

Conceptual structure modulates structural priming in the production of complex sentences[☆]

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Received 18 April 2003; revision received 4 August 2003

Abstract

Speakers tend to reproduce syntactic structures that they have recently comprehended or produced. This structural or syntactic priming occurs despite differences in the particular conceptual or event roles expressed in prime and target sentences (Bock & Loebell, 1990). In two sentence recall studies, we used the tendency of speakers to paraphrase the finite complements of object-raising verbs as infinitive complements (e.g., “John believed that Mary was nice” as “John believed Mary to be nice”) to test whether an additional conceptual role would affect priming. Prime constructions with identical constituent orders as object-raising infinitives but an additional conceptual role (“John persuaded Mary to be nice”) resulted in fewer paraphrases. Contrasts with other constructions suggest that the critical difference between primes was this extra conceptual role. Thus, subtle differences in conceptual structures can affect how speakers grammatically encode message elements.

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Keywords: Language production; Structural priming; Syntax; Message planning; Semantics; Sentence recall

Introduction

The meaning of an utterance constrains the form of its expression. For instance, a speaker who wishes to talk about one thing affecting another thing is more likely to create a sentence with two noun phrases than a sentence with only one noun phrase. Given information about what a speaker intends to express and the context of the utterance, there is a limited set of constructions

that the speaker can felicitously use. Yet, despite the many systematic meaning-form correspondences present in languages, the mappings between them are not always one-to-one (for discussion, see e.g., Givón, 1995; Goldberg, 1995; Lambrecht, 1994; Smith, 2000). Many messages can be expressed by more than one sentence structure. One of the puzzles of sentence production is how utterances end up with the structures they do.

In the present study, we used the phenomenon of structural priming to explore the relationships between meaning and form as they relate to constructing sentences. In the context of language production, structural priming refers to the tendency of speakers and writers to reuse syntactic structures that they have recently read, heard, or produced (e.g., Bock, 1986; Estival, 1985; Hartsuiker & Kolk, 1998a; Pickering & Branigan, 1998; Potter & Lombardi, 1998; Weiner & Labov, 1983). For example, a passive sentence is more likely to follow another passive sentence than follow an active one; a prepositional dative construction is more likely to follow

[☆] Experiment 1 was presented at the 15th Annual CUNY Sentence Processing Conference in 2001. The second author submitted a report of these experiments to fulfill the requirements for an honors thesis from the Symbolic Systems Program at Stanford University in June 2002. Partial funding was provided by Undergraduate Research Opportunities and Undergraduate Research Projects at Stanford University, and the National Institutes of Mental Health R03 MH61318-01.

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another prepositional dative than follow a double object construction. So, after experience with a passive such as *A compromise is being suggested by the chairperson*, speakers are more likely to describe an unrelated picture of a bee stinging a man as *A man is being stung by a bee*, rather than using an active or intransitive sentence structure. This phenomenon is also called *syntactic persistence* and *syntactic priming*.

Language production begins with a pre-linguistic representation of what a speaker intends to express and accomplish with a speech act. Such *messages* are conceptual structures containing semantic and pragmatic specifications for message elements or event participants, as well as information about the relationships among these elements, such as their thematic or event roles (see e.g., Jackendoff, 1990, for a theory of conceptual structure).¹ That is, messages represent who-did-what-to-whom and how to frame who, what, and whom for an addressee in the current situation. Although a syntactic structure may also represent who-did-what-to-whom, it only does so accurately if it corresponds to an intended message. Structural priming reflects overlap in encoding messages and comprehending sentences (e.g., Bock, Loebell, & Morey, 1992).

In the experiments reported here, we compared the structural priming caused by constructions with identical syntactic descriptions in terms of constituent order (e.g., noun phrase followed by verb, NP V) and grammatical functions (e.g., subject, direct object), but different conceptual relationships between message elements. Finding that two constructions produce equivalent priming would suggest that the difference in their messages is ignored in creating syntactic structure. That is, equivalent priming would suggest that the common properties of the constructions' message representations are the ones used to assign grammatical functions and construct phrases, while the difference between the messages lies in a property ignored by structural processes. In contrast,

different structural priming patterns for constructions would suggest processing differences that are associated with the specific differences in message representations. We begin by summarizing the role that meaning, and particularly conceptual roles, have been shown to play in structural priming.

Meaning in structural priming

Repeating content words or referents across sentences indicates conceptual overlap in the sentences' messages. Such repetition across sentences increases the likelihood that the sentences have the same syntactic structure (Estival, 1985; Pickering & Branigan, 1998; Weiner & Labov, 1983). In addition, overlap in the semantic features of message elements in similar roles (such as goat and sheep as topics) across prime and target sentences make speakers more likely to re-use a construction (Cleland & Pickering, 2003). However, structural priming reliably occurs even in the absence of conceptually similar message elements (Bock, 1989; Bock & Loebell, 1990; Cleland & Pickering, 2003; Estival, 1985; Weiner & Labov, 1983). Increasing the similarity of message elements simply increases the likelihood that the messages will be processed similarly, resulting in similar syntactic structures.

It seems inevitable that some shared meaning or message property is necessary for the construction of one sentence to influence the construction of another. But what is the relevant type of shared meaning? Sentence meaning may be characterized in many ways, some of which are clearly unrelated to structure. For example, double object datives such as *The girl gave her mother the letter* can be primed by non-dative double object constructions such as *The accident cost the driver his life* (Potter & Lombardi, 1998), which involve taking rather than giving. Thus, the valency of events appears irrelevant to structural priming and the processes that encode messages as sentences. What about other aspects of sentence meaning?

Given identical phrase structures (NP V NP PP) across constructions, Bock and Loebell (1990) tested whether differences in event roles affected the priming of prepositional datives. Caused-motion constructions such as *The widow drove her Mercedes to the church* primed the production of prepositional dative sentences such as *A student is giving an apple to his teacher* to the same extent as other prepositional datives did. The magnitude of priming was insensitive to whether the object of the preposition was a destination (*the church*) or a recipient (*his teacher*).² Similarly, intransitives with locative

¹ We will use the term message or conceptual structure to refer to all of the information to be expressed. These terms include semantic structure (e.g., Jackendoff, 1990; Pinker, 1989), cases in Case Grammar (Fillmore, 1968), thematic or event roles (e.g., Ladusaw and Dowty, 1988), and information structure (e.g., Lambrecht, 1994). Messages contain elements, which we will often call event participants for convenience, although messages may have content that is not readily discussed in terms of events. These event participants have roles that relate them to each other and to predicates. For example, for the sentence, *The dog bit Dan and his cat*, the role of *bit's* patient is filled by Dan and his cat. Although Dan and his cat are two different entities in the real world, their conjoined noun phrases form a direct object noun phrase and they fill the patient role like a single event participant. At a level of representation that does not affect the highest levels of constituent or message structure, the participant Dan has an additional role as the possessor of a cat.

² Potter and Lombardi (1998) found that such caused motion sentences produced priming intermediate between that of prepositional datives and controls, but noted that, unlike Bock and Loebell's stimuli, their caused motion sentences differed in animacy from the datives.

prepositional phrases (e.g., *The airplane is landing by the control tower*) primed full passives with agentive prepositional objects (e.g., *A nurse is being hit by a truck*). Thus, structural priming appears indifferent to differences in particular event roles that message elements have.

Other aspects of sentence meaning do modulate or block structural priming. The messages of prime and target sentences must have the same number of event participants or roles. Evidence for this claim comes from the use of intransitive sentences as neutral primes and fillers for transitive and dative structural primes (e.g., Bock, 1986). In addition to differing from transitives and datives in their number of constituents, intransitives have fewer event participants and roles in their messages. For example, intransitive sentences such as *Vic snores* have one event participant (*Vic*) and one event role (snorer), whereas dative sentences like *Santa gave me a rowing machine* have three participants and roles. If all phrase structures primed all subsequent utterances without regard to the number of event participants or roles, intransitives would prime speakers to produce intransitives even when an intransitive structure could not express all the event participants and roles in the intended message. Specifically, speakers would try to produce clauses of the form NP V to describe a picture of a man giving a boy a hamburger. Even when multiple intransitives precede and could potentially prime such a picture, speakers do not produce intransitive descriptions such as *Man giving* or *Boy getting* (e.g., Bock & Griffin, 2000). Moreover, the persistent influence of a single dative prime over 10 intervening intransitive or predicate adjective sentences (Bock & Griffin, 2000) would be very hard to explain if intransitive and predicate adjective sentences exerted as strong an influence on descriptions of dative-eliciting picture as dative primes do.³

Together, these observations suggest that structural priming requires a similar number of event roles and

participants in the messages of primes and targets, but not identical roles or similar participants. Furthermore, having identical event roles does not necessarily increase structural priming, but overlap in the event participants filling those roles does. When prime and target messages have the same number of event participants and roles, the target may potentially be expressible with the same sentence structure as the prime – this is a sensible prerequisite for structural priming. More broadly, given a target message that can be expressed with alternative constructions, existing research suggests that the minimal properties of an effective structural prime are that it (a) has the same constituent order as one of the alternative constructions, and (b) has the same number of event participants, roles, or both, as the target.⁴

In this paper, we explore the relationship between conceptual representations and structural priming by examining syntactic constructions with identical constituent orders but a different number of event roles for event participants. The results indicate that this property of conceptual structure modulates structural priming.

