

Processing correlates of lexical semantic complexity

Silvia Gennari

David Poeppel

Cognitive Neuroscience of Language Laboratory
University of Maryland

Running Title: Verb meanings

Corresponding author:

Silvia Gennari

1401 Marie Mount Hall

University of Maryland

College Park, MD 20742

Abstract

This paper explores how verb meanings that differ in semantic complexity are processed and represented. In particular, we compare eventive verbs, which denote causally structured events, with stative verbs, which denote facts without causal structure. We predicted that the conceptually more complex eventive verbs should take longer to process than stative verbs. Two experiments, a lexical decision task and a self-paced reading study, confirmed this prediction. The findings suggest that (a) semantic complexity is reflected in processing time, (b) processing verb meanings involves activating properties of the event structure beyond participants' roles, and (c) more generally, lexical event structures, which subsume thematic roles, may mediate between syntactic knowledge and semantic interpretation.

Introduction

How are verb meanings processed and represented? Several studies have provided processing evidence showing that lexical semantic properties such as thematic roles and argument structure are quickly accessed by the processor when the verb is recognized (e.g., Trueswell, Tanenhaus & Garnsey, 1994; Tanenhaus, Carlson & Trueswell, 1989; Tanenhaus & Carlson, 1989; MacDonald, Pearlmutter & Seidenberg, 1994; McRae, Ferretti & Amyote, 1997, Altmann, 1999). For example, Trueswell et al. (1994) found that the semantic fit between the subject NP and the verb's thematic structure plays a critical role in facilitating the reading time of ambiguous garden path constructions. Similarly, several studies have shown that verbs are typically associated with a preferred (most frequent) argument structure, even in contexts biasing the less frequent structure (MacDonald, 1994; MacElree, 1993; Trueswell, Tanenhaus & Kello, 1993; Shapiro, Zurif & Grimshaw, 1987; Shapiro, Nagel & Levine, 1993).

Other studies investigating word recognition in restricted contexts or in isolation have also suggested that argument and thematic structure have processing correlates. Ferretti, McRae & Hatherell (2001) have shown that verbs prime their typical agents and patients (e.g., praying primes nun) when

presented in isolation and in consistent syntactic contexts, but not in inconsistent contexts. They argue that verb meanings are represented in structured situation schemas containing participant slots plus sets of typical thematic features that are computed on-line. Moreover, McKoon & Macfarland (2000, 2002) have found that recognition times of verbs denoting externally caused events (*_break_*) are longer than those of internally caused verbs (*_grow_*). These verb classes differ in that externally caused verbs, but not internally caused ones, conceptually require two participants. Their findings thus show argument structure complexity effects. Taken together, these findings suggest that thematic and argument structures are processed when the verb meaning is activated to construct a schematic representation of the event referred to. Such lexical properties, which are projected onto sentential arguments, are thus taken to mediate between parsing mechanisms and sentential semantic interpretation (e.g., Tanenhaus et al. 1989).

It is commonly assumed, however, in both linguistics and psycholinguistics that thematic roles and syntactic arguments do not exhaust verb meanings. Rather, these properties may be derived from other properties of the event structure (MacDonald et al., 1994; Tanenhaus et al., 1989; Tanenhaus & Carlson, 1989). Lexical semanticists in particular argue that thematic roles and argument structure are subsumed by the event structure defined in terms of causal properties (Jackendoff, 1987, Ladusaw & Dowty, 1988, Grimshaw, 1990; Dowty, 1991; Croft, 1998; Van Valin & Wilkins, 1996): For example, the agent in a breaking event is the initiator of a causal chain affecting the patient. This sort of information is required to semantically distinguish verbs such as *_love_* and *_discover_*, which are both associated with the <experiencer, theme> thematic structure. The critical property distinguishing these verbs is whether they denote a change of states.

Linguists and philosophers argue that several verb types can be distinguished depending on their causal structure. One general distinction typically made is that between states and events (Vendler, 1967; Davidson, 1971, Dowty, 1979; Taylor, 1977; Verkuyl, 1993; Jackendoff, 1990, 1991; Rappaport-Hovav & Levin 1998; Parsons, 1990; Smith, 1991; Moens & Steedman, 1988; Pustejovsky, 1991): Eventive verbs entail one or several changes from an initial situation to a resulting one (e.g., *_destroy_*, *_discover_*, *_play_*), while stative verbs entail a single stable situation (e.g. *_love_*, *_belong_*, *_contain_*). These verb types thus differ in their ability to entail sub-situations and changes (the change-of-state entailment, cf. Dowty 1979). This fundamental conceptual distinction between eventive and stative verbs led lexical semanticists to propose that their lexical meanings differ in complexity: eventive verbs entail simpler conceptual units such as CAUSE, BECOME or CHANGE and resulting STATE, corresponding to the event's internal dynamics they denote, while stative verbs lack any such causal entailments. Table 1 exemplifies this sort of logical analysis and various event substructures classified as eventive verbs: accomplishment verbs (e.g., *_break_*), achievement verbs (e.g., *_discover_*), and activity verbs (e.g., *_carry_*), each defined by the presence/absence of the relevant sub-component.

