A basis for generating expectancies for verbs from nouns

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We explore the implications of an event-based expectancy generation approach to language understanding, suggesting that one useful strategy employed by comprehenders is to generate expectations about upcoming words. We focus on two questions: (1) What role is played by elements other than verbs in generating expectancies? (2) What connection exists between expectancy generation and event-based knowledge? Because verbs follow their arguments in many constructions (particularly in verb-final languages), deferring expectations until the verb seems inefficient. Both human data and computational modeling suggest that other sentential elements may also play a role in predictive processing and that these constraints often reflect knowledge regarding typical events. We investigated these predictions, using both short and long stimulus onset asynchrony priming. Robust priming obtained when verbs were named aloud following typical agents, patients, instruments, and locations, suggesting that event memory is organized so that nouns denoting entities and objects activate the classes of events in which they typically play a role. These computations are assumed to be an important component of expectancy generation in sentence processing.

The role of expectancy generation in sentence processing has attracted increased attention over the past several years. There has long been reason to believe that comprehenders generate expectations about upcoming words as they process sentences presented incrementally (Kutas & Hillyard, 1984; Marslen-Wilson & Welsh, 1978), and computational modeling suggests that implicit expectancy generation can lead to the discovery of underlying syntactic structure (Elman, 1990). More recently, a number of researchers have suggested that although language understanding is clearly about more than simply anticipating what comes next, expectation does appear to play a critical role in language processing (Altmann, 2002; Federmeier & Kutas, 1999; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2003). Two questions that immediately arise are the following: (1) Which elements in a sentence can be used to gener-

ate expectancies? and (2) What connection exists, if any, among expectancy generation, higher levels of understanding (e.g., event knowledge), and the extraction of meaning? In what follows, we will sketch a response to these questions, arguing that verbs are an important source of expectancy generation but that sentential nouns can be so as well, via the activation of generalized event knowledge. We tested this hypothesis with a set of priming experiments.

Expectancy Generation From Verbs and Nonverbs

In response to the first question, it is clear that verbs play a central role in sentence processing and, by logical extension, are likely to be powerful generators of expectancies. Nouns may stand alone, but verbs rarely do. As predicating functions, verbs exhibit regular and systematic restrictions on their complements. Although verbs as a category enter a child's language later than do nouns, they are associated with the first appearance of real grammar. From that point on, it is clear that verbs play the major role in organizing the event structure that underlies sentences (Gentner, 1982; Tomasello, 1992).

Among other things, a verb imposes syntactic constraints on the phrases with which it co-occurs (its argu-

ments), as well as semantic constraints, such as the thematic roles it assigns to those arguments. Experimental work has demonstrated that these restrictions influence comprehension (among numerous other findings, see those in Boland, Tanenhaus, Carlson, & Garnsey, 1989; Carlson & Tanenhaus, 1988; Ferreira & Clifton, 1986; Frazier, 1987; Frazier, Clifton, & Randall, 1983; Rayner, Carlson, & Frazier, 1983; for a review, see Tanenhaus & Trueswell, 1995). Clearly, there are a myriad of ways in which verbs lie at the heart of sentence processing.

Furthermore, it is clear that the information available from verbs is remarkably fine-grained both structurally and semantically and that this information interacts in complex ways with other cues in the sentence (Altmann, 1998, 1999; MacDonald, Pearlmutter, & Seidenberg, 1994; McRae, Ferretti, & Amyote, 1997). For this reason, computational models have proven to be invaluable tools both in understanding the empirical phenomena and in uncovering the deeper principles that guide processing (Christiansen & Chater, 1999; Elman, Hare, & McRae, 2004; Spivey-Knowlton & Tanenhaus, 1998; Tabor & Tanenhaus, 2001). One of the major lessons of this computational modeling is that—in these models, at least—a sentential element's effect on processing does not depend directly on its grammatical category but, instead, reflects that element's predictive value. Given that verbs are a powerful source of constraint, as a category, they can be expected to loom large in the guiding of processing. But the verb may not be the only element in the sentence that plays this role. Nouns, prepositions and adjectives possess valence restrictions, for example, although to a weaker degree than do verbs. Thus, words from other major syntactic categories may exert constraining forces as well.

There are at least two reasons to believe that this possibility is exploited in language comprehension. First, if the verb alone determines the roles played by other elements in the sentence, the depth to which the sentence can be processed will be limited pending the verb's appearance. However, there are languages, such as German and Japanese, in which the verb often appears in clause- or sentence-final position. A computational mechanism that defers any hypothesis about structure and meaning until the end of the clause or sentence would be highly inefficient (Frazier, 1987) and inconsistent with the results of studies showing that information is rapidly and incrementally integrated as a sentence is processed (Marslen-Wilson, 1975; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Indeed, recent studies suggest that incremental syntactic processing does occur in verb-final constructions in German and Japanese (Kamide & Mitchell, 1999; Kamide, Scheepers, & Altmann, 2003). Thus, at the very least, nonverb elements must play some role in such languages in generating hypotheses about the ultimate structure.