Experiment 1

To vary conceptual structures expressed with identical constituent orders, we used clausal complement constructions. These constructions are not readily elicited by line drawings, so we used Potter and Lombardi's (1998) sentence recall paradigm for structural priming. This task takes advantage of people's better recall for gist than for syntactic structure (e.g., Mehler, 1963; Sachs, 1967) and the evidence that speakers regenerate the structure of recalled sentences (Lombardi & Potter, 1992; Potter & Lombardi, 1990). In this paradigm, structural priming occurs when prime constructions lead participants to misrecall or paraphrase target sentences with the structure of a prime sentence. Sentence recall has a long history as a tool in language production (e.g., Blumenthal, 1967; Bock, 1977; Clark & Stafford, 1969; Ferreira & Dell, 2000; Turner & Rommetveit, 1968; see Bock, 1996, for discussion).

Clausal complement constructions contain a main verb that takes another clause as a complement. For ease of exposition, we will refer to these constructions according to the type of verb used in the main clause and the finiteness of the complement clause. Table 1 illustrates the types of constructions used in Experiment 1. For example, *suspect* can take a complement clause that encodes the suspected proposition, as in the first example of Table 1. An important feature of this

³ Due to the differences in the event roles of intransitive and dative sentences, speakers would be more likely to construe events differently and thus create messages with fewer event participants to effectively describe the dative-eliciting pictures with intransitive sentences. For example, in describing the picture of a man giving a boy a hamburger at a barbeque, speakers might pick out part of the event that would permit them to describe it intransitively, such as "A father and son are barbequing." However, speakers do not seem to do this in response to intransitive priming sentences. If anything, they seem to become more likely to construe dative-eliciting stimuli in terms of dative events across the course of an experiment and even in the presence of intransitive primes (e.g., Hartsuiker & Kolk, 1998a, 1998b; Pickering, Branigan, & McLean, 2002). So, although speakers may experience some priming in the construal of pictures or the number of event participants to include in messages (Hartsuiker & Kolk, 1998a, 1998b), the shift seems to favor the inclusion of more event participants rather than matching the number in any prime sentence.

⁴ Structural priming by single verbs that typically appear in only one construction suggests that primes need only activate these representations rather than overtly express them (Mellinger & Döbel, 2002).

Table 1
Example sentences for Experiment 1

Complement	Verb	Example
Finite	Object raising	The police suspected that <i>Joan</i> was the criminal
Infinitive	Object raising	A teaching assistant reported <i>the exam</i> to be too difficult
Infinitive	Object control	Rover begged <i>his owner</i> to be more generous with food
Infinitive	Subject control	<i>Jenny</i> actually intended to be a runner in the race
None	Intransitive	The UN peacekeeping force finally intervened

Note. The controller or implicit subject of the complement appears in italics.

type of construction is that the same proposition can often be paraphrased with a direct object noun phrase and infinitive complement, as in *The police suspected Joan to be the criminal*. Reflecting the similarity between versions, the infinitive constructions were derived from the same base phrase markers as finite ones in classic transformational grammar (Chomsky, 1969). However, there are small systematic differences between the typical content of finite and infinitive constructions. For example, when used with an infinitive complement, the *controller* (Joan) of the complement's verb tends to be definite or general, as well as more topical and more directly manipulated by the agent of the main clause (Givón, 1984, 1993). Syntactically, the finite and infinitive complements of object-raising verbs differ in that the infinitive verb lacks morphological marking, not even agreeing with the noun phrase (NP) that controls it. Instead of appearing as a grammatical subject, this NP instead appears as a direct object. This is most easily seen by substituting *she* or *her* for *Joan*. In finite clauses, *Joan* can only felicitously be replaced by *she*, and in infinitive complements, *Joan* can only be felicitously replaced with *her*. Because this NP is marked as a subject in finite clauses and as a direct object in infinitive ones, the derivation has been called *subject-to-object raising* or *object raising* for short (e.g., Postal, 1974). These constructions occur in discussions of exceptional case marking because the controller seems to receive accusative case from the main verb, which the infinitive cannot provide in Case Theory (see e.g., Napoli, 1993, for review). We will refer to constructions that use object-raising verbs as object-raising constructions, even when they are used with finite complements.

Just as experiencing a prepositional dative sentence can prime speakers to use a prepositional dative construction, the use of an object-raising verb with an infinitive complement may increase the production of infinitive rather than finite complements with object-raising verbs. As caused-motion constructions with their *NP V NP PP* constituent orders made the production of *NP V NP PP* prepositional datives more likely despite their conceptual differences (Bock & Loebell, 1990), a construction with the same constituent order and a small

conceptual difference may prime the use of infinitive complements with object-raising verbs. The analogous construction for object-raising infinitive complements is called an *object-control* construction.

Sentences with object-control verbs have the same *NP V NP infinitive VP* constituent order as infinitive object-raising constructions. With respect to meaning, they differ in that object-control verbs tend to involve manipulation events (e.g., *force*, *beg*, and *command*), whereas object-raising verbs tend to involve perception, cognition, and volition (e.g., *sense*, *know*, and *wish*). The complements of object-raising verbs express propositions that are perceived, known, or desired. In contrast, object-control verbs describe how someone interacts with someone else to bring about the situation described in the proposition. These differences are apparent in transformations posited for the two constructions (Chomsky, 1965) as well as the answers they give to test questions such as "Is the direct object verbed?" In Table 1, the owner is begged, Rover is the beggar, and the goal of begging is that the owner be more generous. Object-control verbs assign event roles to their direct objects. Object-raising verbs do not (Chomsky, 1965; Pollard & Sag, 1994). For example, in *The experimenter expected the student to no-show*, does the experimenter "verb" the student? In fact, the experimenter does not expect the student at all.

Indeed, complements of object-raising verbs may be passivized and paraphrased in a number of ways without altering the truth status of the underlying propositions, because the event participant encoded as the direct object NP does not have an event role related to the action expressed by the main verb. Fig. 1 illustrates partial representations for an object-raising and an object-control sentence based on Head Driven Phrase Structure Grammar (Pollard & Sag, 1994). Note that the constituent orders are identical for the two constructions. They differ only in whether the referent of the direct object NP, [2], has an event role in the main proposition. Despite identical constituent orders and grammatical function assignments, the message representations of object-raising and -control sentences differ.

To the extent that structural priming is indifferent to such a small difference in conceptual structures as it was

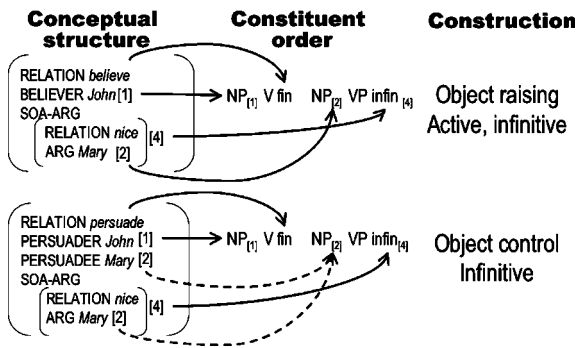


Fig. 1. Example of the mapping between conceptual structure and constituent orders for an object-raising infinitive sentence, *John believed Mary to be nice*, and an object-control infinitive sentence, *John persuaded Mary to be nice*. Dashed arrows mark the event roles that correspond to the direct object NP. Representations are based on Head Driven Phrase Structure Grammar (Pollard & Sag, 1987, 1994). SOA-ARG stands for state-of-affairs argument or an embedded proposition.

to differences in event roles in Bock and Loebell (1990), object-control and object-raising infinitive complements should equally prime the production of infinitive complements for object-raising verbs. As in other structural priming studies, intransitives may be used as neutral structures for these constructions because they differ from the primes in number of event participants and roles, as well as in constituent order.

We chose to include an additional prime construction to test whether infinitive complements increased infinitive paraphrases of targets even without identical constituent orders and grammatical functions. The verbs used in these constructions subcategorize for infinitive complements but lack direct object NPs. In Experiment 1, these sentences primarily contained *subject-control* verbs such as *agree* (see Table 1). These constructions typically describe someone's intention to perform an action. The subject of the main verb controls the infinitive complement. So, the potential runner in the example sentence is *Jenny*. Like intransitives, these subject-infinitive constructions should not prime object-raising infinitives because they have different constituent orders as well as fewer event participants and roles. Thus, they serve as another baseline condition for testing the effect of identical constituent order.