The question now arises whether there are empirical correlates of such event representations, and, in particular, correlates of their differences in semantic complexity. If semantic properties are immediately processed when the verb is activated, as in previous findings, and if the number of arguments/roles is kept constant, differences in semantic complexity may emerge: eventive verbs, which have more complex meanings (more entailed properties), should take longer to process than stative verbs. The rationale for this hypothesis is that processing the meaning of a stative verb requires the activation of a single

non-dynamic situation. In contrast, processing the meaning of a dynamic event entails activating more substructure or entailed sub-situations, such as an initial state, a change and a final state. In processing terms, more semantic structure (however represented) is accessed or activated with eventive verbs. More time would then be required for the relevant activation to spread (cf. Seidenberg & McClelland, 1989), and therefore, for the reader to fully process the meaning.

In this paper, we ask whether eventive and stative verbs, which by hypothesis differ in their semantic-conceptual complexity, are processed in ways consistent with this complexity difference. Although the processing and semantic literature suggests that semantic complexity effects are likely to arise, no such effects have been demonstrated. Early studies on verb meanings failed to find evidence supporting semantic complexity effects (e.g., Fodor, Garrett, Walker, & Parkes, 1980; Rayner & Duffy, 1986). These findings, together with Fodor's and colleagues' theoretical arguments (Fodor 1997; Fodore & Lepore, 1998), were taken to support the view that verb meanings lack internal causal structure.

Studies

To test whether the semantic complexity of eventive and stative verbs involves differential processing costs, we conducted two psycholinguistic experiments. The first experiment was a self-paced reading study, in which the reading time of verbs occurring in sentences was measured. To exclude an explanation of complexity effects in which reading times are due to the cost of integrating the verb with prior information, the second experiment was a visual lexical decision task. This task has been shown to be sensitive to influences of meaning (see Balota, 1994; Balota, Ferraro & Connor, 1991 for reviews) and several semantic effects such as abstract vs. concrete, semantic polysemy, imageability and participants' templates have been reported (Blesdale, 1987; Paivio, 1991; Rodd, Gaskell & Marslen-Wilson, 2002; James, 1975; Strain, Patterson & Seidenberg, 1995; McKoon & Macfarland 2000, 2002).

Experiment 1: Self-paced reading

Materials: 88 sentences containing 44 stative and 44 eventive verbs (plus 88 fillers) were selected according to criteria discussed in the linguistic literature (e.g., the verbs' ability to occur with progressive tense, simple present tense, and various adverbials, cf. Dowty, 1979). Eventive verbs included the eventive sub-types shown in Table 1, and took at least two syntactic arguments (NP or PP). Test verbs and sentences were pair-wise matched for a number of variables known to affect processing cost: word frequency (mean log-frequency for both verb types = 3.96 according to Collins Cobuild corpus), word length (mean word length was 6.11 characters for events, 5.82 for states), argument structure, frequent syntactic frames and plausibility.

Number of syntactic arguments and most frequent syntactic frames were obtained using Schulte im Walde's (1999) automatic parses (calculated from the Bank of English corpus - 320 million written and spoken words). Each matched verb pair had the same number of possible syntactic frames and for the most frequent frame, the same number of arguments. Verbs with equally frequent frames were matched with verbs of similar frame distribution. Appendix A shows the verb stimuli with the proportions of corpus occurrences per syntactic frame.

Test sentences were exactly alike up to the point of the critical verb, and in some cases, completely alike except for the verb. Test sentences had the structure exemplified in (1) and were presented in past tense. Appendix B

includes the set of sentences used in this experiment.

- (1) a. The retired musician built his second house from scratch. (event)
- b. The retired musician loved his second child very much. (state)

To control for the plausibility relation between the subject NP and the verb, we independently obtained judgments from 26 native speakers, who rated the typicality of the subject-verb relation. We asked them to rate in a 1-7 scale how typical it was for a given subject NP to perform the corresponding action denoted by the verb (cf. Trueswell, et al., 1994, McRae, et al., 1997). The ratings compared across word types did not differ significantly (states' mean = 5.48, events' mean = 5.63, $t < 1$).

