding is what we call *integration.* In processing the sentence more deeply, the reader makes an additional process: the inference that ("indeed," or "apparently") stranston is a material that is advantageous when there is much mud. On the basis of the distinction between integration and inference, the paradox mentioned earlier can be solved as follows: The results concerning the causal and additive relations allow for two interpretations. First, in understanding the causal sentences, no inferences are made. The understanding consists of the integration of the two clauses: One clause is considered as the cause for the other clause. Integrating causal sentences is quicker than integrating additive sentences. Second, an inference is made but the slowing down due to the inference process is wiped out by the speeding up that is attributed to the faster integration of a causal sentence than an additive sentence.

The question now arises of how the integration process relates to the inference process. We suggest that integration and inference relate to different kinds of representations and occur at different moments during processing. In understanding a text, different kinds of discourse representations can be identified: a surface representation, a propositional representation, and a mental model representation. The surface representation contains the literal information. The propositional representation contains the meaning of the sentences and can be expressed in terms of propositions. It also expresses how the propositions in the text are related to each other. The mental model representation contains, in addition, inferences derived from the text on the basis of world knowledge. The different representations are constructed in real time, and there is some temporal dependence among them. The surface representation is constructed initially and is gradually replaced by the propositional representation. The mental model representation is a further elaboration of the propositional representation. One may then hy-

pothesize that the integration process in understanding causal sentences plays a role in the propositional representation: It affects the way in which propositions are related to each other. Inferences deal with the mental model representation: They are deductions on the basis of world knowledge. If the representations are more or less ordered in time, the integration process should occur earlier than the inference process in understanding a causal sentence.

A number of experiments have been conducted in our lab to test this idea (Cozijn, 1992; Noordman & Vonk, 1997; see also Millis & Just, 1994). In one experiment, participants read texts in which two causally related sentences were either connected by the conjunction *because* or separated by a period, for example, "On his way to work that morning he was delayed [. There / , because there] was a traffic jam on the highway." The durations of eye fixations were measured. If readers in understanding this sentence integrate the two clauses in a causal way, the presence of the conjunction should facilitate this integration process and should be reflected in shorter fixations on the words in the second clause. This is expected on the assumption that the process of causally integrating words in the second clause to the first clause occurs immediately during reading. An inference process, on the other hand, requires the availability of the propositions of the two clauses and the activation of world knowledge and will occur somewhat later, probably at the end of the sentence. Cozijn indeed found that the average fixation duration was significantly shorter for the words in the second clause when the second clause contained a conjunction than when it did not, suggesting that the integration process was facilitated by the conjunction. On the other hand, the fixation duration for the final word was longer in the condition in which the conjunction was present than when it was absent, suggesting that an inference process in normal reading needs the presence of a conjunction and takes place at the end of the sentence.

Causality and the Order of the Information

Understanding causal relations implies activating a causal scheme ("e1 causes e2") and testing whether its conditions are fulfilled in the situation described by the text. Does it make a difference whether the information is presented in the order of cause–consequence or in the order of consequence–cause? The order of cause–consequence might be more fundamental than the order of consequence–cause. We learn causality by discovering in the real world the co-occurrence between causes and consequences, in which the causes precede the consequences. Perceptually, the cause–consequence order is primary to the consequence–cause order. It is on the basis of cause–consequence co-occurrences that we learn to relate in an inverse relation consequences to their causes. If the order of cause–consequence is more fundamental than the order of consequence–cause, we should prefer to reason from causes to consequences instead of from consequences to causes. There have been a number of studies in the literature on causal inferences,

