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The Persistence of Structural Priming: Transient Activation or Implicit Learning?

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Structural priming in language production is a tendency to recreate a recently uttered syntactic structure in different words. This tendency can be seen independent of specific lexical items, thematic roles, or word sequences. Two alternative proposals about the mechanism behind structural priming include (a) short-term activation from a memory representation of a priming structure and (b) longer term adaptation within the cognitive mechanisms for creating sentences, as a form of procedural learning. Two experiments evaluated these hypotheses, focusing on the persistence of structural priming. Both experiments yielded priming that endured beyond adjacent sentences, persisting over 2 intervening sentences in Experiment 1 and over 10 in Experiment 2. Although memory may have short-term consequences for some components of this kind of priming, the persisting effects are more compatible with a learning account than a transient memory account.

Speakers repeat themselves. Sometimes their repetitions are intentional, made for emphasis or other stylistic and social purposes (Giles & Powesland, 1975; Tannen, 1987), and sometimes they are accidental. They may involve almost any stretch of speech, from sounds, words, or phrases to entire utterances. They can create perseveration errors (as when *Bush's budget* became "Bush's boodget" in the mouth of an acquaintance) or mere prolixity (as in "It's not at all inconsistent with it at all"), or they can be subtle enough to pass without notice.

Among the subtlest of repetitions are those that involve the use of the same syntactic structures in successive clauses or sentences. This kind of repetition can also be intentional or unintentional, stylistic (e.g., to create parallel structure in composition) or erroneous (one of our colleagues recently said "Once you're in it, you can't get out it"), and may include repeated words (Levelt & Kelter, 1982; Pickering & Branigan, 1998) or may not (Bock, 1989). It is easy to observe apparently inadvertent repetitions of structural patterns in natural, error-free speech. Some of the observations that point toward the existence of this kind of repetition in everyday conversation can be found in Estival (1985), Kempen (1977), Levelt and Kelter (1982), Schenkein (1980), and Weiner and Labov (1983). Even in experimental settings that reduce or eliminate many of the natural confoundings in normal conversational interaction, there is a tendency for speakers to repeat sentence structure (Bock, 1986; Bock & Loebell, 1990; Bock, Loebell, & Morey, 1992; Hartsuiker & Kolk, 1998b; Potter & Lombardi, 1998). This unintentional and pragmatically unmotivated tendency to repeat the general syntactic pattern of an utterance is called *structural priming*.

One method for eliciting structural priming in the laboratory is illustrated in Figure 1. It involves using whole sentences to prime simple event descriptions. During each priming trial, participants hear a priming sentence such as "The car's windshield was struck by a brick." They repeat this sentence aloud. Then they see and describe a pictured event in one sentence, perhaps saying something along the lines of "The boy got jolted awake by an alarm clock," or "The boy is being wakened by a noisy alarm." Other participants receive the priming sentence, "A brick struck the car's windshield," and then describe the same event. Structural priming is said to occur when the participant's description of the event has the same basic structural configuration (i.e., has the same construction; Goldberg, 1995) as the priming sentence. With this method, priming has been demonstrated for transitive sentences (actives and passives) and dative sentences (prepositional and double-object sentences) in both English and Dutch.

Structural priming occurs even though the priming manipulation is covert, with the priming trials embedded in long lists of filler pictures and sentences that are unrelated and appear to be haphazardly arranged. In the method illustrated in Figure 1, the event descriptions are introduced as

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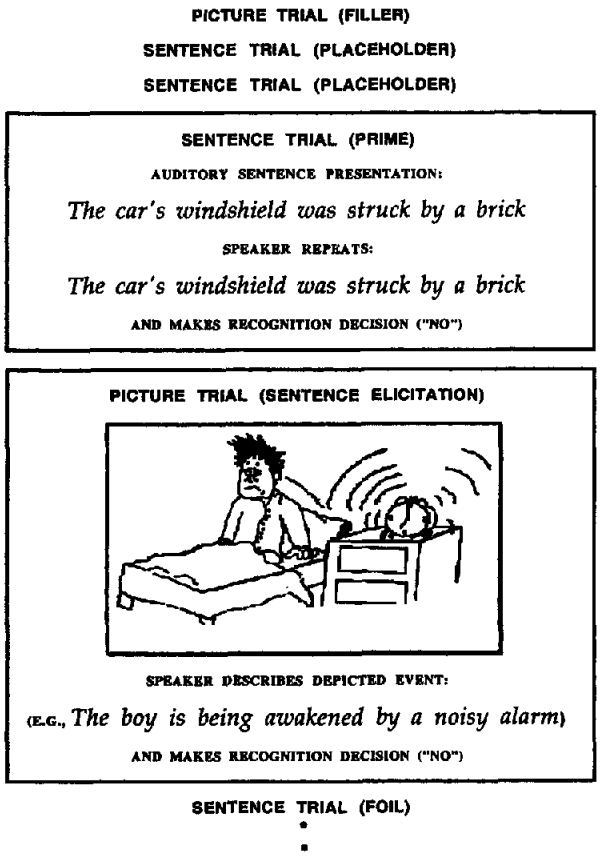

Figure 1. Sequence of events on a sample Lag-0 structural priming trial.

subsidiary to the performance of a running recognition-memory test in which participants indicate whether sentences and pictures are repetitions of earlier ones. The tasks of repeating sentences and describing pictures are assigned ostensibly as memory aids. The participants describe the events with no restrictions on what they say, so whatever structures occur are spontaneously produced. There are no obvious semantic or pragmatic connections between the priming sentences and target pictures, and there is no conversational partner who might benefit from the use of parallel syntactic structures. In short, nothing in the procedure promotes the repetition of structures from the prime to the target.