Finally, we checked the frequency of the verbs' uses in reduced relative clauses (e.g. The retired musician loved by everyone was...) to control for the possibility that a reduced-relative reading may unequally affect the reading times for a verb class. Only 25% of our verbs appeared in all 6563 reduced relatives found in the Wall Street Journal and Brown parsed corpora. Of these verbs, the mean occurrence of reduced stative versus eventive verbs did not differ ($t < 1$). Moreover, reduced uses occurred more often with inanimate rather than animate NPs for both verb classes ($p = .02$). Therefore, inanimate subjects were avoided in the stimuli when possible.

Design and Procedure: 30 native English speakers, students at the University of Maryland, read sentences on a computer screen, using the self-paced word by word moving window paradigm. Each participant saw 22 eventive and 22 stative sentences but never the two versions of the same item. Fillers and test sentences were pseudo randomly intermixed. After each sentence, participants answered a comprehension question.

Results: Repeated measure ANOVAS comparing reading times at the verb position revealed a significant word type effect ($F(1, 29) = 10.66$, $p = .003$; $F(1, 43) = 8.9$, $p = .004$). Eventive verbs took 27 ms longer to process than stative verbs. Table 2 shows mean reading times and standard deviations for these analyses. Figure 1 represents the mean reading times for the noun preceding the verb, the verb position and the next word (an article or a preposition). To check that the verb effect was localized only on the verb, we performed further analyses with word position as a factor. We expected an interaction between word position (noun - verb - next word) and sentence type (stative - eventive). Repeated measure ANOVAS with these two factors revealed a significant effect of word position ($F(29, 2) = 17.24$, $p < .0001$; $F(2, 43) = 19.59$, $p = .0001$) and a significant interaction ($F(58, 2) = 4.46$, $p = .01$; $F(2, 86) = 5.95$; $p = .004$). Post-hoc Fisher comparisons revealed a significant difference of sentence type only at the verb position (across subjects: $p = .001$; across items: $p = .009$).

Finally, to check that the effect was not due to a reduced relative-main verb ambiguity, we compared 12 pairs (indicated with "*" in Appendix A) where eventive verbs were either syntactically unambiguous (e.g., built) or had impossible theme/patients as subjects (e.g., the accountant deducted...). The comparison remained significant ($F(1, 30) = 6.7$, $p = .01$; $F(1, 11) = 8.7$, $p = .01$), suggesting that our results are independent from the possibility of a reduced relative reading.

These data strongly support the hypothesis that semantic differences in event structures between the verbs are responsible for the effects, independently of argument structure complexity.

Experiment 2: Visual Lexical Decision

Materials: 30 stative verbs and 30 eventive verbs were selected as before (plus 60 filler nouns). The items were not categorically ambiguous and were

pair-wised matched for word length, frequency (Associate Press Corpus), number of senses (WordNet database), orthographic neighborhood density (measured as the number of words that differ from the stimulus words in one letter, cf. Coltheart, Davelaar, Jonasson, & Besner, 1977), subjective familiarity ratings (independently collected from 43 subjects), and most frequent syntactic frame (transitive/intransitive). Means and standard deviations for these word variables are given in Table 3. Appendix C shows the words used in this experiment, with their log-frequency and most frequent syntactic frames. Non-words (= 118) were pronounceable words similar to real words, which favors deeper processing (Seidenberg, Petersen, MacDonald & Plaut, 1996).

In a pre-test, imageability ratings were collected to control for the contribution of this factor. We subsequently used the items' imageability ratings as a covariate in the analysis. Previous results show that higher imageability ratings are associated with faster reaction times (James, 1975; Paivio, 1991; Strain et al., 1995). We used the instructions provided in Chiarello, Shears, & Lund (1999). Comparisons of these ratings across categories revealed a significant difference, with eventive verbs more imageable (events' mean = 4.21 in a 1-7 scale, states' mean = 3.25, $p = .001$). Note that if imageability alone is responsible for reaction times (RTs), this factor makes the opposite prediction from the semantic complexity factor, i.e., eventive verbs should take faster, rather than longer, to process than stative verbs.

Procedure: 50 native English speakers, students at the University of Maryland, participated in this study. The experiment was carried out using Psyscope (Cohen, MacWhinney, Flatt, & Provost, 1993). Words were presented at varying inter-trial time (500-1500 ms) on the center of the screen. Before each stimulus word or non-word, a fixation point was presented for 500 ms. Participants pressed a key on the keyboard as fast as they could indicating whether the letter string on the screen was a word of English.

Results: The mean proportion of errors was .08 for states and .09 for events. An ANCOVA across items, with RTs as the dependent variable and imageability ratings as covariate, revealed a significant main effect of imageability ($F(1,61) = 13.48$, $p = .0005$), a main effect of word type ($F(1, 57) = 13.09$, $p = .001$) and no interaction. The subjects' analysis with no covariate also showed an effect of word type ($F(1, 49) = 15.6$, $p = .0003$). Stative verbs were recognized 24 milliseconds faster than eventive verbs (see Table 4). This finding indicates that both imageability and word type had an effect on RTs, but that the latter effect did not depend on imageability (as there was no interaction). Also, the direction of the effects was the opposite of that expected on imageability grounds. Overall, these results support the prediction that stative verbs are recognized faster than eventive verbs, consistent with an effect of semantic complexity.