Second, many psycholinguistic experiments have demonstrated that the assignment of thematic roles in sentences involves a complex interaction between the verb and the nonverb elements. For example, the goodness of fit of specific noun phrases (NPs) with the verb's thematic roles influences the interpretation of temporary ambiguities (MacDonald, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998). The influence is not limited to the nouns serving as the verb's arguments: Adjectival modifiers (*shrewd heartless gambler* vs. *young naive gambler*) can influence the interpretation of a noun as either a good agent or a good patient of its verb (*manipulated*) and, consequently, can influence the interpretation of a temporarily ambiguous structure (McRae et al., 1997).

Even more strikingly, the extent to which an NP may be a good fit for a thematic role may depend not only on the verb, but also on the other arguments (Altmann, 1999; Kamide, Altmann, & Haywood, 2003). In a head-mounted eye-tracking study, Kamide et al. (2003) showed that the preferred patient for the verb *ride* varied as a function of the agent NP: On hearing *the girl will ride*, participants preferentially looked at a picture of a carousel, but after *the man will ride*, they looked more often at a motorbike. These results are particularly challenging for traditional theories of verb representation. It is difficult enough to imagine how to encode the fine-grained nature of verb-specific role/filler expectations in traditional symbolic accounts in which the representation includes only a finite set of verb-general thematic roles, such as agent (Fillmore, 1968; Gruber, 1965). It is even harder to envision how to capture the higher order contingencies by which one argument determines the goodness of fit of another. In other words, these results are difficult to interpret within a framework in which the verb is the sole generator of a comprehender's expectancies.

Thus, with regard to the first question—Which elements in a sentence can be used to generate expectancies?—we conclude that there is good evidence to believe that nonverb elements may play an important role. We turn now to the second question: What connection exists, if any, among expectancy generation, higher levels of understanding, and the extraction of meaning?

Expectancy Generation and Event Knowledge

One possibility, consistent with the two-stage serial models (Ferreira & Clifton, 1986; Frazier, 1987; Frazier, et al., 1983), is that predictive processing is driven strictly by low-level heuristics that are sensitive only to coarse-grained information, such as grammatical category and syntactic relationships. The other possibility, consistent with constraint-based probabilistic models (Altmann, 1999, 2002; MacDonald, 1994; McRae et al., 1998; Trueswell, Tanenhaus, & Garnsey, 1994), is that there may be significant interactions between, for example, *lexical* and *world knowledge* information and that, therefore, predictive processing is sensitive to syntactic, semantic, and pragmatic constraints.

This view is broadly consistent with those of researchers who have stressed the role of situation models in language comprehension (e.g., Garrod & Sanford, 1981; Kamide et al., 2003; Potts, Keenan, & Golding, 1988; Vu, Kellas, Petersen, & Metcalf, 2003). The interaction of lexical and world knowledge also is consistent with the view of thematic roles developed recently by McRae and colleagues

(Ferretti, McRae, & Hatherell, 2001; McRae et al., 1997), who proposed that thematic role assignment involves detailed experiential knowledge that is highly specific to events denoted by individual verbs. As in Dowty (1991), a thematic role is considered to be a concept with internal structure. But on McRae's account, role concepts are formed not from a limited set of verb-general features, but through everyday experience with the entities and objects that play specific roles in specific types of events. This view concurs with recent linguistic characterizations of thematic roles in claiming that they are verb specific (e.g., Sag & Wasow, 1999) but differs in viewing them as more than simply lexical information. One's concept of the agent role of *accuse*, for example, is formed by generalizing over experiences with those who accuse others (experienced either directly or through linguistic descriptions of the event). This conceptual/world knowledge is then computed and used immediately in online language processing. Note that higher level, verb-general aspects of thematic roles, as in Dowty, follow from this account as well, because they can be described as emerging through the conspiracy of many idiosyncratic thematic role representations of related verbs (see McRae et al., 1997, for further discussion).

One prediction of this account is that verbs, as they are accessed, should immediately activate highly specific knowledge about the entities that typically participate in the event that they encode. Ferretti et al. (2001) tested this in a series of priming experiments demonstrating that verbs primed agents, patients, and instruments that were typical role fillers for those verbs (although they did not find priming for typical locations). These results are consistent with the claim that when the verb is encountered, the activated representation includes knowledge of the event that it denotes. This event knowledge then drives the priming of the nouns, which are verbal labels for salient participants in the activated event memory.

Consistent with the literature on the organization of autobiographical event memory (Anderson & Conway, 1997; Reiser, Black, & Abelson, 1985), this account also predicts that verbs are not the sole source of constraint. The event—encoded linguistically through the verb—clearly is central in organizing and accessing the associated knowledge (Kolodner, 1984; Schank, 1982). But the knowledge of a generalized event, such as *skating* or *accusing*, can be computed and accessed in multiple ways (Brown & Schopflocher, 1998; Lancaster & Barsalou, 1997). For example, in offline studies, Lancaster and Barsalou found that comprehenders are adept at organizing short narratives in terms of multiple components of events. Activity (i.e., the verb) is an important component, but time, location, and participants, such as the agent and patient, are important as well.