By coupling this method to variations in the relationships between prime and target sentences, previous work has shown that structural priming does not rely on similarity of the event roles between the primes and targets (Bock & Loebell, 1990), on the repetition of function words (Bock, 1989), on metrical similarity (Bock & Loebell, 1990), or on broad semantic similarities between the words of the primes and the targets (Bock et al., 1992). In short, it occurs despite changes in event roles, function words, prosody, and the basic semantic features of words. In the sense of Posner (1978), it appears to be functionally isolable (see Bock & Kroch, 1989).

So, as its name implies, structural priming may depend on the structural features of sentences. Sentences with superficially similar sequences of words but different structures had different consequences for production in a study by Bock and Loebell (1990, Experiment 3): A prepositional-dative prime such as "Susan brought a book to Stella" elicited increased numbers of prepositional-dative descriptions of pictures (e.g., "The children are showing a picture to a man") unlike primes such as "Susan brought a book to study," which had no impact on dative use.

It appears that structural priming grows out of some kind of experience-dependent adjustment within a system that builds utterances. The nature of the adjustment is, however, unknown. One candidate has to do with the temporary activation of information in memory, analogous to traditional accounts of lexical priming (Collins & Loftus, 1975). For example, De Smedt (1990) hypothesized that structural priming might be traced to increased activation of syntactic categories (noun, verb, etc.) and syntactic segments (fragments of structural trees), just as changes in the activation of words and phonemes are used to account for speech errors in influential models of language production (Dell, 1986). Such changes take place over a fairly short timescale: Empirically, the increase in rate of speech that is necessary to achieve a two-word naming deadline of 500 ms produces significant changes in the patterns and types of speech errors, compared to performance at deadlines of 1,000 ms (Dell, 1988). In terms of the model parameters, 87% of the activation dissipates after 1 s and is completely gone after 2 s. Similarly, in research on semantic priming in word recognition, typical priming manipulations yield rapidly diminishing effects when unrelated words separate a semantically related prime and target word (Meyer, Schvaneveldt, & Ruddy, 1972; see Joordens & Becker, 1997, for review).

It is essential to activation accounts that priming is attributed to activity in a particular memory location or representation. For additional information to be processed, activation must shift away from a current focus of processing to the next. For example, to explain serial ordering in language and other sequential behaviors, one unit of the series must be inhibited to make way for the next (Dell, Burger, & Svec, 1997). Accordingly, one prediction from what we call an *activation* account of structural priming is that priming should degrade rapidly, giving it a readily observable time course.

Some findings that are consistent with a fairly fast decline in the magnitude of structural priming were reported in work by Levelt and Kelter (1982). Levelt and Kelter explored structural matches between questions that experimenters asked and answers that speakers provided in natural and laboratory-elicited speech. They found that the tendency to match the form of an answer to the form of a prior question declined significantly with as little as a single intervening clause, although a weaker matching effect persisted over longer intervals.

An important feature of the Levelt and Kelter experiment was that the structural matching effect involved lexical repetition: The critical structures were prepositional phrases in which a preposition could be repeated between a question

(Q) and the subsequent answer (A) to the question (e.g., Q: "At what time do you close?" A: "At seven") or simple noun phrases without prepositions (Q: "What time do you close?" A: "Seven"). To determine whether lexical repetition played a role in structural matching, Levelt and Kelter examined the strength of the relationship between participants' ability to explicitly recall the preposition and the tendency to give corresponding answers. The relationship was very strong, suggesting that memory for the format of the question supported the production of a structurally and lexically similar answer. Because this memory decayed rapidly under normal response conditions, Levelt and Kelter's results suggested that the strength of the tendency toward structural matching may be related to maintenance of a question's wording or form in memory. Similar findings have been reported by Branigan, Pickering, and Cleland (1999) in a written production task.

At the same time, there are indications that structural priming occurs in the absence of lexical repetition and over intervals that are unlikely to involve memory maintenance. Bock (1989) compared structural priming between dative sentences with and without repetition of the same preposition and found equivalent priming in both cases. In written production, Pickering and Branigan (1998) found significant priming in the absence of repetition, although the magnitude of priming was considerably larger when the same verb occurred in both the prime and target sentences.

Some hints that this kind of lexically independent structural priming may be more persistent than what Levelt and Kelter (1982) observed comes from observations of residual priming over long intervals. Bock and Kroch (1989) analyzed an incidental effect of structural priming that survived over 12 intervening trials. Related work (Bock, 1989; Bock & Loebell, 1990) pointed toward a dilution of priming when a competing structure was primed an average of 6 trials before a priming trial for the alternative structure, relative to the magnitude of priming after 10 to 12 intervening trials. Hartsuiker and Kolk (1998b) found equivalent priming in immediate and 1-s delay conditions, and Boyland and Anderson (1998) reported priming over a 20-min delay after multiple repetitions of a priming form. Such effects are unlikely to be due to intentional efforts to remember the forms of the primes: Bock (1986, Experiments 1 and 2) found structural priming under conditions that offered no motivation to remember the priming sentences, and the priming effects were actually larger than those under conditions that encouraged remembering the priming sentences (Bock, 1986, Experiment 3; see also Hartsuiker & Kolk, 1998a).