focusing on the question of whether readers make inferences about causes, including goals, and about consequences (Graesser et al., 1994; Magliano, Baggett, Johnson, & Graesser, 1993). These studies suggest that inferences about causes and goals are made because they explain the events that are mentioned in the text. Inferences about consequences, however, are not made, "because there are too many alternative hypothetical plots that could potentially be forecasted" (Graesser et al., 1994, p. 382). On this view, there should be a preference to process a causal relation in the order of consequence–cause rather than in the order of cause–consequence. In the consequence–cause order, the cause sentence is facilitated by an inference about the cause. The reading time for the cause sentence should decrease if it is preceded by the consequence sentence. This prediction requires, of course, that the cause can be identified on the basis of the consequence. In the cause–consequence order, on the other hand, no facilitation by a consequence inference is expected. The reading time for the consequence sentence should not decrease if it is preceded by the cause sentence. This argument seems to rest on the assumption that inferences about causes are more constrained or predictable than inferences about consequences. However, what if both the cause and the consequence of a causal relation are very predictable? Is there still a preference for the consequence–cause order? An alternative prediction rests on the assumption that the cause–consequence order reflects our causal knowledge. The reading of the consequence sentence should be facilitated by the preceding cause sentence. This prediction requires, of course, that the consequence can be identified on the basis of the cause.

In an experiment with Meyer Viol (1984), we tested this hypothesis. The experimental texts contained a causal relation that was expressed in two different orders. The following fragment is an example:

> In order to earn some money, John was cutting out weeds in his mother's garden. It was a tough job, because the stinging-nettles were a meter high. After two hours, he took a short break. The job was half finished. The sun stood high in the sky and it was sweltering hot. He wiped away the sweat from his forehead with his hand. He had touched the stinging-nettles with his hand. His hand itched terribly.

In this condition, the cause sentence ("He had touched the stinging-nettles") preceded the consequence sentence ("His hand itched terribly"). In the other condition, the cause sentence and the consequence sentence were reversed ("His hand itched terribly. He had touched the stinging-nettles."). The materials were constructed in such a way that the consequence sentence was indeed a very likely, natural, and predictable consequence of the cause. This was verified by three judges. In addition, as required by the alternate hypothesis, the cause sentence was very predictable by the consequence sentence. This was tested in a pretest with 47 participants. They had to indicate what the most plausible cause was, given the

consequence. Only those materials for which more than 80% of the participants gave the intended cause were used. The reading times for the consequence sentences were significantly shorter when preceded by the cause sentences than when not preceded by the cause sentences. On the other hand, the reading times for the cause sentences were not shorter when preceded by the consequence sentences than when not preceded by the consequence sentences. So, the occurrence for causal inferences rather than consequence inferences, reported in the literature, might be due to a difference in predictability. If the causes constrain the consequences, consequence inferences are made. In this case, a cause sentence speeds up the processing of a subsequent consequence sentence, but a consequence sentence does not speed up the processing of a subsequent cause sentence. So, readers do not make the inference from consequence to cause, whereas they do make the inference from cause to consequence. What this experiment demonstrates is a kind of iconicity between cognitive structure and language. Readers infer consequences from causes but not causes from consequences, although the causes could be predicted by the consequences, as had been determined by the pilot experiment.

Content Versus Epistemic Relations: Direct Versus Indirect Causality

In the previous experiment, the order of the cause and consequence was reversed. If we make the causality of the relation explicit, we obtain the sequences: "because he had touched the stinging-nettles, his hand itched terribly," and "his hand itched terribly, because he had touched the stinging-nettles." In both cases, the subordinate clause corresponds to what conceptually is the cause in the real world and the main clause to the consequence in the real world. Linguistically, the subordinate sentence in a *because* or *if* sentence is the antecedent, and the main clause is the consequence. So, there is a correspondence between what linguistically is the antecedent (the subordinate clause) and consequence (the main clause) and what conceptually is the cause and consequence. This is not always the case. There are causal sentences in which the subordinate clause expresses the consequence of the causal relation. Compare "John came back because he loved her" with "John loved her, because he came back" (Sweetser, 1990). These sentences express different kinds of relations (Oversteegen, 1997; Sanders et al., 1992; Sweetser, 1990). The first sentence expresses a content relation; the second sentence, an epistemic relation. There is a content relation between two clauses if the two clauses express events or situations in the world, and the relation exists between the events or situations in the world. In "John came back because he loved her," the fact that John loved her caused John's returning. There is an epistemic relation between two clauses if the propositions in the two clauses are embedded in epistemic operators. In Sweetser's example, "John loved her, because he came back," the event of John's returning does not cause John's love but "the speaker's knowledge of John's return (as a premise) causes the conclusion