Thus, if knowledge of the roles associated with a verb is event knowledge, nouns denoting salient participants should also quickly activate well-learned event knowledge and, in doing so, should predictively activate the corresponding verb. More precisely, we assume that a concept or class of concepts (rather than a specific word) will be activated, and priming will occur if the target verb overlaps substantially with the predicted event space.[1]

Goals

The experiments presented below were designed to test whether a single noun (stripped from sentence context) can lead to the computation of information concerning a class of events. Although our experiments involve word–word priming only, these results would be consistent with the literature showing that as a sentence is read or heard, comprehension is based on the rapid incremental integration of the information from incoming words (Tanenhaus et al., 1995; Vu et al., 2003). As such, we see this work as bridging the gap between theories of sentence processing and those of lexical-semantic processing: A participant's performance on word–word priming tasks reflects the semantic information that is computed when a word is read or heard, and it is reasonable to assume that this same information is also computed when people read normal connected text or hear connected speech. Although researchers such as Kahan, Neely, and Forsythe (1999) refer to a prime as "providing a semantic context that 'sets the stage' for the target's processing" (p. 105), it has been unusual to use word–word priming studies to draw inferences regarding online sentence comprehension. However, one advantage of the priming task is that it represents a lower bound on the information available to the comprehender by eliminating constraints offered by the other nouns in the sentence, case marking, context, and so on. Word–word priming, as a measure of what is activated in the absence of other constraints, thus offers a stringent test for studying these phenomena.

EXPERIMENT 1

In Experiment 1, we used short stimulus onset asynchrony (SOA; the time between the onset of the prime and the onset of the target) priming from nouns to verbs to test the predictions of the event-based account. The noun primes refer to typical fillers of the thematic roles of the verb that describes the event—that is, the agents, patients, or instruments that are typically involved in the event denoted by the target verb or the locations at which the event typically occurs. Short-SOA priming was used because it is assumed to provide a window into the organization of semantic memory, with effects being uncontaminated by strategic processing, particularly when pronunciation latency is the dependent measure. Studies such as those of de Groot (1984), den Heyer, Briand, and Dannenbring (1983), and Stolz and Neely (1995) have shown that explicit expectancy-based priming does not occur with SOAs of 250 msec or less. Note that this type of explicit expectancy generation, often viewed in terms of generating a set of possible ensuing words, as in Becker's (1980) verification model, differs from the type of implicit expectancy generation that is believed to occur in normal sentence processing (Altmann, 2002; Elman, 1990; Federmeier & Kutas, 1999). We predicted shorter naming latencies for verbs primed by their typical thematic role fillers than for

verbs primed by unrelated nouns, on the assumption that the related noun will activate knowledge of an event in which it typically participates, thus facilitating processing of the verb denoting that generalized event.

Method

Participants. Forty University of Western Ontario undergraduates participated in the priming experiment for course credit. All the participants were native speakers of English and had normal or corrected-to-normal visual acuity.

Materials. To tap comprehenders' knowledge of the types of events in which certain entities and objects play a specific role, we used what we will refer to as *thematic-based event generation norms*. These norms are designed to estimate the conditional probability of a generalized event, given an entity or object playing a specific role. Participants were asked to generate verbs in response to typical agents, patients, instruments, and locations. In the agent norms, the participants were given nouns such as *nun* and were asked to "list the things that these people commonly do." In the patient norms, the participants were given nouns such as *guitar* and were asked to "list the things that these objects/people commonly have done to them." In the instrument norms, participants were given nouns such as *crayon* and were asked to "list the things that people commonly use each of the following to do." Finally, in the location norms, the participants were given nouns such as *cafeteria* and were asked to "list the things that people commonly do at/in each of these locations." For each item, space was provided for 10 responses. No time limit was imposed. The participants were undergraduate students from Bowling Green State University. Each participant completed only one list (i.e., only for one of agents, patients, instruments, or locations); there were approximately 25 items per list. In total, 20 participants responded to each item.

Note that by design, we did not conduct word association norms for choosing the items for these experiments. On the one hand, responses in such norms have a strong tendency to be members of the same grammatical category as the stimulus: Noun stimuli are likely to elicit nouns, verbs to elicit verbs, and so on. Since our prime–target pairs come from different grammatical categories, few would likely show up as *associated* by this criterion. Hence, conducting word association norms with these items may not have been informative or compelling. More important, participants' performance on the word association task is driven by a number of other factors, including their knowledge of semantic relations and the ways in which words co-occur to express these relationships. In some ways, then, our thematic-based event generation norms are a version of a word association task: We provided participants with a word stimulus and asked them to produce a linguistic response. The key difference, however, is that our norms targeted specific types of semantic relations, and the responses reflected these underlying relationships, not simply undifferentiated associations.