To accommodate these findings, an explanation of structural priming in terms of learning processes may be better able to account for longer term adjustments within the sentence production system (Bock, 1986; Levelt, 1989). Because the structural processes involved in the assembly of sentences normally operate outside of awareness (Bock, 1982) and because speakers can be wholly oblivious to the features of their speech that are susceptible to structural priming (Bock, 1990), the changes induced by priming may be construed as a species of learning that is procedural or implicit (N. J. Cohen & Eichenbaum, 1993; Tulving & Schacter, 1990).

As described by N. J. Cohen and Eichenbaum (1993), procedural learning does not involve storing the outcomes of processing operations but tuning the processing operations themselves. That is, the act of processing leaves behind a change within the system. In consequence, this kind of learning is manifest only in performances of tasks that make use of the same processing operations that were engaged during the original learning experience. Seger (1994) defined implicit learning as involving knowledge that is (a) not accessible to consciousness, (b) fairly complex and abstract, (c) an incidental consequence of some task performance, and (d) preserved in cases of amnesia. On its face, structural priming has all of these characteristics (see Bock, 1990), including preservation in anterograde amnesia (extrapolating from preliminary results in Bock, Ferreira, Cohen, & Wilson, 2000).

With existing data, however, it is impossible to assess the normal time course of priming under carefully controlled conditions, especially with respect to any longer term components of priming. There are a number of reasons why it is important to be able to arbitrate between a transient memory-based account and a longer term learning account. As a fleeting event, priming could serve a number of discourse and conversational functions. Such functions include fostering cohesion in text by tacitly encouraging the use of parallel structures (Chambers & Smyth, 1998; Frazier, Taft, Roeper, Clifton & Ehrlich, 1984; Silverstein, 1984), aiding the process of gap filling in creating and understanding elliptical utterances (R. J. Matthews, 1979; Tanenhaus & Carlson, 1990), and supporting the formation and interpretation of answers to questions (Levelt & Kelter, 1982). All of these functions may reflect basic memory and production processes that help to explain the nature of short-term recall (Potter & Lombardi, 1998).

But if there is also a longer term component to priming, it may have broad repercussions for our understanding of language learning and language change. Language learning most obviously encompasses first-language acquisition, where developmental analogues of priming are occasionally reported (Brooks & Tomasello, 1999; deVilliers, 1980; Whitehurst, Ironsmith, & Goldfein, 1974), but extends to second-language learning (where phenomena like transfer and interference might be understood better with an account of priming effects in hand; Loebell, 1989). Ranging further, structural priming may play a part in the individualities of style that permit author identification from the characteristics of texts (Foster, 1996), in promoting the unintended and unwanted echoes of another's language in unconscious plagiarism (Brown & Murphy, 1989), in supporting ongoing idiolect or dialect adaptations in individual speakers (S. J. Matthews, 1989; Reed & Cowan, 1989), and in driving language changes across history (Harris & Campbell, 1995; Kroch, 1989). It could even help to explain the strong tendency for languages to display abstract structural consistencies over phrases of various kinds (Dryer, 1992; Greenberg, 1966).

For such reasons, the nature of the mechanism behind

structural priming deserves more attention. The two experiments described here were designed to chart the time course of structural priming systematically, so as to better evaluate a transient-activation account of structural priming against an implicit-learning account. Relying on the priming paradigm described earlier, we varied the numbers of unrelated filler utterances that separated the priming sentences from the target trials. In both experiments, the prime immediately preceded the target picture on one third of the trials. In Experiment 1, another third of the priming trials were separated from the target by a single filler trial, and on the remaining third, by two filler trials. In Experiment 2, the separations (lags) were increased to 4 and 10 fillers. Dative and transitive sentences were used as prime and target sentences in both experiments. The experiments together made it possible to gauge changes in the magnitude of immediate priming for two sentence types when filled delays were interposed that included 1 to 10 other events. If priming is short-lived, based perhaps on an activated memory representation of the priming sentence, then the magnitude of any priming effect is expected to fall off steeply with any interruptions between primes and targets. A slow decline, or no decline, suggests a persistent change consistent with regarding priming as a type of learning.

Experiment 1: Priming Over Short Lags

Method

Participants. Students from the University of Illinois took part in the experiment. In return, they received either a $5 payment or partial credit toward fulfillment of an introductory psychology course requirement. A total of 72 students (out of approximately 86 tested) were included in the analyses. The remainder were excluded because of equipment failures (7) or insufficient numbers of codable picture descriptions (7).

Materials. The primary materials for the experiment consisted of a set of 86 pictures (line drawings of simple events) and a set of spoken sentences. There were 48 experimental pictures, listed by picture type in Appendix A. Half of them were selected to elicit simple active-transitive sentences (e.g., "An ambulance is hitting a policeman") and full passive sentences (e.g., "A policeman is being hit by an ambulance"). These pictures illustrated events involving two principals, generally a nonhuman or inanimate source or initiator of an action (the ambulance in the aforementioned example), and an animate or inanimate undergoer of the action (the policeman in the example). The other half of the experimental pictures were selected to elicit prepositional dative sentences (e.g., "A boy is giving an apple to a teacher") and double-object dative sentences (e.g., "A boy is giving a teacher an apple"). These pictures showed events involving three principals, typically a human initiator of an action (the boy), an object undergoing the action (the apple), and a human beneficiary of the action (the teacher). Another 36 pictures served as fillers, and 2 others served as practice items. The events in these pictures typically included a single animate actor and were commonly described with intransitive sentences (e.g., "A woman is ironing").