Methods

Participants

Fifty-four undergraduates from Stanford University, native speakers of American English, participated in the hour-long experiment. They received either credit for an introductory psychology class or \$10. Data from four participants were lost due to equipment problems.

Materials and design

Thirty-six object-raising verbs were selected for target sentences. Target sentences had finite complements accompanied by the complementizer *that*. With minimal changes, all of the sentences could easily be paraphrased with infinitive complements. Nine other object-raising, object-control, subject-infinitive,⁵ and intransitive verbs were selected to be main verbs in priming sentences. All of the object-raising, object-control and subject-infinitive complements contained a form of the verb "to be." Although the intransitive primes were one word shorter than the others on average, a one-way analysis of variance on the number of words in sentences of each prime type did not reach significance, $F(3, 32) = 2.01$, $p > .10$. Examples appear in Table 1 and the complete set of critical sentences is in the Appendix.

Thirty-six sentence pairs and 36 pictured scenes served as fillers. The sentences were equally divided between prepositional datives, simple transitives, bare intransitives, and intransitives with locations in prepositional phrases. Fillers were unrelated to critical stimuli. Each of four stimulus lists included all 144 sentences (72 pairs). Target sentences always occurred in the same pseudo-random positions. Across stimulus lists, sentences from the four priming constructions rotated through four groups of target sentences according to a Latin Square. Thus, the independent variable of prime construction was manipulated within subjects and items (defined as target sentences). The dependent measure was the percentage of target sentences that were recalled with infinite rather than finite complements, out of the total recalled targets that followed recalled primes.

Apparatus

The experiment was performed on a PowerMac G3 running PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). The participants wore a lapel microphone connected to a PMD221 Marantz tape recorder with a Shure headset microphone recording their voices. The experiment was displayed on a 17 inch Macintosh color monitor.

Procedure

Participants were tested individually in a sound-dampened chamber. They recalled a pair of practice sentences and described a picture before beginning the experimental trials. The experiment consisted of 144 sentences and pictures divided into 72 trials of two sentences each and a picture on filler trials. Target sentences were presented before prime sentences were, and

⁵ Six of the nine verbs among the subject infinitive complements were subject-control verbs and the other three were subject-raising verbs.

their recall cues appeared in the reverse order. Trials began with a mask of five asterisks presented for 500 ms, followed by a target sentence presented with rapid serial visual presentation (RSVP) at a rate of 200 ms per word. Then, a mask of 10 percentage signs appeared for 200 ms, followed by a prime sentence in RSVP for 200 ms per word, another mask of ten percentage signs for 200 ms, and a cue to recall the second sentence. This cue remained visible until participants pressed a key to indicate that they were done recalling the sentence. A cue to recall the first sentence replaced it. For intransitives, the subject noun phrase was presented as the recall cue, leaving participants to recall verbs, adverbs, and sometimes prepositional phrases. Otherwise, the initial words of each sentence up to its main verb acted as recall cues. For example, *The teacher expected* served as the cue to recall *The teacher expected the worst student to be an athlete*. By recalling the prime before the target, the prime's structure was more likely to be accurately recalled, so we could then evaluate its influence on the recall of the target (see Potter & Lombardi, 1998). Asking participants to recall the primes also allowed us to confirm that they were understood. Participants were told that they could take breaks in between trials by waiting to press the button to continue after the second recall. The minimum intertrial interval was 1500 ms.

Results

Repeated measures analyses of variance (ANOVA) were carried out on arc-sine transformed proportions (Winer, Brown, & Michels, 1991) of subject₁ and item₂ means with Geisser-Greenhouse corrections for violations of variance assumptions. The original degrees of freedom are reported for each omnibus ANOVA, followed by the Geisser-Greenhouse correction, and *p* values after corrections were applied. Sequential Bonferroni corrections with a family-wise alpha of .05 by subjects and by items were used for post hoc contrasts.

To be included in analyses of paraphrases, both prime and target sentences in a trial had to be adequately recalled. This meant that prime sentences had to be recalled with their original structures and the recalled complements of target sentences had to be acceptable when paraphrased as finite or infinitive. On 328 (18.2%) trials, speakers forgot or altered primes or targets. This percentage of forgotten trials was greatest for intransitive primes, mean 19.8%, and least for subject-infinitives, 16.7% (see Table 2). There was no significant effect of prime construction on the percentage of forgotten trials, *F*s < 1. Therefore, any differences in the rate of paraphrases for these prime constructions are unlikely to be due to differences in general recall difficulty.

Fig. 4 shows the percentage of finite target sentences that were recalled with infinitive complements as a function of prime construction. Speakers were most

likely to paraphrase targets when they were paired with infinitive object-raising constructions and least when paired with intransitives. The object-control and subject-infinitive constructions resulted in an intermediate percentage of infinitive paraphrases. The main effect of prime construction was significant, $F_1(3, 147) = 11.05$, $\hat{e} = .92$, $p < .0001$; $F_2(3, 105) = 10.79$, $\hat{e} = .93$, $p < .0001$. Planned contrasts against the intransitive baseline condition indicated significantly more infinitive paraphrases when targets were paired with object-raising primes, $F_1(1, 49) = 27.98$, $p < .0001$; $F_2(1, 35) = 24.05$, $p < .0001$; object-control primes, $F_1(1, 49) = 14.11$, $p < .001$; $F_2(1, 35) = 12.21$, $p < .005$; and subject-infinitive primes $F_1(1, 49) = 9.65$, $p < .005$; $F_2(1, 35) = 3.95$, $p < .06$. Post-hoc contrasts established that the object-raising primes resulted in significantly more infinitive paraphrases than did object-control primes, $F_1(1, 49) = 6.03$; $F_2(1, 35) = 7.22$; or subject-infinitives $F_1(1, 49) = 6.47$; $F_2(1, 35) = 11.40$. Object-control and subject-infinitive primes did not differ, *F*s < 1.3.

Discussion

Despite identical constituent orders, object-control infinitives did not elicit as many infinitive paraphrases of target sentences as object-raising infinitives did. In fact, the identical constituent order of object-control infinitives resulted in the same percentage of infinitive paraphrases as prime sentences with a very different conceptual structure and constituent order. Unexpectedly, the presence of any infinitive complement in a prime (as in the subject-infinitive condition) resulted in significantly more infinitive paraphrases than the baseline intransitives did. Several potential reasons for this pattern of results are suggested.

Object-raising primes had the identical constituent order as object-control primes, so another property must contribute to the difference in infinitive paraphrases following the two constructions. The object-raising and -control constructions differed primarily in three properties. First, the object-raising verbs tended to express

Table 2
Mean percentage of infinitive paraphrases and mean percentage of forgotten trials in Experiment 1, with standard errors for point estimates

Prime	Mean infinitive	SE	Mean forgotten	SE
Object raising	23.7	3.0	18.4	1.8
Object control	16.5	2.5	18.0	2.5
Subject infinitive	15.3	2.5	16.7	2.0
Intransitive	8.5	1.5	19.8	2.2

perception, cognition, or communication, whereas the object-control verbs were verbs of manipulation. Because this type of semantic difference between verbs does not seem to have modulated priming in other structural priming studies, it seems an unlikely source of this priming effect. For example, verbs of motion primed dative verbs (verbs of giving) in Bock and Loebell's (1990) experiments. However, semantic similarity between arguments of primes and targets does increase structural repetition (Cleland & Pickering, 2003) and the enhanced structural priming from repeated verbs (e.g., Pickering & Branigan, 1998) could be due to similarity between the predicates of prime and target messages. In Experiment 2, we test whether having the same verb type in primes as in target sentences suffices to produce greater infinitive priming by using object-raising verbs in a different infinitive construction.

The second difference was that infinitive object-control constructions include one more event role in their conceptual structures than infinitive object-raising constructions do. So, the messages of object-raising targets were more similar to those of object-raising primes than to those of object-control primes. When sentences lack co-indexed event participants, their number of event participants and their number of event roles are identical. A difference in the number of event roles between primes and targets has not previously been shown to affect priming independent of the number of event participants. However, a difference in the number of event participants and roles has a large effect, in that dative sentences do not tend to be misrecalled as intransitives when paired with intransitive primes (e.g., Potter & Lombardi, 1998). Having an additional event role for a participant is similar to having an additional event participant. This can be seen in Fig. 2 where the object-control sentence has an additional event role listed: the persuadee. It is only the fact that the event participant filling this role is identical to (i.e., coindexed with) the referent in the embedded proposition (state-of-affairs argument in Pollard & Sag, 1994) that keeps this role from introducing a new event participant. In effect, adding an event role is as close to adding an event participant as one can get without actually adding one. Thus, this is a plausible source of the priming difference for object-control and -raising constructions.