Responses in the event generation norms were scored on the basis of their rank order within a participant and on their response frequency. That is, each response was scored in terms of the number of participants listing it 1st, 2nd, 3rd, through to 10th. A weighted score was calculated for each response by multiplying the frequency with which it was produced as the first response times 10, second times 9, and so on, and then summing those products. Wherever possible, noun–verb pairs were chosen for the priming experiment by taking the verb with the highest weighted score. In a few cases, the response with the highest weighted score could not be used because it was a multiword phrase, such as *play hockey* for *arena*, and the constraints of the naming task demanded a single-word verb target. In a few other cases, the same verb was the best response for more than one item (e.g., *cut* for both *chainsaw* and *knife*) or was too general to serve as an appropriate prime (*sees*). When the best item could not be used, we chose either another highly ranked response or a synonym or near synonym of the best response.

From these norms, we chose 30 agents paired with the present participle of a verb, such as *nun–praying*, *waiter–serving*, and *lawyer–defending*; 30 patients paired with the past participle form of a verb, such as *guitar–strummed*, *teeth–brushed*, and *tax–paid*; 32 instrument–present-participle pairs, such as *crayon–coloring*, *pen–writing*, and *chainsaw–cutting*; and 24 location–present-participle pairs, such as *cafeteria–eating*, *bedroom–sleeping*, and *bathroom–showering* (all the items are presented in the Appendix). The weighted scores for the verbs for each thematic role were the following (maximum of 200): agents, $M = 104$, $SE = 8$; patients, $M = 115$, $SE = 9$; instruments, $M = 145$, $SE = 8$; and locations, $M = 131$, $SE = 9$.

Target verbs were presented in present participle form with the agent, instrument, and location primes. Verb targets paired with typical patients were presented in their past participle forms to avoid including prime–target pairs that formed coherent familiar phrases, such as *cigar smoking*.

Lists. Two lists were created for each role (i.e., agents, patients, instruments, and locations). Each list contained half of the targets paired with related primes and the other half of the targets paired with unrelated primes. Unrelated prime–target pairs were created by re-pairing the nouns and verbs from the related trials in the opposite list (e.g., *praying* was preceded by *nun* in List 1 of the agents and by *sniper* in List 2). Filler trials consisted of unrelated noun–verb pairs, such as *magician–petting*. Each list contained four times as many unrelated filler trials as related target items (relatedness proportion was .17, which is quite low for studies of this sort). Thirty-five unrelated practice trials were used for the practice session for every participant. No participant saw any word twice.

Procedure. For each trial, the participant was instructed to silently read the first word presented on the computer screen and to pronounce aloud the second word as quickly and accurately as possible into the microphone. The stimuli were presented on a color monitor connected to a Macintosh computer using PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). A microphone connected to a CMU button box measured naming latency in milliseconds as the time between the onset of the target and the onset of the participant's pronunciation of it. Each trial consisted of the following: a focal point (*) for 250 msec; the prime for 200 msec; a mask (&&&&&&&&) for 50 msec; and the target until the participant named it.[2] The intertrial interval was 1,500 msec, and a break was given every 40 trials. Testing sessions began with the practice trials and lasted approximately 20 min. The experimenter recorded trials in which the participant mispronounced a word (a pronunciation error), extraneous noise caused the voice key to trigger (a machine error), or the voice key failed to trigger (a machine error). The participants were assigned randomly to be tested on either the agents and locations or the patients and instruments. The order of the two lists was counterbalanced across participants (i.e., 10 participants were tested on agents and then locations and another 10 on locations and then agents, and the same for the patients and instruments).

Design. Naming latencies and the square root of the number of pronunciation errors (Myers, 1979) were submitted to separate two-way ANOVAs for each thematic role (agents, patients, instruments, and locations). The factor of interest was relatedness (related vs. unrelated), which was within both participants (F_1) and items (F_2). List was included as a between-participants dummy variable and item rotation group as a between-items dummy variable in order to stabilize variance that might result from rotating participants and items over the two lists (Pollatsek & Well, 1995).

Results and Discussion

Naming latencies greater than three standard deviations above or below the grand mean were replaced by that value (1% of the trials). Two participants were dropped because their soft speaking style resulted in an extreme number of trials in which the voice key was not activated.

Machine errors, the majority of which were caused by the microphone's failing to register the participant's response, occurred on 4% of the trials and were excluded from all analyses. Pronunciation errors were excluded from the latency analyses. Mean naming latency and percentage of pronunciation errors are presented for each condition in Table 1. Verbs were named more quickly when preceded by a related versus an unrelated noun for each of the four thematic roles [agents, $F_1(1,18) = 6.19, p < .05$, and $F_2(1,28) = 4.12, p < .06$; patients, $F_1(1,18) = 7.54$, $p < .05$, and $F_2(1,28) = 11.98, p < .001$; instruments, $F_1(1,18) = 5.66, p < .05$, and $F_2(1,30) = 7.64, p < .01$; locations, $F_1(1,18) = 5.33, p < .05$, and $F_2(1,22) = 10.41$, $p < .01$]. There were no reliable differences in pronunciation error rates (all $Fs < 1$).