Description norms were collected for 47 of the 48 experimental pictures (all 24 of the dative pictures and 23 of the 24 transitive pictures; the remaining picture was inadvertently omitted). These norms were gathered by asking students (none of whom participated in the main experiments) to describe the events portrayed in a large set of assorted pictures. The pictures were presented in a randomly ordered list and displayed on a computer screen. The students typed their descriptions on the computer keyboard. The median use of simple transitive (passive or active) descriptions for the transitive pictures was 56%, with a range between 32% and 94%. Within the set of transitive descriptions, the mean proportions of passives and actives were .42 and .58, respectively. The median use of dative (prepositional or double object) descriptions for the dative pictures was 54%, with a range between 29% and 93%, and the mean proportions of prepositional and double-object forms were .43 and .57, respectively. On the basis of these norms, the less frequently used sentence forms (the passives and prepositional datives) were designated as the experimental targets. The corresponding active and double-object datives were designated as the alternative forms.

The sentence primes for the experimental pictures came from a set of 48 sentence pairs. Half of the pairs were transitive sentences, and the other half were dative sentences. The transitive pairs were actives and their full-passive counterparts, with the same content words in different syntactic structures. For the actives, the basic structure comprised a subject noun phrase and a transitive verb phrase containing a direct-object noun phrase (e.g., "A gang of teenagers mugged the building manager"). The passive counterpart ("The building manager was mugged by a gang of teenagers") contained a subject noun phrase (identical to the direct object of the corresponding active, "the building manager"), a verb phrase (the passive form of the active's verb, "was mugged"), and a prepositional phrase with a noun phrase (identical to the subject noun phrase from the active, "a gang of teenagers") after the preposition *by*.

The 24 dative pairs were prepositional datives and their double-object counterparts, also with the same content words in different structures. The prepositional-dative structure (e.g., "The credit card company mailed an application to the student") included a subject noun phrase, a dative verb, a direct-object noun phrase, and a prepositional phrase beginning with *to* or *for* followed by a noun phrase. The corresponding double-object form (e.g., "The credit card company mailed the student an application") was the same up to and including the verb. The verb was followed by a noun phrase (the first object noun phrase, identical to the noun phrase from the prepositional phrase in the prepositional-dative form; *the student*) and then another noun phrase (the second object noun phrase, identical to the direct object in the prepositional dative; *an application*). Appendix B lists the priming sentences used to elicit the target forms.

In addition to the priming sentences, a set of 55 sentences served as placeholders for the lag manipulation, and a set of 48 foil sentences was used to implement the memory cover task. The placeholder sentences consisted of intransitives (e.g., "The real estate agent blundered") and predicate adjectives (e.g., "The books were expensive"). The foils were derived from the priming sentences by replacing or reversing content words to create changes in the meanings of the sentences. Two additional sentences, neither of them in the critical syntactic structures, served as practice and example items for the instructions.

All of the sentence materials were digitally recorded at a sampling rate of 22 Hz by a male speaker of North American English. The recordings were checked for fluency, naturalness of intonation and pronunciation, comprehensibility, and uniformity. Any sentences that did not meet these criteria were recorded and checked again. The resulting sound files were stored on disk for analog-converted presentation during the experimental sessions.

Each pair of priming sentences from the transitive and dative sets was coupled with an experimental picture of the same type to form 48 priming items. The constraints on these couplings were that (a)

the primes and the expected picture descriptions did not share any content words, and (b) there were no obvious thematic or narrative relationships between the priming sentences and the anticipated descriptions.

These materials were arranged and presented as mixed lists of pictures and sentences. Each of the two lists contained 48 priming trials consisting of two placeholder sentences, a single priming sentence, the experimental picture, and a foil sentence. Dative and transitive pictures alternated throughout each list so that participants never encountered two pictures of the same type on successive priming trials, and the two different forms of each prime type also alternated, yielding the rotation double-object dative, active, prepositional dative, and passive. The order of the priming trials was the same on both lists.

The priming trials were separated by one filler picture. For the purposes of the cover memory task, 12 of the 36 filler pictures and 41 of the 55 placeholders were repeated once in the course of the list. The same filler pictures occupied the same list positions for all participants. The assignments of specific placeholders to list positions were made randomly for each participant, and the selection of the placeholders to be repeated was also made randomly for individual participants. Including the repetitions, a total of 288 items occurred in each list.

The assignments of priming sentences to lists were counterbalanced so that every list contained only one sentence from each of the 48 priming-sentence pairs. Equal numbers of sentences in each of the four priming forms (active, passive, prepositional, and double object) occurred on each list.

The foils were also counterbalanced so that on one quarter of the trials they were identical to the primes, on another quarter they were the same in meaning but different in structure (i.e., the foil was the prime's structural pairmate), on another quarter they were different in meaning but not structure, and on another they differed in both meaning and structure. The consequence of the foil counterbalancing was that participants who received each of the two lists were further divided into four groups so that equal numbers received each of four foils for each item, and each participant received one instance of each foil type in each cell of the experimental design. Foil counterbalancing was conducted for reasons related to a companion experiment with somewhat different aims. Because this counterbalancing was immaterial to the purposes of the current work and because its effects did not interact with the factors of primary interest, we omit further details of the manipulation here and in the subsequent experiment and focus on the results of analyses that pooled the data from different foil types.