A third difference between object-control and -raising primes may have influenced priming. It turns out that object-raising verbs are used with infinitives less frequently than object-control and subject-control verbs are.⁶ This follows from the ability of object-raising verbs to take finite complements in addition to infinitive ones. So, the greater priming from infinitive complements with

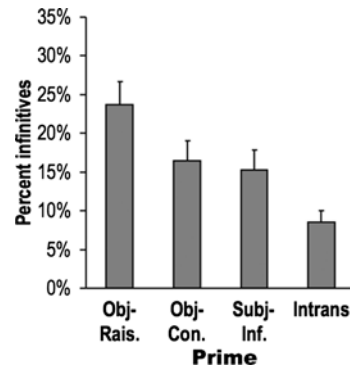


Fig. 2. Percentage of target object-raising sentences with finite complements that were paraphrased with infinitive complements as a function of prime construction in Experiment 1. Error bars indicate estimated standard errors for point estimates of the mean of subject means.

object-raising verbs relative to other verbs could be due to the existence of another option for expressing the message of object-raising sentences but no such option for the other prime constructions. Such a difference seems particularly likely if structural priming is the result of error-driven learning as in the Chang, Dell, Bock, and Griffin (2000) model. For example, a single use of an infinitive complement with an object-raising verb might require a relatively big change in weights to overcome a tendency to produce finite complements for such verbs. Because the object- and subject-control verbs usually take infinitive complements anyway, there might be relatively little need to adjust weights to produce them and therefore little priming. However, the ability of caused-motion constructions to prime prepositional datives in both speakers (Bock & Loebell, 1990; Potter & Lombardi, 1998) and a model trained with error-driven learning (Chang et al., 2000) suggests that effective primes need not have structural alternatives. Furthermore, minimal correlations between verb-construction co-occurrence frequency and magnitude of priming provide no support for the idea that priming magnitude varies with verb flexibility (Bock & Griffin, 2000; Hartsuiker & Kolk, 1998b). However, regardless of the verb used, uncommon constructions may show larger structural priming effects (e.g., Hartsuiker & Westenberg, 2000). Experiment 2 incorporates a test of a co-occurrence account as well as testing the contribution of verb meaning and conceptual structure.

Experiment 2

Experiment 2 differed from Experiment 1 in two important respects. First, the object-control condition was replaced by a new construction, created by making

⁶ We thank Maryellen MacDonald, Robert Thornton, and other former members of the MacDonald-Seidenberg lab for bringing this to our attention.

passive versions of the object-raising prime sentences.⁷ For example, the active prime, *Shannon discovered her fiancée to be completely untrustworthy*, was passivized to *Shannon's fiancée was discovered to be completely untrustworthy*. This change maintained the frequency with which object-raising verbs were used with infinitive complements and the cognition, perception, or volition meaning of the verbs, while altering their constituent order and the mapping of event roles onto grammatical functions and constituents. When the agent was not expressed in a *by* phrase, the passive versions also had fewer filled event roles in their main propositions.

Equivalent priming should result from active and passive object-raising primes if the critical difference between object-raising and object-control primes was related to differences in verb meaning such as expressing perception as opposed to manipulation. Likewise, equivalent priming would be expected if the possibility of paraphrasing the prime with a finite complement were the critical property. Passive versions of object-raising primes can be further paraphrased as in *It was discovered that Shannon's fiancée was completely untrustworthy*, or more awkwardly, *That Shannon's fiancée was completely untrustworthy was discovered*.

To the extent that constituent order matters, passive primes should yield fewer infinitive paraphrases than active ones. The passive constructions lack a direct object noun phrase, making their structure less like that of the object-control and -raising constructions and more like subject-raising ones such as *The computers in the public library continued to be unreliable*. Furthermore, the controller of the infinitive verb is encoded as the grammatical subject of the main clause in passive object-raising sentences, as it is in subject-raising sentences. Fig. 3 shows the conceptual structures and constituent orders for a sentence with a passive object-raising verb, *Mary was believed to be nice*, and a sentence with a subject-raising verb, *Mary seemed to be nice*. When an agent-less passive is produced, the mappings between conceptual structures and constituents are identical for the two sentence types.

For the second change in the experiment, all subject-control constructions among the subject-infinitive primes were replaced with subject-raising constructions, using subject-raising verbs such as *continue*, *start*, and *appear*. This permitted passive object-raising constructions to be directly compared to structurally similar subject-raising ones. Like object-raising verbs, the controller of the infinitive verb in subject-raising sentences has no event role assigned by the main verb. So, in Table 3's example, possums may appear dead, but they do not simply appear. This can be diagnosed by paraphrasing the sentences with a dummy *it*. Compare *It appears that*

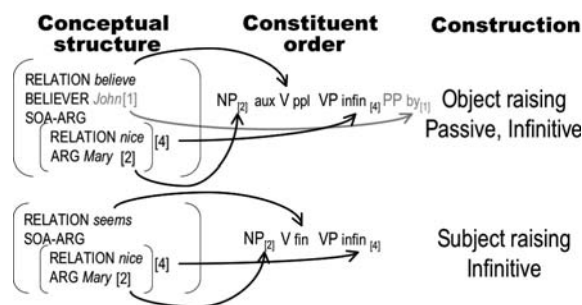


Fig. 3. Example of the mapping between conceptual structure and constituent orders for a passive object-raising infinitive sentence such as *Mary was believed to be nice (by John)* and a subject-raising infinitive sentence such as *Mary seemed to be nice*. Representations are based on HPSG. SOA-ARG stands for state-of-affairs argument or an embedded proposition. Aux = auxiliary verb. Ppl = past participle.

possums are dead when they aren't, with **It intends that Jenny run the race*.

These changes in the priming constructions allowed us to evaluate which differences between object-raising and -control infinitive-complement constructions contributed to different priming patterns. Cognition, perception, and orientation verbs are more semantically related to one another than they are to manipulation verbs. To the extent that this form of semantic similarity drives the greater infinitive priming from object-raising verbs, their passives should prove as effective as their active versions. To the extent that the greater infinitive priming from object-raising primes in Experiment 1 was due to their greater overlap with targets in the number of event roles for the referent of the direct object NP, the passive versions should be significantly weaker primes than actives because they have no direct object at all. Instead, the passive object-raising primes should produce priming effects similar to subject-raising primes. Finally, to the extent that the greater priming observed previously was due to object-raising verbs being used with infinitive complements less often than other verbs are, the active and passive primes should prime equivalently because they involve the same verbs with infinitive complements. In addition, subject-raising verbs may show infinitive priming similar to that of the object-raising constructions, because they too may take finite complements and therefore appear less often with infinitive complements that control verbs do.

Methods

Participants

Twenty-four undergraduate and graduate students from Stanford University and 36 undergraduates from Georgia Institute of Technology participated in the hour-long experiment. Data from four Tech students were lost

⁷ We are indebted to Carson Schütze for suggesting this manipulation.

Table 3
Example sentences for Experiment 2

Complement	Verb	Example
Finite	Object raising	Romeo professed that <i>his love for Juliet</i> was immortal
Infinitive	Active object raising	The programmer hypothesized <i>the problem</i> to be in his search algorithm
Infinitive	Passive object raising	<i>The problem</i> was hypothesized to be in programmer's search algorithm
Infinitive	Subject raising	<i>Possums</i> sometimes appear to be dead when they aren't
None	Intransitive	The lucky daytrader succeeded and promptly retired

Note. The controller or implicit subject of the complement appears in italics.

due to problems with tape recording. All participants were native speakers of American English and received the same compensation as the earlier participants.

Materials, design, and procedure

Eighteen sentences with infinitive complements were created with object-raising verbs that sounded sensible in both active and passive voice. In addition, primes included nine sentences with subject-raising verbs and nine with intransitives. Example sentences appear in Table 3. The intransitive prime sentences (a mean of 7.4 words) were significantly shorter than the active object-raising (10.3), passive object-raising (10.3), and subject-raising (10.1) sentences, $t_s > 3.23$, $p_s < .05$, which did not differ among themselves. Thirty-six other object-raising verbs were used with finite complements in target sentences.

Half of the object-raising prime verbs were assigned to the active condition and half to the passive condition. The prime sentences were then paired with different target sentences according to a Latin Square over four stimulus lists. Replacing the active object-raising sentences with their passive versions and vice versa created four additional stimulus lists. Thirty-six pairs of filler sentences from Experiment 1 were included in the stimulus lists along with an additional 14 intransitive filler pairs. A pictured scene to be described followed every pair of sentences. So, 86 scenes were included in the experiment. Thirty-six tended to elicit dative descriptions and the remainder elicited intransitives. In

other respects, the procedure and design were the same as in Experiment 1.

Apparatus

Ten Stanford students and all of the Tech students were run with the same equipment used in the earlier experiments. The other 14 participants at Stanford were run on a Macintosh G4 Cube with a 19-inch monitor. They wore a lapel microphone connected to a Sony TCS-30D handheld tape recorder.

Results

Location was included as a between-subjects and within-items factor in analyses. In other respects, the analyses were carried out in the same way as in Experiment 1. One cell lacked a mean for the item analysis of infinitive paraphrases and was estimated using Winer's method (Winer et al., 1991).