In Experiment 1, noun–verb pairs were chosen using thematic-based event generation norms designed to tap into comprehenders' knowledge of the conditional probability of a generalized event, given an agent, patient, instrument, or location. Significant noun–verb priming was obtained in all four cases. We take these results as evidence that this event knowledge allows a comprehender to generate expectancies for upcoming concepts in the language stream—in this case, for ensuing verbs.

One question that remains is whether these results could be due to word association. Here, we note that in the most general sense of *association*—that is, the relationship between things or words that are temporally or spatially contiguous in the world or in language—our stimuli are, of course, associated. The thematic-based event generation norms used to choose the stimuli were designed to tap into people's knowledge of events in the world—namely, knowledge of the types of events that involve specific types of agents, patients, instruments, and locations. The actions described by the verb and aspects of those actions described by these nouns are clearly associated in this sense, and multiple experiences of related associations of this sort are instrumental in the learning of event knowledge. Crucially, however, we argue that what is learned is not simple associations; instead, the learner bootstraps from the experience of these repeated contiguities to knowledge of the meaningful relationship that underlies them.

In summary, our items certainly are associated in the general sense of association; they are bound together through co-occurrence in real-world events and in linguistic descriptions of those events. This does not, however, contradict the claim that the pairs are salient examples of specific types of event-based relations. Further issues concerning word association and spreading activation networks will be discussed in the General Discussion section.

Finally, it should be pointed out that Ferretti et al. (2001) found robust priming from verbs to nouns referring to their typical agents, patients, and instruments. This raises the possibility that the present results might have been due to backward priming from the verb. If this were the case, it would seriously reduce the theoretical import of our results (they would be a recapitulation of Ferretti et al.'s results). A number of researchers have investigated backward priming, using compounds (e.g., priming from *hop* to *bell*) and items for which the prime–target versus target–prime word association strengths differ. For example, Kahan et al. (1999) and Peterson and Simpson (1989) have shown that backward priming with such items may occur in a naming task at a short SOA, such as that used in Experiment 1, but not at an SOA of 500 msec (although they seem to occur at both SOAs for lexical decision). Therefore, Experiment 2 was a replication of Experiment 1, using a 500-msec SOA. If verbs are primed, we can conclude that backward priming was not responsible for the Experiment 1 results. It should be noted that a lack of priming at a 500-msec SOA is unlikely for our items, given the strength of noun–verb relationships as measured by the thematic-based event generation norms.

EXPERIMENT 2

Experiment 2 replicated Experiment 1, using a long SOA. Again, we predicted shorter naming latencies for verbs primed by their typical thematic role fillers than for verbs primed by unrelated nouns, thus demonstrating that the Experiment 1 results were not due to backward priming from the verb.

Method

Participants. Sixty-eight undergraduates at Bowling Green State University participated for course credit. All the participants were

Table 1
Mean Verb-Naming Latencies (in Milliseconds) and
Percentages of Pronunciation Errors, Experiment 1

Dependent Measure	Agents		Patients		Instruments		Locations	
	M	SE	M	SE	M	SE	M	SE
Response latency								
Unrelated	592	21	583	20	565	20	578	16
Related	574	19	561	18	549	17	560	19
Facilitation	18*		22*		16*		18*	
Percentage of errors								
Unrelated	1.9	0.8	3.2	1.4	1.4	0.7	2.5	1.2
Related	1.9	0.9	1.9	0.8	1.1	0.6	1.5	0.8
Facilitation	0		1.3		0.3		1.0	

*Significant by participants and items.

native speakers of English and had normal or corrected-to-normal visual acuity.

Materials. Primes, targets, fillers, and practice items were identical to those in Experiment 1.

Procedure. The procedure differed from that in Experiment 1 in only two respects. First, the SOA was 500 msec, so that each trial now consisted of the following: a focal point (*) for 250 msec; the prime for 200 msec (as in Experiment 1); a blank screen for 300 msec; and the target until the participant named it. Second, lists were now fully between participants. The participants were randomly assigned to be tested on either List 1 or List 2 of one of the four roles. Sixteen participants were tested on each of the agents, instruments, and locations (8 per list), whereas 20 participants (10 per list) were tested on the patients.

Design. The design was identical to that in Experiment 1.

Results and Discussion

Naming latencies greater than three standard deviations above or below the grand mean were replaced by that value (1% of the trials). One participant was dropped and replaced because of experimenter error. There were two trials with machine errors (caused when the microphone failed to register the participant's response), and these were excluded from all analyses. Pronunciation errors again were excluded from the latency analyses.

Mean naming latency and percentage of pronunciation errors are presented for each condition in Table 2. Verbs were named more quickly when preceded by a related versus an unrelated noun for each of the four thematic roles [agents, $F_1(1,14) = 4.99$, $p < .05$, and $F_2(1,28) = 4.85$, $p < .05$; patients, $F_1(1,18) = 4.99$, $p < .02$, and $F_2(1,28) = 6.99$, $p < .02$; instruments, $F_1(1,14) = 9.17$, $p < .01$, and $F_2(1,30) = 8.50$, $p < .01$; locations, $F_1(1,14) = 5.76$, $p < .05$, and $F_2(1,22) = 4.31$, $p < .05$]. The only reliable difference in error rates was in the instruments, and then only in the item analysis [instruments, $F_1(1,14) = 2.08$, $p > .1$, and $F_2(1,30) = 5.57$, $p < .05$; agents, $F_1(1,14) = 3.15$, $p > .1$, and $F_2(1,28) = 3.41$, $p > .07$; patients, $F_1(1,18) = 1.04$, and $F_2(1,28) = 2.31$, $p > .1$]. There were no pronunciation errors for the locations.