General Discussion

The results of these experiments show that events take longer to process than states by about 25 ms. These findings cannot be attributed to argument structure differences among verbs, to the assignment of thematic roles to sentential arguments, or to plausibility relations between subject and verb. These alternative interpretations are excluded by the factors controlled for and by the lexical decision results. Instead, they must be attributed to the manner in which semantic or conceptual structures contained within the lexicon are processed, and in particular, to the fact that accessing verb meanings entails

accessing properties of the corresponding event representations such as the initial state, the change and resulting state. To our knowledge, this is the first time that such properties have been shown to have processing correlates, thus challenging previous results.

Our results have important implications for both theories of processing and of meaning representation. First, they illuminate the question of how and when meanings are computed during sentence processing. Note that the effect of semantic complexity emerged at the sentential verb position, suggesting that form and meaning are quickly (and perhaps automatically) paired during sentence processing, in line with recent visual world studies (e.g., Altmann & Kamide, 1999). However, although very rapid, access to the verb semantic substructures is not instantaneous. The more complex the structure, the longer the time to access, or activate, those structures. This observation is easily accommodated within spreading activation models of word recognition, although it does not exclude other views. The more the information encoded, the more distributed within the network, and the longer it takes for activation to spread.

Second, the results illuminate the nature of the semantic properties built into lexical meaning and activated during processing; in particular, whether these properties refer to thematic roles, causal properties or both. Several studies propose that verb meanings are represented as structured situations that contain participant slots plus thematic features (Tanenhaus, et al., 1989; Tanenhaus & Carlson, 1989; McRae et al., 1997; Ferretti, et al., 2001). Although some thematic features are correlated with causal structures, the differences in processing cost observed here suggest that verb meanings must include information about events that goes beyond participant slots and thematic features. Note that statives such as *_exist_* could have the same participant roles as eventives such as *_vanish_*, and yet the latter were more costly to process in post-hoc comparisons in both experiments (experiment 1 (n= 14): $F1(1,29)= 4.4$, $p=.04$; $F2(1,6)= 5.2$, $p= .06$; experiment 2 (n=16): ($F1(1,49)= 22.7$, $p= .0001$; $F2(1,14)= 5$, $p=.04$). Participant slots and thematic features alone therefore do not capture the differences between events and states.

In conclusion, the present data establish that there are processing correlates of semantic complexity manifested during the activation of the lexical representations of verbs, rather than during integration with prior context. The data also suggest that event structure properties are activated during processing, and that these properties subsume those of thematic roles and argument structure. We believe, therefore, that the processing of event structures, rather than thematic roles per se, operates at the interface between syntactic parsing and semantic interpretation.

References

- Altmann, G. (1999). Thematic Role Assignment in Context. *_Journal of Memory and Language_*, 41, 124-145.
- Altmann, G., & Kamide, Y. (1999). Incremental Interpretation at verbs: restricting the domain of subsequent reference. *_Cognition_*, 73, 247-264.
- Balota, D. (1994). Visual word recognition: The journey from features to meaning. In M. A. Gernsbacher (Ed.), *_Handbook of psycholinguistics_* (pp. 303-358). San Diego, CA: Academic Press.
- Balota, D., Ferraro, F., & Connor, L. (1991). On the early influence of meaning in word recognition: a review of the literature. In P. J. Schwanenflugel (Ed.), *_The psychology of word meanings_* (pp. 187-218). Hillsdale, NJ: Erlbaum.
- Blesdale, F. (1987). Concreteness-dependent associative priming: separate

lexical organization for concrete and abstract words. *Journal of experimental psychology: learning, memory and cognition*, 13, 582-594.

Chiarello, C., Shears, C., & Lund, K. (1999). Imageability and distributional typicality measures of nouns and verbs in contemporary English. *Behavioral Research Methods, Instruments, & Computers*, 31(4), 603-637.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments, and Computers*, 25, 257-271.

Coltheart, M., Davelaar, E., Jonasson, J., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and Performance - Vol. VI*, Hillsdale, NJ: Erlbaum.

Croft, W. (1998). Event Structure in Argument Linking. In M. Butt & W. Geuder (Eds.), *The Projection of Arguments: Lexical and Compositional Factors* (pp. 21-63). Stanford, CA: CSLI Publications.

Davidson, D. (1971). Eternal vs. ephemeral events. *Nous*, 5, 335-349.

Dowty, D. (1979). *Word meaning and Montague grammar*. Dordrecht: Kluwer.