Data from six participants were excluded due to forgetting sentence content for 50% or more of the experimental trials. In the remaining data, inadequately recalled primes and targets (and failure to record 3 trials) led to the exclusion of 27.9% of trials, leaving 1298 trials. Table 4 reports the mean percentage of forgotten sentences and the mean percentage of infinitive paraphrases for the recalled sentences as a function of experiment location and prime construction. Unlike Experiment 1, active object-raising primes tended to have the highest percentage of forgotten trials for

Table 4
Mean percentage of infinitive paraphrases and mean percentage of forgotten trials in Experiment 2, with standard errors for point estimates

Prime	Stanford				Georgia Tech			
	Mean infinitive	SE	Mean forgotten	SE	Mean infinitive	SE	Mean forgotten	SE
Active object raising	23.5	4.1	37.7	3.4	32.4	4.6	30.3	3.7
Passive object raising	17.7	3.2	25.8	3.0	25.7	4.0	27.3	3.2
Subject raising	19.4	4.6	30.2	3.6	23.0	5.0	22.7	2.9
Intransitive	10.8	3.1	21.0	2.6	17.3	4.4	27.3	4.6

participants in both locations. However, the fewest forgotten trials were in the intransitive condition for the Stanford location and in the subject-raising condition for the Tech location. In the analysis of forgotten trials, the main effect of prime construction was significant, $F_1(3, 144) = 3.41$, $\hat{e} = .93$, $p < .03$; $F_2(3, 105) = 3.66$, $\hat{e} = .95$, $p < .02$; but neither location nor its interaction with prime construction was significant. Planned contrasts against the intransitive baseline only showed a significant difference for active object-raising primes, $F_1(1, 48) = 7.09$, $p < .02$; $F_2(1, 35) = 8.98$, $p < .006$. In Experiment 1, intransitives had the highest percentage of forgotten trials and the lowest percentage of infinitive paraphrases. If that reflects a negative correlation between general memory for sentences and the likelihood of paraphrases, active object-raising primes should have shown the lowest percentage of infinitive paraphrases in Experiment 2 but this was not the case.

The active object-raising infinitives resulted in the highest percentage of infinitive target complements. Fig. 4 shows the mean percentage of infinitive complements produced in target sentences for each prime construction. The subject-raising and passive constructions elicited an intermediate percentage of infinitive paraphrases and the intransitives elicited the fewest. The main effect of prime type was significant, $F_1(3, 144) = 46.86$, $\hat{e} = .93$, $p < .0005$; $F_2(3, 105) = 9.53$, $\hat{e} = .90$, $p < .0001$. All planned contrasts between intransitives and the other primes reached significance; the 13.7% difference for active object-raising primes, $F_1(1, 48) = 16.81$, $p < .0003$; $F_2(1, 35) = 25.75$, $p < .0001$; the 7.5% difference for passive object-raising, $F_1(1, 48) = 10.91$, $p < .002$; $F_2(1, 35) = 9.05$, $p < .005$; and the 7.2% difference for subject-raising, $F_1(1, 48) = 4.81$, $p < .04$; $F_2(1, 35) = 4.46$, $p < .05$. Three post hoc contrasts compared the primes with infinitive complements to each other. The 6.2% difference

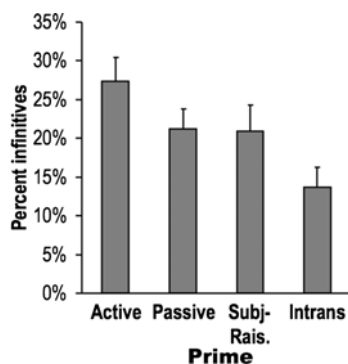


Fig. 4. Percentage of target object-raising sentences with finite complements that were paraphrased with infinitive complements as a function of prime construction in Experiment 2. Active and passive are versions of object-raising infinitives. Error bars indicate estimated standard errors for point estimates of the mean of subject means.

in infinitives paraphrases for active as opposed to passive object-raising primes was only significant by items, $F_1(1, 48) = 1.88$, ns ;⁸ $F_2(1, 35) = 7.60$. Active object-raising primes elicited significantly more infinitive paraphrases than did subject-raising primes, a 6.5% difference, $F_1(1, 48) = 4.16$; $F_2(1, 35) = 10.26$. The tiny 0.3% difference between passive object-raising and subject-raising primes did not approach significance, $F_s < 1.2$.

Georgia Tech students paraphrased targets on 6.8% more trials than Stanford students did. This difference only reached significance in item analyses, $F_1(1, 48) = 3.21$, $p < .08$; $F_2(1, 35) = 5.83$, $p < .03$. The pattern of priming effects was the same for the two populations, so the interaction between prime and location did not approach significance, $F_s < 1$.

Discussion

The analyses of Experiment 2 indicate that passive versions of infinitive-complement object-raising constructions primed infinitive paraphrases more like their structurally identical subject-raising constructions than like active versions of the same sentences. This suggests that the magnitude of infinitive priming is not directly tied to the relative frequency with which a verb occurs with an infinitive complement or whether the verb expresses cognition, perception, or volition. All infinitive primes in Experiment 2 had possible finite paraphrases, so the general ability to appear in more than one structure did not distinguish them. Rather, the difference between active object-raising infinitive primes and the others suggests that infinitive priming is modulated by the correspondence between the conceptual and syntactic relationships in prime and target sentences. In addition, the mere presence of an infinitive complement in a prime sentence elicited significantly more infinitive complements in recall than intransitives did.

General discussion

In two experiments, speakers were primed to paraphrase finite complements as infinitive ones. Speakers produced these paraphrases most often when target sentences were paired with prime sentences that contained object-raising verbs in active voice with infinitive complements, such as *The media prematurely proclaimed the wrong person to be the winner*. Not sur-

⁸ In the ANOVA on untransformed proportions, which underestimates the error variance, the difference approached significance, $p < .06$. Based on the overall pattern of means and statistical analyses, we will consider the active and passive versions to prime differently.

prisingly, speakers produced infinitive paraphrases least often when they recalled target sentences primed by complement-less intransitive sentences. The primary question was whether object-control constructions that shared identical constituent orders, NP V NP infinitive VP, with active object-raising infinitives, would elicit an equivalent number of infinitive paraphrases despite a small difference in their conceptual structures. They did not. In Experiment 1 and a pilot experiment,⁹ object-control primes elicited significantly fewer paraphrases than object-raising ones did, suggesting differences in how their messages were grammatically encoded. In Experiment 2, passive versions of the object-raising primes elicited fewer paraphrases than active versions did, suggesting that verb meaning and the ability to take a finite complement were not the critical differences between object-control and -raising primes. Instead, the results suggest that the additional event role in object-control primes caused their messages to be processed differently than the messages of active object-raising primes despite the resulting identical constituent orders. Unexpectedly, despite large differences in constituents and conceptual structures, all of the prime constructions that included infinitive complements resulted in significantly more infinitive paraphrases than intransitive primes did.

These results can be summarized with two statements. First, the presence of an infinitive complement in a priming sentence significantly increased the likelihood that finite complements in targets would be paraphrased as infinitive, regardless of other conceptual and syntactic differences between the sentences. We will refer to this as a *general infinitive priming effect*. Second, speakers produced infinitive complements even more often when priming sentences contained direct object NPs that were not patients of the main verb. Due to the additional constraints on the occurrence of this priming, it will be called the *specific infinitive priming effect*.

We begin this discussion by considering our experimental task and its relationship to normal language production. We continue by discussing the general infinitive priming effect and then, the specific priming associated with active object-raising constructions. Last, we turn to language production models of structural priming and how they might account for specific infinitive priming.

Failures of recall

All of the experiments reported here used Potter and Lombardi's (1990, 1998; Lombardi & Potter 1992)

method for eliciting altered sentences in recall. This method relies on the old observation that recall for gist is better than recall for particular words or syntactic structures (e.g., Mehler, 1963; Sachs, 1967). Lombardi and Potter (1992) showed that speakers incorporated distracter verbs with compatible meanings into recalled sentences regardless of mismatches between the distracter's subcategorization frame and the surface structure of the original sentence. For instance, when the non-alternating verb *donate* was substituted for *give* in *The widow gave the orphans toys*, speakers instead produced *The widow donated toys to the orphans*. The lack of a modulating effect of target's original syntactic structure suggested that only the conceptual structure of the original sentence was used in regeneration, not its syntax. The authors argued that distracter verbs intruded in the recall of targets due to their meaning and then their subcategorization frames guided the structurally different regeneration of the original sentences. While the structures of the original sentences were likely primed, they were not strongly associated with the contents of the sentences and the intruding verbs were incompatible with their use. These findings and others suggest that sentence recall involves many of the normal processes of language production (e.g., Clark & Stafford, 1969; Ferreira & Dell, 2000). Pickering and Garrod (in press) go so far as to argue that recall studies may share more features with normal sentence production than other methods such as picture description because of the strong tendency to re-use words and structures across utterances in normal speech.