The goal of Experiment 2 was to test whether the Experiment 1 results were due to backward priming from verbs to typical role fillers; if this had been so, no priming should have been found in Experiment 2. The fact that significant verb priming effects of magnitudes similar to those in Experiment 1 obtained in all four cases shows that the priming indeed occurred from the nouns to the verbs.

GENERAL DISCUSSION

Understanding language involves constantly updating a situation model that represents what is being described as the linguistic input unfolds over time (Sanford & Garrod, 1981). Researchers have argued that one element of this process is generating expectancies of the classes of concepts that ensue in speech or text (Elman, 1990; Kamide et al., 2003). A number of studies have focused on the variety of expectancies that may be generated from the verb, with verbs allotted a central role precisely because they often provide strong structural and semantic constraints (Altmann & Kamide, 1999; Garnsey, Pearlmutter, Myers, & Lotocky, 1997). In contrast, we have presented two sets of experiments to provide evidence that event-based expectancies might be generated from elements of a sentence other than a verb. Noun–verb pairs were chosen, using thematic-based event generation norms designed to tap into people's knowledge of the conditional probability of a generalized event, given an agent, patient, instrument, or location. In word–word priming experiments, agents, patients, instruments, and locations primed verbs that denote events for which they are typical. Experiment 1 was a short-SOA priming study, the type of study that is assumed to provide insight into the organization of memory. Priming obtained in all four cases. Given that it was crucial to establish that the priming occurred from agents, patients, instruments, and locations to verbs, rather than in the other direction, Experiment 2 tested for backward priming. With a longer SOA, significant priming effects similar in magnitude to those in Experiment 1 were obtained. Together, these experiments suggest that people's memory for generalized events is organized in such a manner as to promote expectancy generation from nouns to verbs in online sentence comprehension, provided that those nouns serve as sufficiently strong cues to those events.

These results are consistent with those in other priming studies that have been interpreted in terms of event memory. The results of Ferretti et al. (2001), described above, illustrate one such case. A second example comes

Table 2
Mean Verb-Naming Latencies (in Milliseconds) and
Percentages of Pronunciation Errors, Experiment 2

Dependent Measure	Agents		Patients		Instruments		Locations	
	M	SE	M	SE	M	SE	M	SE
Response latency								
Unrelated	584	31	542	25	555	20	540	20
Related	568	28	520	19	533	15	527	19
Facilitation	16*		22*		22*		13*	
Percentage of errors								
Unrelated	2.4	0.5	2.3	0.5	4.6	0.5	0	0
Related	0.3	0.8	4.0	0.6	2.5	0.5	0	0
Facilitation	2.1		−1.7		2.1		0	

*Significant by participants and items.

from Moss, Ostrin, Tyler, and Marslen-Wilson (1995), who investigated a variety of semantic relations and found priming for instrument (*broom–floor*) and script (*restaurant–wine*) relations. We recently have extended these results in short-SOA priming experiments that appear to be interpreted best as arising from event representations (Hare, McRae, Friedrich, Kelly, & Thomson, 2005). Nouns denoting events primed types of people and things that are typically part of those events; location nouns primed people and things that are typically found at those locations; and instrument nouns primed things on which those instruments are typically used.

An Alternative Explanation

Although we used word–word priming to argue that semantic memory is structured to support expectancy generation during comprehension, we also note that priming results of this type have often been described in terms of spreading activation in a semantic network. This raises the issue of whether spreading activation networks could predict the priming of verbs from agents, patients, instruments, and locations. Here, we will consider three instantiations of a spreading activation network and will argue that none offers a compelling alternative to an event memory account.

First, although the original semantic networks focused solely on noun representations (Collins & Quillian, 1969), relatively early extensions incorporated verbs (Gentner, 1975; Rumelhart & Levin, 1975). Verb representations in these models included core meaning plus thematic links to nodes that stood as placeholders for possible noun phrases that fill those roles in sentences. These links could be bidirectional, allowing activation to spread from the thematic role nodes to the verb node (and so allowing for noun–verb priming). However, the thematic links and nodes in such models would be insufficient to account for our results, because they included only minimal semantic content, limited to general selectional restriction information. The thematic link between a verb and an agent node might specify that the filler of that node must be animate, but nothing more detailed or item specific. Our experiments, on the other hand, controlled for general selectional restrictions: The primes in both the related and the unrelated trials were equivalent in animacy. The factors that they differed on (and that determined the results) were more subtle and item specific. Thus, a spreading activation model limited to general selectional restrictions would incorrectly predict no priming in the present experiments.