Dowty, D. (1991). Thematic proto-roles and argument selection. *Language*, 67, 547-619.

Ferretti, T., McRae, K., & Hatherell, A. (2001). Integrating verbs, situation schemas, and thematic role. *Journal of Memory & Language*, 44(4), 516-547.

Fodor, J. (1998). *Concepts*. New York: Oxford University Press.

Fodor, J. A., Garrett, M. F., Walker, E. C. T., & Parkes, C. H. (1980). Against definitions. *Cognition*, 8, 263-367.

Fodor, J. A., & Lepore, E. (1998). The emptiness of the Lexicon. *Linguistic Inquiry*, 29(2).

Grimshaw, J. (1990). *Argument Structure*. Cambridge, MA: MIT Press.

Jackendoff, R. (1987). The status of thematic relations in linguistic theory. *Linguistic Inquiry*, 28, 369-412.

Jackendoff, R. (1990). *Semantic structures*. Cambridge, MA: MIT Press.

Jackendoff, R. (1991). Parts and boundaries. *Cognition*, 41(1-3), 9-45.

James, C. (1975). The role of semantic information in lexical decision. *Journal of Experimental Psychology: Human Perception and Performance*, 1(2), 130-136.

Ladusaw, W., & Dowty, D. (1988). Towards a non-grammatical account of thematic roles. In W. Wilkins (Ed.), *Thematic Relations*. New York, NY: Academic Press.

MacDonald, M. (1994). Probabilistic constraints and syntactic ambiguity resolution. *Language and Cognitive Processes*, 9(2), 157-201.

MacDonald, M., Pearlmutter, N., & Seidenberg, M. (1994). Lexical Nature of Syntactic Ambiguity Resolution. *Psychological Review*, 101(4), 676-703.

McElree, B. (1993). The locus of lexical preference effects in sentence comprehension: A time-course analysis. *Journal of Memory & Language*, 32(4).

McKoon, G., & Macfarland, T. (2000). Externally and internally caused change of state verbs. *Language*, 76, 833-858.

McKoon, G., & Macfarland, T. (2002). Event Templates in the Lexical Representations of Verbs. *Cognitive Psychology*, in press.

McRae, K., Ferretti, T., & Amyote, L. (1997). Thematic Roles as Verb-specific Concepts. *Language and Cognitive Processes*, 12(2/3), 137-176.

Moens, M., & Steedman, M. (1988). Temporal ontology and temporal reference. *Computational Linguistics*, 14(2), 15-28.

Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology*, 45, 255-287.

Parsons, T. (1990). *Events in the semantics of English: a study in subatomic semantics*. Cambridge, MA: MIT Press.

Pustejovsky, J. (1991). The Syntax of Event Structure. *Cognition*, 41, 47-81.

Rappaport Hovav, M., & Levin, B. (1998). Building Verb Meanings. In M. B. a. W. Geuder (Ed.), *The Projection of Arguments: Lexical and Compositional Factors* (pp. 97-134). Stanford, CA: CSLI Publications.

Rayner, K., & Duffy, S. (1986). Lexical complexity and fixation times in

reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory and Cognition*, 14(3), 191-201.

Rodd, J., Gaskell, G., & Marslen-Wilson, W. (2002). Making sense of semantic ambiguity: Semantic competition in lexical access. *Journal of Memory and Language*, 46(2), 245-266.

Schulte im Walde, S. (1998). Automatic Classification of Verbs according to their alternation behavior. Stuttgart University, Stuttgart, Germany.

Seidenberg, M., & McClelland, J. (1989). A distributed developmental model of word recognition and naming. *Psychological Review*, 96, 523-568.

Seidenberg, M., Petersen, A., MacDonald, M., & Plaut, D. (1996). Pseudohomophone effects and models of word recognition. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 22(1), 48-62.

Shapiro, L., Nagel, N., & Levine, B. (1993). Preferences for a Verb's Complements and Their Use in Sentence Processing. *Journal of Memory and Language*, 32, 96-114.

Shapiro, L., Zurif, E., & Grimshaw, J. (1987). Sentence processing and the mental representation of verbs. *Cognition*, 27(3), 219-246.

Smith, C. (1991). *The Parameter of Aspect*. Dordrecht: Kluwer.

Strain, E., Patterson, K., & Seidenberg, M. (1995). Semantic effects in single-word naming. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 21(5), 1140-1154.

Tanenhaus, M., & Carlson, G. (1989). Lexical Structure and Language Comprehension. In W. Marslen-Wilson (Ed.), *Lexical Representation and Process* (pp. 529-561). Cambridge, MA: MIT Press.

Tanenhaus, M., Carlson, G., & Trueswell, J. (1989). The role of thematic structure in interpretation and parsing. *Language and Cognitive Processes*, 4(3-4), 1211-1234.