Another way to think about the task is as a confusion matrix for syntactic and conceptual structure. Prime constructions varied in conceptual structure, syntactic structure, and potentially the processes involved in creating the latter from the former. Given these differences, the question may be framed as: with which constructions did target sentences share enough features to produce infinitive paraphrases in recall? In other words, the more similar the items are, the more likely a person is to confuse their other properties, such as having an infinitive complement. If shared constituent structure were the only feature for determining confusion, object-control and -raising primes would have elicited similar percentages of infinitive paraphrases, but they did not. Active and passive prime sentences with the same conceptual structure but different constituent structures did not prove equally confusable with targets either. Sentences that both shared conceptual structure and constituent order with the infinitive paraphrases led to the greatest level of confusion. Although such an interpretation emphasizes the artificial aspects of the task, it highlights the importance of having similar conceptual structures as a prerequisite for using similar processes to yield syn-

⁹ This result was also found in a pilot experiment, which differed from Experiment 1 in using uninformative recall cues and a variety of verbs in the infinitive complements of primes.

tactic structures. In addition, a potential reason for the trend for intransitive primes to be recalled more poorly than other primes in Experiment 1 may have been their lack of similarity with target sentences. While shared properties increase confusion, they may also allow more efficient storage and recall.

We also acknowledge that unlike much of everyday speaking, the content of the sentences in such an experimental task has no importance to the speakers and no relationship to their thoughts, the environment, or the utterances that preceded and followed them, and in particular, their noun phrases did not refer to anything specific. Yet, whatever semantic representations speakers culled from these contextless sentences sufficed to regenerate sentences with systematically varying syntactic structures and that is all that we required here. Although one should usually be cautious in generalizing from such artificial tasks to natural speech, the observation that structural priming is common and powerful in more natural speaking situations (e.g., Branigan, Pickering, & Cleland, 2000; Estival, 1985; Tannen, 1987; Weiner & Labov, 1983) suggests that similar effects in sentence structure choice apply in these situations.

General infinitive priming

A number of constructions elicited significantly more infinitive complement paraphrases than intransitives did, but significantly fewer than active object-raising primes did. Within this intermediate group were all of the prime constructions that contained infinitive complements: object-control (e.g., *Julie somehow convinced Sebastian to be quiet*), subject-control (e.g., *Kelly vowed to be sober in the future*), subject-raising (e.g., *George seemed to be amused by the movie*), and passive voice object-raising primes (e.g., *The wrong person was prematurely proclaimed to be the winner by the media*). These constructions differ in their number of event participants and roles, and whether or not they had direct objects. The most obvious common element among the prime structures was the presence of an infinitive complement.

One reviewer suggested that primes containing infinitives might have been harder to accurately recall than intransitives, and therefore have taken more mental effort away from accurate (non-paraphrased) recall of target sentences. However, there was no evidence that speakers had more trouble recalling infinitives over intransitives in either experiment. Indeed, the trend was in the other direction in Experiment 1, suggesting that primes and targets were recalled more accurately when both contained complement clauses.

Other than this, there are many differences between intransitives on the one hand and the sentences with infinitive complements on the other that could result in

more infinitive paraphrases. Therefore, there is no particular reason to think that the general infinitive priming effect is a structural priming effect. It could be due to a number of conceptual, lexical, or structural differences. For example, all of the main verbs in infinitive primes subcategorized for infinitive complements. Thus, we do not know whether nominal or adverbial infinitive complements would have the same effect.

All of the infinitive primes tested included the infinitive form of the verb *be*, as did the paraphrased target complements. In contrast, the finite targets typically used a past tense form of *be*. The tendency to use the lemma *be* with the syntactic properties of an infinitive could be enhanced by all primes except intransitives which had no *bes*. However, speakers could and did produce finite complements that included infinitive *be* as in *The student knew that the fourth multiple-choice answer would be the correct one*. So, priming of the use of *be* with its infinitive features would not ensure the production or priming of an infinitive complement, but it probably wouldn't hurt. Priming for infinitive properties could also occur through changes in conceptual structure. The lack of finite time specifications for embedded propositions in prime complements could lead speakers to drop them from the target's embedded proposition.

The present experiments do not serve to distinguish between either a semantic or syntactic source of the general infinitive priming effect. Furthermore, the distinctions between potential sources of priming for infinitives is difficult to discern as it depends on the choice of semantic and syntactic theories, which differ considerably in how they account for raising structures and finiteness (cf. Chomsky, 1969; Creider, 1979; Felser, 1999; Hyde, 2000; Jackendoff, 1987; Pollard & Sag, 1987; Postal, 1974). The unanticipated general infinitive priming effect may be interesting in its own right, because the constructions involve syntactic and conceptual constraints that operate across multiple verbs, and the finite-infinitive complements alternation has not been explored. Here though, the important effect is the one specific to active object-raising constructions.

Specific infinitive priming

The source of specific infinitive priming is easier to identify than the general effect. Only object-raising verbs in active sentences with infinitive complements resulted in this increase in infinitive paraphrases. Comparing the priming from object-raising and object-control verbs indicates that identical constituent order was insufficient for specific priming. Aside from constituent order, the two prime constructions also shared other major syntactic features such as infinitive com-

Table 5
Comparing prime constructions with properties of infinitive paraphrases of target object-raising constructions

Prime	Direct object NP	Main verb type	Flexibility	N participants	N roles
Active object raising	Y	Y	Y	Y	Y
Object control	Y	N	N	Y	N
Passive object raising	N	Y	Y	Y/N ^a	Y
Subject raising	N	N	Y	N	N
Intransitive	N	N	N	N	N

^a When the agent of the passive is unexpressed, there is one fewer event participant mentioned.

plements in their verbs' subcategorization frames, verb morphology, and case marking (e.g., Givón, 1993). This strongly suggests that the source of the additional priming involved more than surface syntactic form. Table 5 shows which properties the prime constructions shared with the infinitive paraphrases of target sentences.

The major difference between the two priming constructions was that object control primes contained an additional event role. Because the patient of the main event was also a participant in the embedded proposition, the constructions had the same number of event participants. Described based on verb properties, object-control verbs had a semantic relationship with their direct objects that object-raising verbs lacked. Returning to the examples in Fig. 1, *John persuaded Mary to be nice* implies that Mary was persuaded by John. In contrast, *John believed Mary to be nice* implies no interaction between John and Mary. Thus, specific priming required that the referents of direct objects in the primes have no semantic relationship with the main event or verb. At the same time, contrasts with other priming constructions indicate that a direct object NP was required. So, the lack of an extra patient role in the main proposition could not be satisfied by sentences with fewer event participants, such as subject-control or -raising infinitives or passive object-raising primes.

Object-raising verbs used in active voice primed infinitive complements more than the same verbs did when used in passive voice. So, specific priming is not a simple function of prime and target sharing the same type of main verb. Additionally, the difference between active object-raising and other raising constructions further suggests that sharing the same flexibility to take a finite or infinitive complement was not sufficient to produce priming either. Comparison of the active and passive object-raising constructions also suggests that specific priming was not related to the controller of the infinitive verb behaving like a patient of the object-raising verb without actually being a patient. In the passive versions, the controller appears as the grammatical subject of the passive object-raising verb.

The critical combination that distinguishes between the construction that produced specific infinitive priming and those that did not is the presence of a message element encoded as a direct object noun phrase that did not have an event role associated with the main proposition. The most straightforward characterization of this difference is that it involves overlap in conceptual structure *and* its syntactic realization. In other words, it is not a simple question of sharing conceptual or syntactic structure, but rather sharing the mapping between the two structures.¹⁰ Thus, the specific infinitive priming effect appears to be due to shared structures, but explicitly includes conceptual structures and the correspondence between elements of conceptual structure and constituents.

Constituent structure, including the linear order of constituents (e.g., Hartsuiker & Westenberg, 2000; Pickering et al., 2002), has emerged as the relevant level of syntactic description in structural priming studies thus far. Active object-raising and -control infinitives share constituent structure, as well as verb morphology, grammatical function assignments, and subcategorization frames. However, syntactic theories differ in the degree to which semantic and pragmatic properties are marked in syntactic representations. To the extent that co-reference is considered a property of both messages and resulting syntactic structures, the comparison of object-raising and -control constructions is not between subtly different conceptual structures and identical syntactic structures. Instead, the comparison concerns conceptual structures differing by one event role and syntactic structures that have the same constituent order, grammatical functions, but different co-indexing and case assigners (e.g., Napoli, 1993). Specifically, according to Binding and Control

¹⁰ The term *structural priming* still seems suitable for this phenomenon because it is tied to mapping from semantic structure to syntactic structure. We would reserve *conceptual*, *message-level*, or *semantic* to apply to effects that can be detected in responses that lack a structural component or occur in multiple unrelated syntactic structures. Potential examples of such *message-level* priming would be changes in the construal of events from dative to intransitive.