A second way in which spreading activation networks might predict priming from typical thematic role fillers to verbs is through undifferentiated links encoding associative relatedness. If the representations of words and/or concepts that often co-occur in events and language become linked (whether in semantics, orthography, and/or phonology) through an unspecified associative relation, those links could serve as the basis for priming from nouns referring to typical components of events to verbs. However, our study forms part of a larger pattern of empirical results, many of which appear to be inexplicable without

recourse to event representation. Truitt and Zwaan (1997), for example, found that the word *hammer* was primed more strongly (with shorter naming times and faster recognition) after a sentence including a verb marked with imperfective aspect (*He was pounding the nail*) than after one with perfect aspect (*He pounded the nail*). This difference occurred, presumably, because the imperfective aspect presents an event as ongoing, whereas the perfect aspect presents an event as already completed. These results, which demonstrate that the interaction between the temporal properties of events and verb aspect influences the activation of world knowledge about events during sentence comprehension, would be very difficult to explain on an undifferentiated word-associative account.

Ferretti (2000) also manipulated verb aspect to reference various components of the temporal structure of events, hypothesizing that if an event is presented in the imperfective and, thus, as in the process of occurring, the location at which the event is taking place should be more salient than if it is presented in the perfect, which, by focusing on the resultant state, references the event as completed. In other words, if someone was in the process of skating, he or she is at the arena. In contrast, if someone had already skated, that person could then be at any location. In a short-SOA priming task, typical locations (e.g., *arena*) were significantly primed by verbs presented in their imperfective aspect (*was skating*), whereas no priming obtained when perfect aspect (*had skated*) was used. Again, these results follow naturally from, and the experiment was inspired by, an account in which priming occurs via event schemas. However, accounting for them in a spreading activation network would require incorporating some mechanism by which aspect can modulate the flow of activation.

In a similar vein, Ferretti et al. (2001) showed that the grammatical cues of active versus passive voice modulate computation of event-based knowledge. In Experiment 4, participants heard sentence fragments such as *She arrested the* or *She was arrested by the* and pronounced aloud visually presented targets, such as *crook* or *cop*. Significant cross-modal priming occurred only for congruent role nouns (i.e., *crook* following *She arrested the* and *cop* following *She was arrested by the*). Current spreading activation accounts, which allow no influence of verbal voice, would incorrectly predict priming from *arrested* to *crook* and *cop* in all cases or would predict no priming at all.

In sentence-priming studies, Vu et al. (2003) used subject nouns, such as *astronomer* or *director*, to promote a situation model that led to disambiguating the meaning of a sentence-final word, such as *star*. They found that their manipulation was sufficient to activate selectively the dominant or subordinate meaning of the ambiguous noun. In this and other research (Vu, Kellas, & Paul, 1998), the authors were careful to rule out a simple word association account of their results. Finally, Hess, Foss, and Carroll (1995) found that responses to sentence-final words were influenced more by their fit with the overall situation being described than by their association to specific words in the sentence.

In summary, these are all compelling empirical phenomena for which basic word associations fail to provide insight into the results. In contrast, all of these results are well accounted for by the event representation expectancy-based approach that we favor.

As a final alternative, spreading activation networks could be expanded by allowing noun nodes representing common agents, patients, instruments, and locations to become linked to corresponding verb nodes. These links might be formed through the learner's experience with events (e.g., noticing that chainsaws are used for cutting) and/or linguistic descriptions of events (through utterances in which *chainsaw* fills the instrument role of *cut* in speech and text). This structure would allow spreading activation networks to predict priming of verbs from typical thematic role fillers: When participants read a noun prime, activation could spread to the verb node, and priming would result. But in this case, the priming would be driven not by an undifferentiated word-associative link, but by a pattern of connectivity reflecting the underlying thematic relationship. Hence, a semantic network altered to encode event knowledge in these ways would no longer be a competing theory; instead, it would be one potential implementation of the event memory account for which we argue in this article.

Implications for Sentence Processing

Although short-SOA semantic priming has long indicated that word recognition rapidly activates lexical-semantic knowledge, previous priming studies have not examined the types of lexical-semantic knowledge that are considered to be relevant to sentence comprehension. Here, we have shown that nouns, by activating events in semantic memory, are able to activate predictively verbs whose thematic roles they typically fill. These results support the hypothesis that during sentence comprehension, the processing of nouns leads to anticipatory semantic computation of the verbs (or semantic class of verbs) with which they may combine later in the sentence. Although the present study was not designed to test processing during sentence comprehension, it nonetheless offers an explanatory mechanism for studies that have shown anticipatory processing in sentential contexts.