that John loved her" (p. 77). The relation exists between the speaker's knowledge of a situation or event in the world and a conclusion the speaker can draw from that. That is what is meant by epistemic operators. The sentence presupposes that, if John returned, one may conclude that he loves her. This presupposition is just the reverse of the one in "John came back because he loved her." In the epistemic relation, the consequence ("John came back") is interpreted as the cause for a conclusion about the cause ("John loved her"). This makes clear that the justification of the epistemic relation is an underlying content relation: I conclude from John's returning that he loves her because, if John loves her, he will return. This kind of epistemic relation expresses a reasoning by abduction.

According to this analysis, content relations more directly reflect the experience in the real world, and epistemic relations are derived from these content relations as inductions. Content relations may be said to express direct causality and epistemic relations indirect causality. Are sentences that express direct causality processed faster than sentences that express indirect causality? One might predict this on the following ground: In direct causality sentences, the real-world cause is expressed as the antecedent and the real-world consequence as the consequence. Accordingly, in these sentences, there is a correspondence between what is linguistically expressed as antecedent and consequence and what is cause and consequence in the real world. In sentences expressing indirect causality, on the other hand, there is no such correspondence. Processing an epistemic relation requires more time because it requires the understanding of the underlying content relation (I conclude from John's returning that he loves her because, if John loves her, he will return).

Noordman (1979) conducted a study with condition–consequence sentences that addressed this point. Participants had to verify conditional sentences against their knowledge of the world. The conditional sentences expressed causal relations. They expressed content relations and epistemic relations. An example of the first type is: "If John is ill, he is not going to his work." The clause that followed the conjunction expressed what cognitively was the condition; the other clause expressed the consequence. An example of the other type is: "If John is not going to his work, he is ill." The clause following the conditional conjunction expressed what cognitively was the consequence; the other clause expressed the condition. In this latter case, "there is an incongruence between what is the condition and the consequence according to the structure of the sentence and what is the condition and the consequence according to the knowledge of the listener and speaker" (Noordman, 1979, p. 97). The verification times for the content relations were significantly shorter than for the epistemic relations. So, sentences that express the real-world cause as the antecedent and the real-world consequence as the consequence are more basic than sentences in which there is no such correspondence.

In addition to this difference in processing time, content relations occur more frequently than epistemic relations in a corpus-analytic study by Noordman and

van Rijswijk (1997). That study dealt with causal contrastive relations expressed by the conjunction *hoewel* 'although'. An example of a content relation is: "Although the neighbors have left, their car is in front of the house." An example of an epistemic relation is: "Although their car is in front of their house, the neighbors have left." In both kinds of sentences, the subordinate clause expresses an event or situation on the basis of which an expectation is created. In that sense, there is a causal relation that underlies the *although* sentence. That expectation is denied in the main clause. In that sense, the *although* sentence is an adversative sentence. The expectation in the content case is: "If the neighbors go out, they go by car." This is a content relation because it describes a relation between events in the world. The expectation in the epistemic case is: "If their car is in front of the house, you may conclude that the neighbors are at home." Underlying this epistemic relation is the content relation ("If they go out, they go by car") as its justification. Noordman and van Rijswijk analyzed news texts from a quality Dutch newspaper. The number of content relations was 5 times greater than the number of epistemic relations. This result agrees with the assumption that a causal content relation is a fundamental category in expressing human thought.

CONCLUSIONS

In the first part of this article, we argued that causality plays an important role in human cognition. The way we experience the world from early childhood on is characterized by the notion of causality. Perception and actions are experiences of causality. In perception, we are affected by the external world, and actions are expressions of our intentionality and are manipulations in the outside world. These experiences are causal in nature. We experience causality also in situations in which we are not ourselves the agent or patient of a causal influence. We interpret co-occurrences between events as causal relations. On the basis of these sensorimotor experiences in the world, we develop the way we conceive of the world and interact with the world. As intelligent human beings, we want to understand the events and situations in the world. This implies that we want to explain the events, to specify them in terms of causal influences, and to predict consequences. Understanding is an explanation-based process. Understanding a text is being able to specify the causes and consequences of the situations and events described by the text. This explanation-based process is knowledge dependent and is therefore memory based.