Theory, in *John persuaded Mary to be nice*, *Mary* is the object of the main verb and PRO is the subject of the infinitive. In contrast, *Mary* is only the subject of the infinitive complement in a version with an object-raising verb such as *believe*. Likewise, in Case Theory, *Mary* receives structural case in the object-control infinitive and exceptional case marking in the object-raising infinitive. One way of accounting for differences in structural priming for object-control and -raising infinitives is to consider them as different in both conceptual and surface syntactic structure and therefore naturally involving different operations in their encoding. Under such an interpretation, the present experiments might be considered to show the relevance of co-reference or case assignment mechanisms in modulating structural priming. In the next section, we discuss another way in which infinitive priming might be realized in a theory of structural priming in sentence production.

Accounting for infinitive priming effects

A few models and theories of language production explicitly try to account for structural priming (Chang, 2002; Chang et al., 2000; Dell, Chang, & Griffin, 1999; Ferreira, 2000; Pickering & Branigan, 1998; Pickering et al., 2002). None of them have straightforward ways of accounting for the present results, particularly specific infinitive priming. The simplest case is that of the Chang models, which are limited by their inability to represent messages that contain more than one proposition. Without solving this non-trivial problem, it is impossible to simulate a solution with them.

In Pickering and Branigan's (1998) extension of Roelofs' (1992, 1993) model, abstract word representations or *lemmas* connect to *combinatorial nodes*, which correspond to the different constituent combinations that verbs may appear with. A (NP, PP) combinatorial node connects to verbs that appear in prepositional dative constructions (*give*) and potentially also caused-motion constructions (*drive*). Dative verbs that can appear in double object constructions are attached to a (NP, NP) node. Structural priming occurs when there is residual activation in a combinatorial node due to its recent use in producing a sentence. The most activated combinatorial node that is linked to a selected verb lemma is the most likely to be selected. For example, the verb lemma *give* and the (NP, PP) node are activated and selected to produce the sentence, *The woman gave a bone to her dog*. Activation of the selected lemma (*give*), combinatorial node (NP, PP), and the link between the two persists for some time after the sentence is produced. When the speaker produces another utterance, verb lemmas compete for selection. If the winning verb lemma is connected to a combinatorial node with residual activation, that

combinatorial node is more likely to be selected than other ones. For example, the verb *offer* is more likely to be used in a prepositional dative construction after a prepositional prime sentence with *give*, due to residual activation in the (NP, PP) node. The Roelofs–Pickering–Branigan (henceforth *RPB*) account thus far (Pickering & Branigan, 1998; Pickering et al., 2002) has not further specified how message information is associated with constituents.

Like the Chang et al. (2000) models, the RPB account has not been extended to deal with multiple clauses, but such an extension is more straightforward for the RPB account because combinatorial nodes would either correspond to verb subcategorization frames (i.e., arguments only) or experienced phrase combinations for words (i.e., both arguments and adjuncts; see Cleland & Pickering, 2003; Pickering et al., 2002). Both object-raising and object-control verbs subcategorize for a noun phrase and an infinitive verb phrase (e.g., Pollard & Sag, 1994). Likewise, both appear with a direct object noun phrase and infinitive verb phrase. Either basis for creating combinatorial nodes would result in object-raising and -control verbs sharing a (NP, infinitive VP) node or a similar combinatorial node. By tying structural priming to combinatorial nodes and combinatorial nodes to constituent combinations, the RPB account suggests that object-raising and -control infinitives should produce similar priming. The fact that the two verb types do not produce equivalent infinitive priming indicates that the RPB account of structural priming and sentence production might benefit from modification. Ideally, any modification would explicate how message elements are associated with the constituents of combinatorial nodes. In addition to providing an account of the present data, such a modification would specify how recipients are mapped onto the first post-verbal NP in double object datives, whereas patients are mapped onto the first post-verbal NP in prepositional datives. Alternatively, the mapping component might be left unspecified by adding PRO or another object-raising vs. -control difference to combinatorial nodes. Because combinatorial nodes for control verbs would include PRO and the raising ones would not, the constructions would not be expected to prime each other.

Another possibility is that object-raising and -control constructions involve the production of identical sequences of major constituents, NP V NP infinitive VP, but differ in how message elements are encoded as constituents. A theoretical assumption behind some models of structural priming is that message elements are encoded in words and phrases incrementally. For example, the commitment to produce a double object dative rather than a prepositional dative is made with the decision to encode the recipient rather than the patient after the verb (Chang, 2002; Chang et al., 2000; Dell et al., 1999). Indeed, when speakers describe dative-

eliciting scenes, they look back and forth between patients and recipients more often during speech when they have little reason to prefer mentioning one before the other than when they are strongly biased to use a particular order (Griffin & Garton, 2003). These gaze transitions appear to occur while speakers articulate a subject noun phrase and prepare the noun phrase to follow the verb. We hypothesize that the difference in conceptual structure for active object-raising and -control infinitives may result in a difference in the sequence in which event roles are encoded in constituents. Under the hypothesis that structural priming is a type of implicit learning of these encoding sequences (e.g., Bock & Griffin, 2000; Chang et al., 2000), a difference in the sequence of event roles encoded would result in structural priming differences despite identical constituent orders. The account we sketch is based on descriptions of incremental grammatical encoding for object-control constructions in Kempen and Hoenkamp (1987) and Levelt (1989) in combination with the theoretical assumptions of the Chang models.

In object-raising infinitives, the direct object NP is invariably a message element from the embedded proposition of the conceptual structure (*Mary* in the brackets labeled SOA-ARG in Fig. 1). So, grammatically encoding the direct object involves lexicalizing part of the embedded proposition. For object-control infinitives, there are two possible event roles in the conceptual structure from which the direct object could be encoded. One of these roles is the patient of the main verb (the PERSUADEE of Fig. 1). The other role is in the embedded proposition (*Mary* as an argument of 'nice'). If the direct object of the object-control verb were always encoded via its role in the embedded proposition, the mapping between conceptual structure and constituents would be identical for object-raising and -control verbs. If so, they should have primed infinitive paraphrases identically, but they did not. If the direct object of the object-control infinitive were sometimes encoded via the embedded proposition and sometimes via the patient role of the main proposition, object-control infinitives should have produced a level of priming between that of active object-raising and subject-control infinitives. Another gradation in infinitive priming would be difficult to detect statistically, but even numerically there was little evidence of such intermediate priming in the present experiments. Finally, if the direct object of object-control infinitives were consistently encoded as a patient of the main proposition rather than part of the embedded one, object-control and -raising infinitives would have different sequences for encoding event roles, but the sequences for encoding object- and subject-control infinitives would overlap with those for object-raising infinitives to the same degree. Thus, differences in which proposition provides the message element for encoding the direct object NP provides one way to account for

specific infinitive priming.¹¹ But why would direct objects in object-control infinitives consistently be encoded using a message element from the main proposition when they could be encoded using an element of the embedded proposition?

The evidence for clause-wise planning in production (e.g., Bock & Cutting, 1992; Ford, 1982; Ford & Holmes, 1978; Garrett, 1975; Goldman-Eisler, 1972) motivates a distinction between the encoding of direct objects for object-control verbs and direct objects for object-raising infinitive constructions. That is, it provides a reason why direct objects of object-control verbs may consistently be encoded as elements of the main proposition rather than the embedded one. Clauses are isomorphic with propositions, so clause-wise planning patterns may simply reflect a bias to encode propositions one at a time. At the point in sequential grammatical encoding when direct objects are encoded in object-control infinitives, an agent and action have already been encoded from the main proposition and only the patient role remains. It makes sense to complete encoding of the main proposition before starting encoding of the embedded one.

A one-proposition-at-a-time bias is consistent with within-language difficulties with multiple embedded clauses and cross-linguistic word order patterns (for comprehension-oriented descriptions of these, see e.g., Gibson, 1998; Hawkins, 1999). A demanding aspect of multiple center-embedded sentences (e.g., *The mouse that the cat that the dog chased ate was poisoned*) is that they involve encoding event roles from embedded propositions before the encoding of the outer propositions is completed. Cross-linguistically, languages favor word orders that minimize the number of partially encoded propositions or simultaneously incomplete clauses. So, heavy NPs such as those with their own embedded propositions expressed as relative clauses tend to shift to the edges of main clauses. In English, they tend to shift to the end of clauses, as in *I bought for my cat the most elaborate cat tree that I could find on the*

¹¹ Although we have focused on incremental grammatical encoding in production here, incremental interpretation in sentence comprehension also leads to different mappings between constituents and event roles in propositions for object-control and -raising infinitives. When a listener hears the noun phrase *Mary* after an object-control verb (e.g., *John persuaded Mary . . .*), *Mary* can and should be interpreted as a patient of the verb. A following infinitive complement just provides more information. In contrast, if a listener interprets *Mary* as the patient or theme of an object-raising verb, the listener may be garden-pathed as in (e.g., *John believed Mary to be a liar*). So, in comprehension as well as production, the constructions differ in the mappings between conceptual and constituent structures. See Chang et al. (2000) on the relationship of comprehension and production in structural learning and priming.

web as opposed to *I bought the most elaborate cat tree that I could find on the web for my cat*. The bias is for the entire main proposition to be expressed before the embedded one (see also Wasow, 1997). In contrast, in head final languages such as Japanese, the preference is to express such relative clauses and their arguments at the start of the sentence, yielding the order embedded proposition before main (Yamashita & Chang, 2001). In both cases, the speaker avoids having two partially encoded propositions at the same time. Some constructions such as subject-raising infinitives (*seem* in Fig. 3) involve encoding information from one proposition before completing another, indicating that such patterns are not impossible. Instead, the data suggest to us that such patterns are avoided and the duration of encoding with two open propositions is minimized.