Taylor, B. (1977). Tense and Continuity. *Linguistics & Philosophy*, 1, 199-220.

Trueswell, J., Tanenhaus, M., & Garnsey, S. (1994). Semantic Influences on Parsing: Use of Thematic Role Information in Syntactic Ambiguity Resolution. *Journal of Memory and Language*, 33, 285-318.

Trueswell, J., Tanenhaus, M., & Kello, C. (1993). Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden paths. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 19, 528-553.

Van Valin, R. D. J., & Wilkins, D. (1996). The Case for 'Effector': Case Roles, Agents, and Agency Revisited. In M. Shibatani, & Thompson, S. A. (Ed.), *Grammatical Constructions: Their form and meaning* (pp. 289-322). Oxford, UK: Oxford University Press.

Vendler, Z. (1967). *Linguistics and philosophy*. Ithaca, NY: Cornell University Press.

Verkuyl, H. (1993). *A theory of aspectuality*. UK: Cambridge University Press.

Appendix A

Verb Stimuli of Experiment 1

	State Verb	Frame	Prop.	Event Verb	Frame	Prop.
1	belong	subj:to:obj	0.72	arrange	sub:obj	0.77
		subj:pp	0.1		subj:to:inf	0.10
2	regard	subj:obj:as	0.72	accuse	subj:obj:pp.of	0.81
		subj:obj	0.08		subj:obj	0.08
3	dislike	subj:obj	0.69	inspect	subj:obj	0.86
4	live	subj	0.25	come	subj	0.21
		subj:pp	0.65		sub:pp	0.54
		subj:obj	0.13		subj:to	0.11

5	resemble	subj:obj	0.58	interrupt	subj:obj	0.67
		subj:obj	0.19		subj	0.32
6	regret	subj:obj	0.41	assert	subj:that	0.39
		subj:that	0.25		subj:obj	0.32
7	respect	subj:obj	0.85	explore	subj:obj	0.88
8	appreciate	subj:obj	0.68	criticize	subj:obj	0.60
		subj:that	0.11		subj:obj:for	0.30
9	admire	subj:obj	0.66	invent	subj:obj	0.78
		subj:obj:pp.for	0.06		subj:obj:obj	0.10
10	own	subj:obj	0.66	visit	subj:obj	0.73
11	deserve	subj:obj	0.56	contact	subj:obj	0.63
		subj:inf	0.18		subj:obj:pp	0.11
12	envy	subj:obj	0.59	elude	subj:obj	0.94
13	possess	subj:obj	0.66	provoke	subj:obj	0.70
14	hate	subj:obj	0.84	paint	subj:obj	0.73
15	love	subj:obj	0.67	build	subj:obj	0.76
		subj:inf	0.10		subj:obj:obj	0.09
16	cherish	subj:obj	0.72	invoke	subj:obj	0.78
17	need	subj:obj	0.38	allow	subj:obj:inf	0.56
		subj:inf	0.39		subj:obj	0.25
18	despise	subj:obj	0.60	clarify	subj:obj	0.84
19	detest	subj:obj	0.52	degrade	subj:obj	0.66
20	reside	subj:pp.in	0.50	mingle	subj:with	0.51
		subj:pp.with	0.05		subj:obj	0.14
21	revere	subj:obj	0.56	disarm	subj:obj	0.77
22	trust	subj:obj	0.51	assure	subj:obj	0.62
		subj:that	0.11		subj:obj:that	0.24
		subj:obj:inf	0.10		subj:obj:of	0.06
23	loathe	subj:obj	0.65	curtail	subj:obj	0.85
24	distrust	subj:obj	0.73	decimate	subj:obj	0.89
25	aspire	subj:pp.to	0.49	deduct	subj:obj	0.46
		subj:inf	0.34		subj:obj:from	0.43
26	lack	subj:obj	0.72	solve	subj:obj	0.88
27	pity	subj:obj	0.76	avenge	subj:obj	0.81
28	fear	subj	0.29	note	subj	0.25
		subj:obj	0.29		subj:obj	0.35
		subj:that	0.40		subj:that	0.21
29	like	subj:obj	0.40	show	subj:obj	0.43
		subj:inf	0.35		subj:that	0.23
		subj:vger	0.03		subj:obj:obj	0.07
30	stink	subj	0.66	exit	subj	0.74
		subj:pp.of	0.29		subj:obj	0.24
31	doubt	subj:that	0.55	stress	subj:obj	0.46
		subj:obj	0.33		subj:that	0.31
32	suspect	subj	0.17	declare	subj	0.16
		subj:obj	0.19		subj:obj	0.36
		subj:that	0.49		subj:that	0.23
33	adore	subj:obj	0.72	bully	subj:obj	0.77
34	comprise	subj:obj	0.64	devise	sub:obj	0.83
35	owe	subj:obj	0.20	award	subj:obj	0.24
		subj:obj:obj	0.22		subj:obj:obj	0.44
		subj:obj:pp.to	0.34		subj:obj:pp.to	0.17
36	consist	subj:pp.of	0.72	review	subj:obj	0.82
47	contain	subj:obj	0.65	remove	subj:obj	0.70
38	constitute	subj:obj	0.83	commission	subj:obj	0.84
39	equal	subj:obj	0.89	distort	subj:obj	0.86
40	exist	subj	0.54	emerge	subj	0.35