The second part of the article dealt with the processing of causal information. It was argued that, if causality plays an important role in structuring human cognition, there should be a tendency to interpret information in a causal way. This is not a trivial prediction because a causal interpretation is not the most parsimonious interpretation, and in general, cognition is characterized by a prin-

ciple to reduce effort. Experimental evidence illustrated a tendency to interpret information in a causal way: If information has a causal relation with its preceding context, it is integrated faster with its preceding context than when it has an additive relation. This is the case even though causal information requires more inferencing. A distinction has been made between integration processes and inference processes. Experimental evidence suggested that integration and inferencing affect different kinds of representations that are constructed during processing. Finally, it has been shown that the way in which causal information is presented in the text affects processing. If the way in which the information in the text is expressed corresponds to the structure of human knowledge, one may predict that this facilitates processing. This correspondence can be considered as an illustration of *iconicity*. Some experimental evidence has been presented for this prediction. First, if the order of presentation corresponds to cause–consequence, processing is facilitated. Second, if the information that is conceptually the antecedent of a causal relation is expressed linguistically as the antecedent, processing is faster than when there is no such correspondence. This can also be formulated as a preference to process direct causation over indirect causation—or to process content relations over epistemic relations.

Causal relations form a basic organizational principle of human knowledge, and this organizational principle has consequences for language production and comprehension. This is an instance of the more general claim that linguistic structure and linguistic processing is constrained by general perceptual and cognitive principles (Bever, 1970; Osgood, 1980). The category of causality is developed in prelinguistic cognitive experience and becomes part of the linguistic and nonlinguistic processing system. Therefore, it seems indeed plausible that, the more sentences correspond to these cognitive categories, the more easily they will be produced and understood.

This position has also been defended in philosophies of knowledge. According to Kant, our cognitive faculty has a structure in itself. Human cognition (perception and comprehension) has a form of its own that determines everything we know. Our cognitive system has certain a prioris by which it operates. These a prioris are properties of the cognitive system, not of the observable world (we do not subscribe the latter restriction), and determine how we perceive our world and how we structure our knowledge. In the perceptual domain, these a prioris are time and space. The intellectual domain is characterized by the fact that we think in terms of substance and attributes, in terms of causes and effects, and in terms of unity and diversity. This idea that the way in which we perceive and understand information depends on our processing system has roots in ancient philosophy. Agrippa, a Greek philosopher of the late Scepticism (De Strycker, 1987) wrote: "Every knowledge is dependent on the knowing subject." Although he used this statement to argue that we have to suspend our judgments, it can also be interpreted as the expression of a fundamental property of the human information processing system.

In the beginning of this article, a distinction was made between two views on text processing. According to the constructionist view, the reading process is characterized by the reader's search after meaning. In the integration view, the reading process is characterized as the integration of the propositions in the current input with the previous input. In our opinion, these two views are not alternatives; they are complementary and should be combined. They both are aspects of memory-based text processing. We argued that this notion had two components: Memory can refer to the previous text propositions as well as to the content of long-term memory. The first aspect implies that the current input makes contact with propositions in the memory representation of the previous discourse. The second aspect of memory-based text processing implies that propositions in the current input resonate to knowledge structures in the reader's long-term memory. What this article showed is that the way in which propositions are integrated with each other depends on the knowledge structure in the long-term memory of the reader. Both aspects of memory-based text processing are intrinsically related to each other. This has been demonstrated for the processing of causal information. It has been argued that causality is an important category in structuring human knowledge. Input is processed faster to the extent that it more closely corresponds to existing knowledge structures. A comprehensive model of text processing should account for the way in which propositional integration depends on knowledge structures.

ACKNOWLEDGMENTS

We are grateful to Edward J. O'Brien, Robert F. Lorch, and Jerome L. Myers for their helpful comments on the article and to Edward J. O'Brien for his excellent editorial help.

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