Procedure. The structure of each priming trial is shown in Figure 1 for the Lag-0 condition. The trial began with two consecutive placeholder sentences followed by a priming sentence, an experimental picture, and then a foil sentence. On all sentence trials, the participants listened to the sentence, repeated it aloud, and indicated whether the sentence had occurred previously in the course of the experiment. This was the procedure on every sentence trial, regardless of whether the sentence was a placeholder, a prime, or a foil, so that the trial types were indistinguishable to the participants. On picture trials, the participants described what was happening in the depicted event and then indicated whether the picture had occurred previously in the course of the experiment. As for the sentences, the procedure on the picture trials was the same for experimental and for filler pictures so that these trials were also indistinguishable from the participants' perspective.

The Lag-1 condition differed from the Lag-0 condition in just one respect: The priming sentence and the placeholder preceding it exchanged places in the list so that the placeholder separated the priming sentence from the experimental picture. In the Lag-2 condition, the priming sentence occurred before the first of the two placeholders so that both placeholders separated the priming sentence from the experimental picture.

The amount of real time that elapsed between the priming-sentence onsets and the onsets of the experimental-picture descriptions was calculated using the actual durations of the priming and placeholder sentences, the estimated durations of the sentence repetitions, a conservative estimate of repetition- and description-initiation times (500 ms for each), and the mean recognition-decision times. The approximate minimum time intervals at each lag averaged 9.0 s at Lag 0, 15.2 s at Lag 1, and 21.3 s at Lag 2.

All of the events during the experiment were controlled by a Macintosh Quadra 650 running PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants used the PsyScope button box to proceed through the experimental lists. Trials began when the participants pressed the green button on the button box. On sentence trials, pressing the green button caused the message "Listen and repeat" to be displayed for 500 ms on the computer monitor. Then a sentence was presented auditorily. At the offset of the auditory sentence, the word "Repeat" appeared on the monitor, cuing the participant to depress a yellow button and reproduce the sentence from memory. When the reproduction was complete (signaled by the participant's releasing the yellow button), the monitor displayed the question "Have you heard this sentence before?" The display terminated when the participant pressed the red ("no") or green ("yes") button on the button box.

On picture trials, the first event after the initiation of the trial was the display of the word "Describe" on the monitor. This served as another cue to the participant to depress the yellow button, which in turn caused a picture to appear on the monitor and remain there while the pictured event was described. After the description, when the yellow button was released, the question "Have you seen this picture before?" appeared and remained until a "yes" or "no" response was made on the button box.

Participants' repetitions and picture descriptions were recorded with Shure SM10A headset microphones connected to a Radio Shack CTR-69 cassette recorder. The audio output from the computer was played through a Realistic SA-10 solid-state amplifier and a Realistic 40-1996B speaker.

Experimental sessions for each participant were conducted individually. Participants were told that their task would be to listen to sentences and look at pictures presented in a continuous list and to try to detect all of the repetitions of the sentences and pictures. They were also asked to repeat each of the sentences aloud and to describe what was happening in each picture. The instructions for the descriptions were simply to "use just one sentence and try not to use any pronouns," in all other respects leaving the participants free to decide for themselves what to say and how to say it. Two examples (one picture and one sentence) were presented as part of the instructions, and two practice items (one picture and one sentence) were presented after the instructions. None of these pictures or sentences elicited the critical sentence constructions.

The experimenter occupied an adjoining room during the experimental session. The computer monitor was visible to the experimenter through a two-way window, and the participant's speech was audible over an intercom. However, the experimenter and participant were not in face-to-face contact.

Design. Every participant received a set of four different experimental pictures in each of the 12 cells of the experimental design. The design crossed the factors of picture type (dative or transitive), prime form (target or alternative sentence form), and lag (0, 1, or 2). For items (where an item is defined as the combination of an experimental picture with either the target or the alternative form on a priming sentence), there was one nested factor of sentence type (dative or transitive). Every item of both types was

presented to 12 participants in the 6 cells of a design formed by crossing the factors of prime form and lag.

Scoring. The participants' repetitions of the priming sentences and their descriptions of the experimental pictures were transcribed from the audiotapes of the experimental sessions and coded. The transcriptions were word-for-word renditions of the participants' utterances, including speech errors, hesitations, and dysfluencies.

The priming sentences were examined for accuracy of reproduction. The majority of the 3,456 reproductions (92%) were fluent repetitions of the priming sentences, produced just once with no prompting from the experimenter and containing no more than minor deviations from verbatim accuracy. The deviations included changes in inflections (e.g., a plural word replacing a singular, or vice versa), changes in closed-class words (e.g., a definite article replacing an indefinite, or vice versa), hesitations, and speech errors that were corrected within one word of the error. An additional 6% of the reproductions contained isolated content-word substitutions or deletions but without changes to the global syntactic configuration of the priming sentence. For example, the passive prime "The players are being assisted by a union leader in organizing the strike," remained passive when reproduced as "The players are assisted by a union leader in organizing a strike," and the double-object prime "The cocktail waitress served the tired executive a martini," remained a double-object dative when reproduced as "The cocktail waitress served the tired businessman a martini." These were also treated as satisfactory reproductions. The remaining 2% of the attempted reproductions did not meet these criteria and were omitted from subsequent coding and analysis.