Kamide et al. (2003), for example, have shown that nouns, in conjunction with other sentential information, play a role in predictively activating later nouns in the sentence. In an eye-tracking experiment, the authors showed that information from the subject NP and the verb, in combination, was able to constrain expectations for the object NP. A second study (in Japanese, a verb-final language) showed that case-marked preverbal nouns influenced the anticipation of other noun arguments, even when no information from the verb was yet available. Stronger evidence for the ability of context nouns alone to influence the activation of a generalized event comes from Altmann (1999). Participants read short paragraphs, such as "Giles had just finished dining in an expensive restaurant. He ordered some chocolates and cigars" and then saw "He drank . . ." At the verb *drink*, although no anomaly had been encountered (it could easily continue as in "He drank some port while smoking his cigar"), the participants were more likely to report that the sentence did not make sense than they were when the context included *ordered some brandy*. One interpretation of these results (Altmann, 2002) is that the verb was anticipated on the basis of the entities introduced in the context and that, in the first context, the verb *drank* violated those expectancies. Similar influences of non-verb–based expectancies are found in English filler-gap constructions (Boland et al., 1989). All of these results can be understood on the basis of an account claiming that multiple elements of a sentence promote the computation of schematic event representations and that these are central to interpreting language. The degree to which each element may do so depends on the degree to which individual lexical concepts and their combinations constrain interpretation.

Although, to this point, we have focused on the activation of semantic knowledge, the conclusions we draw overlap a great deal with lexicalist proposals that syntactic knowledge is also associated with nouns (and other grammatical categories), as well as with the verb (Kim, Srinivas, & Trueswell, 2002). As one example of a syntactic phenomenon, it is well established that verbs that can occur in more than one syntactic frame have a certain probability of occurring in each and that comprehenders are sensitive to these subcategorization biases, anticipating the structure that best fits the verb's bias (Garnsey et al., 1997; Hare, McRae, & Elman, 2003, 2004; Trueswell, Tanenhaus, & Kello, 1993). In fact, Trueswell and Kim (1998) showed, using a "fast priming" technique, that a verb that was briefly presented while participants read sentences influenced the readers' structural expectations. This phenomenon is not limited to verbs, however; certain nouns have syntactic frame requirements as well. In fact, Novick, Kim, and Trueswell (2003) showed, in a parallel study, that this information is activated when the noun is briefly flashed and influences structural expectations.

In summary, a wide range of research has focused on the important role of the verb both in constraining syntactic processing and in the construction of the situation models that are central to language comprehension. However, as the online interpretation of verb-final constructions implies, other elements of sentences can also serve as constraints in language processing. As Sanford and Garrod (1981) stated, "we use a linguistic input to call up representations of situations or events from long-term memory as soon as we have enough information to do so" (p. 115). The present experiments suggest that nouns that denote typical aspects of common events are often "enough information."

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NOTES

1. See Ferretti et al. (2001) for a discussion of the point that it is a prototype-style concept that is activated, rather than words per se.

2. The mask in Experiment 1 was actually unnecessary and was not used in Experiment 2, both for that reason and because it is undesirable with longer SOAs. The participants could easily perceive the 200-msec prime, both with and without the mask.

APPENDIX

Agent–Verb Pairs		Instrument–Verb Pairs	
actor	performing	axe	chopping
assassin	killing	broom	sweeping
athlete	competing	camera	photographing
audience	watching	chainsaw	cutting
burglar	stealing	crayon	coloring
butcher	cutting	crutches	walking
carpenter	hammering	dagger	stabbing
chauffeur	driving	deadbolt	locking
chef	cooking	detergent	washing
cop	arresting	fork	eating
detective	investigating	furnace	heating
hero	rescuing	hose	spraying
janitor	sweeping	keyboard	typing
judge	sentencing	knife	slicing
lawyer	defending	napkin	wiping
maid	cleaning	needle	sewing
merchant	selling	oven	baking
musician	composing	pen	writing
nun	praying	pencil	drawing
postman	delivering	pistol	shooting
professor	lecturing	rag	dusting
reporter	interviewing	razor	shaving
secretary	typing	rifle	hunting
sniper	shooting	rod	fishing
spectator	cheering	ruler	measuring
surgeon	operating	shovel	digging
thief	robbing	soap	cleaning
tourist	visiting	stopwatch	timing
waiter	serving	stove	cooking
witness	testifying	tinfoil	wrapping
		towel	drying
		toy	playing

Patient–Verb Pairs		Location–Verb Pairs	
ball	thrown	airport	flying
battery	charged	arena	skating
book	read	bathroom	showering
bottle	recycled	beach	tanning
cheque	cashed	bedroom	sleeping
cigar	smoked	cafeteria	eating
clothes	worn	casino	gambling
coffee	brewed	church	worshipping
customer	served	factory	working
dice	rolled	garage	parking
egg	fried	gym	exercising
evidence	examined	kitchen	cooking
fugitive	chased	library	studying
gift	opened	lineup	waiting
god	worshipped	mall	shopping
guest	invited	park	playing
guitar	strummed	pool	swimming
hair	combed	pub	drinking
horse	ridden	racetrack	betting
juice	drank	river	fishing
lawn	mowed	road	driving
money	spent	sandbox	digging
movie	rented	sauna	sweating
puzzle	solved	school	learning
suspect	interrogated		
tax	paid		
teeth	brushed		
telephone	answered		
television	watched		
trailer	towed		