		subj:pp	0.32		subj:pp	0.51
41	concern	subj:obj	0.73	discuss	subj:obj	0.70
		subj:obj:pp.with	0.09		subj:obj:with	0.09
42	know	subj:obj	0.45	say	subj:obj	0.40
		subj:that	0.41		subj:that	0.41
		Subj:pp	0.07		subj:obj:pp.to	0.12
43	wish	subj:inf	0.50	begin	subj:inf	0.72
		subj:that	0.25		subj:obj	0.20
44	overlap	subj:	0.59	graduate	subj	0.42
		subj:obj	0.18		subj:obj	0.18
		subj:obj:with	0.20		subj:pp.from	0.23

Note: "Prop." indicates the proportion of corpus counts for each syntactic frame.

Appendix B

Sentence Stimuli of Experiment 1

1. a. The head librarian arranged a new weekly meeting.
b. The head librarian belonged to a union committee.
2. a. The chief resident accused the nurse of being inefficient.
b. The chief resident regarded the nurse as a dear friend.
3. a. The young detective inspected the crime scene.
b. The young detective disliked his senior partner.
4. a. The Lebanese immigrant came to Maryland around 1966. (*)
b. The Lebanese immigrant lived in Maryland since 1966. (*)
5. a. The older daughter interrupted her father.
b. The older daughter resembled her mother.
6. a. The impeached president asserted his constitutional right to immunity.
b. The impeached president regretted his administration's political mistakes.
7. a. The restless scout explored the Amazon basin.
b. The restless scout respected his coach.
8. a. The famous violinist criticized his colleagues.
b. The famous violinist appreciated his colleagues.
9. a. The Renaissance philosopher invented a complex pulley.
b. The Renaissance philosopher admired his ancient predecessors.
10. a. The French ambassador visited the northern provinces of Canada.
b. The French ambassador owned a productive factory since the nineties.
11. a. The political prisoner contacted a Human Rights organization.
b. The political prisoner deserved better treatment.
12. a. The local athlete eluded the anxious reporter.
b. The local athlete envied the Olympic champion.
13. a. The Italian minister provoked an angry response at the UN meeting.
b. The Italian minister possessed an impressive fortune before he took office.
14. a. The senior student painted his room yellow.
b. The senior student hated his greedy roommate.
15. a. The retired musician built his second house from scratch. (*)
b. The retired musician loved his second child very much. (*)
16. a. The old prosecutor invoked the fourth amendment. (*)
b. The old prosecutor cherished his close colleagues. (*)
17. a. The bossy editor allowed one party in the office.
b. The bossy editor needed two phones in his office.
18. a. The army general clarified his political position.
b. The army general despised the navy commander.