When the prime reproduction was satisfactory, the following picture description was coded for syntactic form. To be eligible for coding, the description had to include an appropriate number of noun phrases mentioning key actors from the pictured event (two for transitive events and three for dative events) and a verb of the relevant type (transitive or dative, respectively). If a description contained more than one clause, the clause that was coded was the first one that included the right number of key actors (e.g., in "There's an accident and a nurse is getting hit by a truck," the coded clause was "a nurse is getting hit by a truck"). Apart from speech errors that left syntactic structure intact, the major category of permissible deviations from canonical English sentence structure comprised omissions of articles (e.g., *a, the*) and auxiliary verbs (e.g., *is, are, were*), so that telegraphic descriptions such as "nurse getting hit by truck" were considered acceptable. For transitive pictures, the utterances used to describe them were scored as *active, passive,* or *other.* To be coded as an active, the major criterion was that the relevant clause had to have an acceptable passive counterpart (e.g., "a truck is hitting a nurse" has the passive counterpart "a nurse is being hit by a truck"). Ordinarily, this meant that the clause contained at least two noun phrases, one of which was a subject representing the source (agent, instrument) of the depicted action, and the other was a direct object representing the destination (patient, theme, recipient) of the action and a transitive verb. To be coded as a passive, the clause had to contain a passive verb form (i.e., a main verb preceded by a form of *be* or *get*) followed by a *by-phrase* (i.e., a prepositional phrase headed with the preposition *by*). In addition, the clause had to have an acceptable active counterpart. This meant that the subject usually represented the destination of the action, and the object of the preposition *by* usually represented the source of the action. From the 1,728 transitive trials, 71% of the utterances fell into one or the other of these categories, with 585 coded as actives and 645 as passives.

For dative pictures, the utterances used to describe them were scored as prepositional datives, double-object datives, or other. Analogous to the transitive scoring, prepositional datives had to have acceptable double-object counterparts, and double objects had to have acceptable prepositional counterparts (e.g., the prepositional dative "a woman is showing a dress to a man" has the double-object counterpart "a woman is showing a man a dress"). This required an alternating dative verb with a minimum of three noun phrases (roughly, a subject representing the source of the action, an object representing the destination, and a second object representing something transferred or transferable). Structurally, prepositional datives contained a subject, a dative verb, a direct object (representing the thing transferred), and, after the direct object, a prepositional phrase beginning with *to* or *for* (representing the destination). Double-object datives contained a subject, a direct object (representing the destination), and a second object (representing the thing transferred). From the 1,728 dative trials, 80% of the utterances fell into one or the other of these categories, with 666 coded as prepositional datives and 705 as double-object datives.

All utterances that fell outside of the four structural categories were coded as other and omitted from analysis. Taken together with unsatisfactory prime reproductions, 25% of all trials were omitted.

The reliability of the coding was assessed by having two judges score all of the utterances. There was 98% agreement between the judges, with all discrepancies resolved by discussion.

Analyses. The dependent measures in the main analyses were the number of target (i.e., passive or prepositional dative) structures produced in describing the experimental pictures, represented as a proportion of all the coded sentence structures of a particular type (either transitive or dative). For example, if a participant used two passives and one active in describing the transitive pictures in one cell of the design, the participant's score for that cell would be .67. Similarly, if a particular transitive picture were described with five passives and four actives in one cell of the design, the item's score in that cell would be .56.

Separate analyses of variance (ANOVAs) were conducted treating participants and items as random effects. An additional set of analyses was performed on the arcsine-transformed proportions of responses (Smith, 1976) for both participants and items. Because the results of these additional analyses were virtually identical to those on the raw proportions, we have omitted them from this and the next experiment. In the analyses we report, effects were treated as significant when the probabilities associated with them were less than or equal to .05.

Results

Figure 2 shows the overall priming effect at each of the three lags, in terms of the proportions of target structures (passives and prepositional datives) that were produced after target-structure or alternative-structure primes (respectively, the primed and unprimed conditions). At every lag, there was a higher probability of producing the primed structure than the unprimed, and the magnitude of the priming effect showed little change over the longer lags. Reflecting these patterns, the priming effect was significant and did not interact with lag in the ANOVAs. The proportion of primed structures (.55) was larger than that of unprimed structures (.48), $F_1(1, 71) = 7.94$; $F_2(1, 46) = 13.17$, and the magnitude of the difference was roughly the same at each of the three lags (.05, .08, .07 at Lags 0, 1, and 2, respectively), making the interaction between lag and priming nonsignificant, $F_1(2, 142) = .09$; $F_2(2, 92) = 1.00$. The only detectable effect of lag was a general tendency for a higher proportion

of target structures to be produced at longer than at shorter lags (.49 at Lag 0, .52 at Lag 1, and .54 at Lag 2), and this was significant in the participants analysis only, $F_1(2, 142) = 4.32$; $F_2(2, 92) = .95$.

The mean proportions for each of the two sentence types (dative and transitive) are given in Table 1. Although the two types did not behave identically (most noticeably, transitives gave no evidence of priming at Lag 2), the interaction between sentence type, prime type, and lag was not significant, $F_1(2, 142) = 1.54$; $F_2(2, 92) = 1.31$. There was a tendency for datives to yield larger priming effects than transitives (.06 compared with .03, respectively), but the corresponding interaction was significant only for items, $F_1(1, 71) = 1.76$; $F_2(1, 46) = 4.87$. None of the other main effects or interactions approached significance.

Table 1
Proportions of Target Syntactic Structures Produced After Target and Alternative Primes Over Three Lags (Experiment 1)

Utterance and priming form	Lag 0	Lag 1	Lag 2	*M*
Dative				
Prepositional dative (target)	.48	.54	.61	.54
Double-object dative (alternative)	.43	.42	.47	.44
Transitive				
Passive transitive (target)	.55	.58	.54	.56
Active transitive (alternative)	.49	.54	.54	.52

Discussion

These results establish that structural priming can persist over short filled intervals. Because other utterances were produced during these intervals, this suggests that structural priming is not easily disrupted by general interference from other production events. The absence of any clear-cut reduction in the magnitude of the effects between the immediate and delayed conditions also argues against fast decay of priming.