For these reasons, we hypothesize that the message element in the main proposition's patient role for object-control infinitives is grammatically encoded as a direct object NP before its role in the embedded proposition is considered. When the speaker thereafter encodes message elements from the embedded proposition, the element is discovered to be co-indexed (*token-identical* in Pollard & Sag, 1994) with the element encoded as direct object via the patient role, so it is not encoded again (see Kempen & Hoenkamp, 1987). Encoding continues with the rest of the embedded proposition as an infinitive verb phrase. So, we hypothesize that the direct object NPs of object-raising infinitives are encoded via their role in embedded propositions, whereas direct objects of object-control infinitives are encoded as patients in main propositions, and that this is due to a speaker bias to minimize the number of simultaneous partially encoded propositions.

Conclusion

In conclusion, the present experiments in combination with other recent work are beginning to fulfill the promise that structural priming may elucidate the mental representation of grammatical knowledge (see Bock, 1990; Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995). Structural priming is a particularly useful method for addressing such questions because it results from comprehended sentences as well as produced ones (e.g., Bock, 2002; Branigan et al., 2000; Potter & Lombardi, 1998). It is likely to lead to syntactic processing accounts that relate comprehension and production processes. As seen here, identical constituent orders alone are insufficient to account for the magnitude of structural priming effects (see also Scheepers, 2002). Instead, the specific priming effect for infinitive complements and possibly other forms of structural priming appear to be based on the correspondence between elements in conceptual structures and constituents in syntactic structures.

Acknowledgments

We thank Susan Lagrone, A.J. Margolis, Azucena Rangel, and Amanda Silverio for their help in running subjects and transcribing data. Thanks to Tom Wasow for his help in supervising the thesis and for answering syntactic questions along with Ivan Sag. Any errors in syntactic or semantic theory however are entirely due to the authors.

Appendix

Object-control prime sentences from Experiment 1

Her father persuaded Annie to be a careful skier.
Camille forced her husband to be neater around the house.
Julie somehow convinced Sebastian to be quiet.
Mr. Forbes ordered his servant to be faster.
The scientist asked his assistant to be a harder worker.
The babysitter told her employer to be a better parent.
The daughter allowed her father to be her teacher for a day.
Allen encouraged his roommate to be more studious.
Rover begged his owner to be more generous with food.

Subject-infinitive prime sentences from Experiment 1

Jane steadfastly refused to be someone who borrows money.
Gertrude happily agreed to be the leader for the project.
Beverly solemnly swore to be healthier after her stroke.
Jenny actually intended to be a runner in the race.
Jason volunteered to be the editor of the school newspaper.
Kelly vowed to be sober in the future.
George seemed to be amused by the movie.
Jerry grudgingly began to be a good team member.
Walter finally started to be kind to his mother.

Subject-raising prime complement sentences from Experiment 2

George seemed to be amused by the movie.
Jerry grudgingly began to be a good team member.
Walter finally started to be kind to his mother.
Alice's third husband happens to be a great cook.
California turned out to be the most expensive state in the union last year.
Harry persisted to be the most annoying person that Claire ever met.
The computers in the public library continue to be unreliable.
The new economics building came to be the ugliest building on campus.
Possums sometimes appear to be dead when they aren't.

Intransitive sentences in Experiments 1 & 2

The frustrated dieter's weight fluctuated constantly.
Roy's grade point average slowly improved.
The prosecution's case against the embezzler suddenly crumbled.
The luxurious new minivan's value immediately dropped.
The newborn kittens in the supermarket's parking lot mewed softly.
The lucky daytrader succeeded and promptly retired.
Fred Astaire and Ginger Rogers danced elegantly.

The UN peacekeeping force finally intervened.

Princess Diana and other people in her car died a few years ago. (Princess Diana and other people in her car died dramatically.)

Active object-raising priming sentences with infinitive complements in Experiment 1 (Active and/or passive primes from Experiment 2)

Bo imagined the other party's candidate to be an idiot. (The other party's candidate was imagined to be an idiot by his competitors.)

Even the NRA considers legalizing grenades to be dangerous. (Legalizing grenades was considered to be dangerous even by the NRA.)

A teaching assistant reported the exam to be too difficult. (The exam was reported to be too difficult for introductory students.)

The cook preferred sauces to be spicier. (The cook's sauces were preferred to be spicier.)

The mechanic rated the wrench to be an excellent tool. (The mechanic rated the shiniest wrench to be the best tool. The shiniest wrench was rated to be the best tool.)

Rebecca believed her new lawyer to be the best. (Rebecca believed her new coach to be the best. Rebecca's new coach was believed to be the best.)

The plumber hypothesized the problem to be internal. (The programmer hypothesized the problem to be in his search algorithm. The problem was hypothesized to be in programmer's search algorithm.)

The professor expected the worst student to be an athlete. (The other students expected the class clown to be a failure. The class clown was expected by other students to be a failure.)

The suspicious husband guessed his wife's excuse to be false. (The salesperson identified the diamond-studded bracelet to be the stolen one. The diamond-studded bracelet was identified to be the stolen one.)

(The young couple felt the condominium to be too small for them. The condominium was felt to be too small for the young couple.)

(The aging millionaire designated his personal secretary to be his only heir. The aging millionaire's personal secretary was designated to be his only heir.)

(The media prematurely proclaimed the wrong person to be the winner. The wrong person was proclaimed to be the winner.)

(Mark's new neighbors decreed Thursday to be party night. Thursdays at Mark's new neighbors' were decreed to be a party night.)

(Channel E! fancied the Academy Award winner to be an artist. The Academy Award winner was fancied to be an artist.)

(The expensive lawyers counseled the gangsters to be more careful about who they threatened. The gangsters were counseled to be more careful about who they threatened.)

(A physician diagnosed the soprano's tumor to be benign. The soprano's tumor was diagnosed to be benign.)

(Shannon discovered her fiancée to be completely untrustworthy. Shannon's fiancée was discovered to be completely untrustworthy.)

(The expert certified the broken antique to be genuine. The broken antique was certified to be genuine.)

Targets - Object-raising verbs with finite complements in Experiments 1 & 2

Alison wished that the bad news was a mistake.

Amy confessed that her love for country music was genuine.

An airline employee confirmed that the jet was late.

Andy correctly predicted that his stock would be valuable.

Brett incorrectly assumed that the variables in the computer program were integers.

Dr. Hilbert acknowledged that Craig was sick.

Einstein understood that the Theory of Relativity was limited.

Flora's mother heard that a nasty rumor was spreading.

Jamie thought that his face was unusually long.

Jane Stanford envisioned that Stanford would be the nation's finest university.

Laura unnervingly foresaw that the senator was corrupt.

Lawyers rarely observe that a case is unwinnable.

Martha judged that the punishment was inadequate.

Prof. Reed admitted that her colleague's argument was convincing.

Romeo professed that his love for Juliet was immortal.

Stubborn Zach finally conceded that his answer was wrong.

Susan held that her charm was irresistible.

The expert affirmed that the obscure document was actually forged.

The foot surgeon determined that his patient's case was untreatable.

The graduate student established that the necessary precondition was satisfied.

The intelligent explorer recognized that granola was a good source of energy.

The logician brilliantly deduced that the proof was bogus.

The mayor loudly declared that the proposition was under discussion.

The millionaire found that money was the best incentive.

(The manager found that money was the best incentive.)

The New York Times announced that the treaty was a success.

The physicist showed that his assumption was valid.

The police suspected that Joan was the criminal.

The psychic sensed that her client was doomed.

The reporter noted that the CEO of the new company was a convicted felon.

The salesman guaranteed that the used car was reliable.

The student knew that the fourth multiple-choice answer was the correct one.

The theatrical magician willed that a chair become invisible.

The university deemed that the student was qualified.

The weatherman anticipated that the coming week would be drenched in rain.

The widow desired that her husband were alive.

The writer discerned that the complicated sentence was well-formed.

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