19. a. The teaching assistant degraded his supervisor.
b. The teaching assistant detested his supervisor.
20. a. The celebrated investor mingled with his friends. (*)
b. The celebrated investor resided in New York. (*)
21. a. The idealistic peacekeeper disarmed the guerilla fighter.
b. The idealistic peacekeeper revered his pacifist ancestors.
22. a. The experienced manager assured the stockholders of success.
b. The experienced manager trusted his employees.
23. a. The executive director curtailed the workers' rights. (*)
b. The executive director loathed the company's lawyer. (*)
24. a. The frontier rangers decimated the illegal settlements.
b. The frontier rangers distrusted the Mexican immigrants.
25. a. The savvy accountant deducted the outrageous fees. (*)
b. The savvy accountant aspired to the bank's presidency. (*)
26. a. The visiting scientist solved the intricate math problem. (*)
b. The visiting scientist lacked any knowledge of English. (*)
27. a. The popular Democrat avenged the workers' unfair treatment.
b. The popular Democrat pitied the homeless of New York.
28. a. The Chinese emperor noted that his subordinates were hungry.
b. The Chinese emperor feared that his subordinates were furious.
29. a. The controversial governor showed evidence in his defense.
b. The controversial governor liked limousines with a bar.
30. a. The dirty player exited instantly. (*)
b. The dirty player stank terribly. (*)
31. a. The Russian diplomat stressed the importance of the economic measures.
b. The Russian diplomat doubted the importance of the economic measures.
32. a. The despotic dictator declared an embargo against Cu.
b. The despotic dictator suspected a conspiracy against him.
33. a. The young boy bullied his parents.
b. The young boy adored his parents.
34. a. A few diligent men devised a novel communication system. (*)
b. A few diligent men comprised the king's entire army. (*)
35. a. The Swedish academy awarded a Nobel Prize to an unknown scientist.
b. The Swedish academy owed its success to its wealthy founder.
36. a. The advising committee reviewed the hospital's rules on patient treatment.
b. The advising committee consisted of several international representatives.
37. a. The previous administration removed evidence compromising its subordinates.
b. The previous administration contained innumerable bureaus and departments.
38. a. The food factory commissioned a small part of the necessary equipment.
b. The food factory constituted a small part of the senator's assets.
39. a. The recent polls distorted the candidate's judgment.
b. The recent polls equaled the newspaper estimate.
40. a. Many economic problems emerged in Europe after the Second World War. (*)
b. Many economic problems existed in Europe after the Second World War. (*)
41. a. The famous book discussed the financial implications of the Gulf War.
b. The famous book concerned the financial implications of the Gulf War.
42. a. The department chair said that the students did not come to class. (*)
b. The department chair knew that the students did not come to class. (*)
43. a. The clever tyrant began to negotiate with the national parties. (*)
b. The clever tyrant wished to negotiate with the national parties. (*)
44. a. The executive staff graduated from the Harvard School of Business.
b. The executive board overlapped with the advising committee.

Appendix C

Table C1: Stimuli of Experiment 2

States	Log(freq)	Events	Log(freq)	Syntactic Frame
abhor	1.430	delude	1.26	transitive
detest	1.300	deduce	1.15	transitive
despise	1.590	devour	1.57	transitive
abound	1.910	vanish	2.07	intransitive
reside	2.060	concur	2.08	intransitive
adore	1.640	berate	1.63	transitive
aspire	1.860	descend	2.58	intransitive
revere	1.970	coax	2.00	transitive
covet	1.980	adorn	2.11	transitive
entail	2.020	conquer	2.23	transitive
pertain	2.000	molest	2.11	transitive
denote	2.120	avenge	2.16	transitive
resent	2.280	engulf	2.27	transitive
admire	2.400	invent	2.44	transitive
possess	2.710	betray	2.33	transitive
differ	2.820	embark	2.45	intransitive
comprise	2.850	punish	2.87	transitive
deserve	2.970	alter	2.80	transitive
exist	3.570	emerge	3.27	intransitive
believe	4.220	borrow	3.11	transitive
cherish	2.1	align	2.11	transitive
belong	3.270	attract	3.29	transitive
contain	3.630	create	3.84	transitive
loathe	1.4	detect	2.98	transitive
afford	3.070	ascend	1.89	transitive
deplore	2.097	defend	3.45	transitive
intend	3.606	impede	2.25	transitive
beware	1.580	confess	2.64	intransitive
envy	1.260	detach	1.65	transitive
depend	3.28	harass	2.67	transitive

Note: "transitive" means that the verbs take an NP as a complement, while "intransitive" means that the verbs co-occur with prepositional phrases such as locatives.

Author Notes

We thank Gerry Altmann, Colin Phillips, Juan Uriagereka, Amy Weinberg and Maryellen MacDonald for insightful discussions, support and encouragement of this work.

Figure Captions

Figure 1: Verb reading times as a function of word position and verb class in Experiment 1.

Note: Error bars indicate standard error.

Tables

Table 1
Examples of lexical entailments

Type	Lexical Entailments
EVENTS	break -> _x_ CAUSE(BECOME (_y_ be-broken))
	discover -> BECOME(_x_ knows _y_)
	carry -> _x_'s ACTS(CAUSE(BECOME(_y_ be-
displaced)))	
STATES	deserve -> _x_ deserve _y_
	possess -> _x_ possess _y_

Table 2
Results of Experiment 1: Mean reading time in milliseconds at the verb position

Analysis	Verb Type	Mean	SD
Items	event	452	48
	state	425	44
Subjects	event	455	99
	state	430	90

Table 3
Matched word properties of the stimuli of Experiment 2.

Word properties	Eventive verbs		Stative verbs	
	Mean	SD	Mean	SD
Log frequency	2.38	.64	2.37	.78
Character Length	5.90	.62	6.10	.80
Number of senses	2.76	1.50	2.26	1.36
Number of Neighbors	2.36	2.24	1.80	1.33
Subjective frequency	3.48	.91	3.87	1.13

Note: All unpaired comparisons were not significant.

Table 4
Word recognition times in Experiment 2

Analysis	Verb Type	Mean	SD
Items	event	693	64
	state	670	51
Subjects	event	677	138
	state	655	137