Further evidence for the persistence of priming came from analyses that considered the effects of the foils used for the cover memory task. As we noted in the Methods section, the foils were included for purposes ancillary to those of the present experiment and their effects did not interact with any other factors. So for simplicity, we pooled the data from different foil types in the analyses carried out and reported in connection with Experiment 1. Still, it is possible to use the foils to prospect for long-distance priming effects.

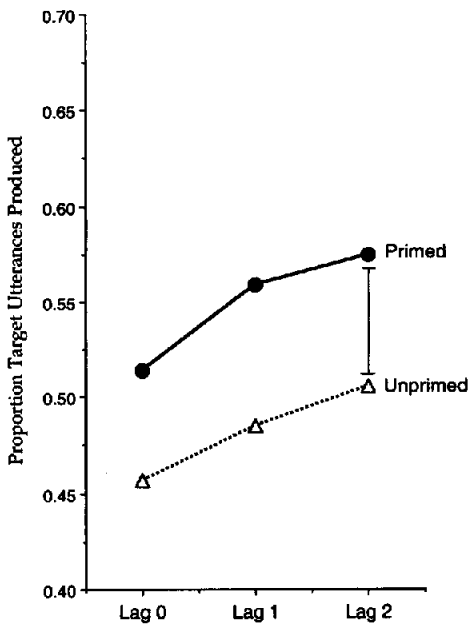

Figure 2. Structural priming across 0, 1, or 2 intervening sentences (lag) after structure-matching (primed) or structure-mismatching (unprimed) priming sentences. The error bar represents the 95% confidence interval for a pairwise planned comparison (.062), as calculated from the error term for the interaction between prime type and lag in the analysis of variance by participants.

Recall that a foil sentence was presented on every priming block in the experiment. The foil always followed the experimental picture as the last event in each priming block and, correspondingly, preceded the next experimental picture of the same kind by 10 trial events (including a priming block for the other sentence type, either dative or transitive). Because the foils always had either the same structure as the preceding prime or the same structure as the prime's alternative, it is possible to determine whether the structure of the foil itself affected the structure of the next produced critical sentence, 10 trials later. We call this a *remote-foil* effect. On the 46 trials that were preceded by remote foils (the initial experimental trials for each sentence type lacked a preceding foil, of course), the structure of the subsequent sentence matched the structure of the remote foil in .52 of the scorable responses and mismatched in the remaining .48, independent of the structure of the intervening prime itself. The effect held at the same magnitude for both datives (.52 to .48) and transitives (.52 to .48) and was significant by participants in an ANOVA that included remote-foil structure as a factor, $F_1(1, 71) = 7.10$; $F_2(1, 44) = 2.57$. This unanticipated long-distance echoing of foil structure hints that priming may persist in some form across at least 9 intervening trials.

One other aspect of the results from Experiment 1 is worthy of note, having to do with differences between the dative and transitive structures. As in earlier experiments (Bock, 1986; Hartsuiker & Kolk, 1998b), the datives generally yielded clearer patterns of priming than the transitives. Although the differences between the two structures in the magnitude and persistence of priming did not reach statistical significance, transitive priming was absent at the longest lag and was on the whole somewhat weaker than for datives.

Other signs of this variability came from a pilot experiment in which lag was varied between rather than within subjects. In most other respects, the preliminary experiment was identical to the present one in materials and methods. The results were also similar: Table 2 shows the priming effects, expressed as differences between the primed and

Table 2
Summary of Priming Effects Over Lags for Datives and Transitives

Utterance type and experiment	Lag 0	1	2	4	10
Dative					
Experiment 1	.05	.12	.14	—	—
Experiment 1 pilot	.09	.11	.10	—	—
Experiment 2	.12	—	—	.07	.10
Transitive					
Experiment 1	.06	.04	.00	—	—
Experiment 1 pilot	.00	.06	−.01	—	—
Experiment 2	.16	—	—	−.05	.05

Note. Priming effects are expressed as the differences between the proportions of target utterances in the primed conditions compared with the unprimed conditions. Dashes mark lag conditions that were absent from the corresponding experiments.

unprimed conditions, for datives and transitives at each lag in Experiment 1 and the pilot experiment. The datives exhibited consistent priming at all lags; the transitives showed little or no priming in three of the six lag conditions. Because there was no transitive priming at the longer lag in either experiment, it is tempting to suggest that transitives may be more vulnerable to decay, inhibition, or interference. However, this is inconsistent with the results of the remote-foil analysis and with findings from other laboratories (Boyland & Anderson, 1998; Hartsuiker & Kolk, 1998a; Saffran & Martin, 1997), where stronger or longer lasting priming has sometimes been found for transitives than for datives. Likewise, the absence of priming at Lag 0 in the preliminary experiment argues against a simple decay or interference account. We come back to these problems in the General Discussion.

To return to the main point, the existence of structural priming beyond the immediate Lag-0 condition indicates that priming can, in some circumstances and for some structures, survive the effects of time and of intervening events. In Experiment 2, we pressed the limits of this persistence further.

Experiment 2: Priming Over Longer Lags

The second experiment was conducted in an effort to better assess the duration of priming and to obtain answers to some of the questions raised by the first experiment. The finding that structural priming can persist beyond a speaker's immediate experience with a construction is in line with some previous observations of structural repetition over nonconsecutive utterances in spontaneous conversation (Estival, 1985; Weiner & Labov, 1983) and in experimental settings (Bock & Kroch, 1989; Boyland & Anderson, 1998), but as yet the limits of the persistence have not been established.

In Experiment 1, there was no clear decline in the magnitude of the priming effect for datives. Indeed, the trend was for priming to increase over lags. This is superficially at odds with Levelt and Kelter's (1982, Experiments 2 and 3) results which, if interpreted as a reflection of structural priming, point to a substantial short-term component of priming that is vulnerable to interference from an interrupting clause. Furthermore, the tendency for passives in the first experiment was different and more indicative of a degradation in priming. Experiment 2 again included both sentence types to explore any differences between them at longer lags.

A third goal of the experiment was to assess whether longer term structural priming encourages the use of the primed structure, discourages the use of the unprimed structure, or both. Bock (1986, Experiment 1) used a neutral condition in which intransitives served as immediate primes for datives and found that the production of target structures in the neutral condition fell roughly midway between the primed and unprimed conditions (see also Branigan, Stewart, & Pickering, 1998). Experiment 2 included the same kind of neutral condition to determine whether and how this effect changes over longer lags.

Method

Participants. Students from the University of Illinois again took part in the experiment, receiving either a $5 payment or partial credit toward fulfillment of an introductory psychology course requirement. Of 179 students tested, 144 were included in the analyses. None of them had participated in Experiment 1 or its replication. The remaining participants were excluded because of equipment failures and experimenter errors (7) or low rates of codable picture descriptions and prime repetitions (28).

Materials. The materials for the experiment were comparable to those used in the previous experiment, with four changes made to implement the longer lags between the priming sentences and experimental pictures. One change was in the number of priming trials. From the 48 item sets in Experiment 1, 12 were eliminated. The 36 sets that remained included 18 of each of the two structural types, transitive and dative, selected from those that yielded the lowest percentages of other responses in Experiment 1. (In the preliminary norms, the dative pictures retained for Experiment 2 yielded a median of 63% dative descriptions, .40 prepositional dative to .60 double-object dative, and the transitive pictures yielded a median of 76% transitive descriptions, .46 passive to .54 active.) This selection was done to maximize the sensitivity of the experimental contrasts. The 36 item sets were then divided into two groups of 18 (half transitive and half dative) for presentation to different participants. These changes made the lengths of the experimental lists suitable for 50-min sessions.

A second change affected the placeholders. An additional 67 of these placeholders were created and recorded, with the same guidelines as in the first experiment. The new placeholders were used in addition to (or, in two instances, as replacements for) the placeholders from Experiment 1. The third change was in the number of filler pictures. As part of the effort to keep the list lengths wieldy, only 13 filler pictures were used, with 5 repeated. Finally, the number of foil types was reduced to two, one different in structure from the prime and the second different in both structure and meaning.

To create a neutral priming condition, we added a single intransitive priming sentence (shown in Appendix B) to each item set. The criteria for coupling these neutral primes with accompanying pictures were the same as for the transitive and dative primes. All 36 neutral sentences contained a subject noun phrase with an intransitive verb, alone or with an adverb. For each of the neutral sentences, a foil was created by changing a content word so that the

meaning of the foil differed. The neutral primes and foils were recorded according to the procedures described for Experiment 1.

These materials were arranged and presented as mixed lists of pictures and sentences. Each of the four lists contained 18 priming trials. The trials consisted of 10 placeholder sentences, a single priming sentence, the experimental picture, and a foil sentence. Foils were assigned to priming trials so that in a given list there was an equal number of structure-changing or meaning-and-structure-changing foils (approximately balanced within sentence types) and, across lists, each prime occurred equally often with its structure-changing and its meaning-and-structure-changing foil. Each neutral prime was always accompanied by its meaning-changing foil. These foil manipulations, like those in the first experiment, were carried out in connection with a companion project and will not be discussed further.

The priming trials were separated by 1 filler picture. For the purposes of the cover memory task, 5 of the 13 filler pictures and an average of 60 of the 120 placeholders were repeated once in the course of the list. The same filler pictures occupied the same list positions for all participants. The assignments of specific placeholders to list positions were made randomly for each participant, and the selection of the placeholders to be repeated was also made randomly for individual participants. Including the repetitions, a total of 252 items occurred in each list.

The assignments of priming sentences to lists were counterbalanced so that each list contained 1 sentence from half of the 36 priming-sentence triples (including the neutral primes) and equal numbers of sentences in each of six priming forms (active, passive, neutral, and prepositional, double object, neutral). Across lists, every form of each of the priming sentences was presented once. Transitive and dative pictures alternated throughout each list so that participants never encountered two pictures of the same type on successive priming trials. In addition, the order of the priming sentences was counterbalanced so that half of the participants received target forms of the primes before the alternative forms and then a neutral prime, and the other half received the primes in the order alternative–target–neutral. These counterbalancings created 12 basic list arrangements, not including the foil or lag manipulations.

Procedure. The priming trial-structure differed from that in Experiment 1 in just one important respect that was designed to create the longer lags. Instead of the 2 placeholders that occurred on each trial (see Figure 1), there were 10 placeholders. In the Lag-0 condition, all of the placeholders preceded the priming sentence. In the Lag-4 condition, 6 placeholders preceded the prime and 4 followed; for Lag-10, all 10 placeholders followed the prime. The average amounts of time that elapsed in each lag condition, conservatively estimated as described in the first experiment, were 7.7 s at Lag 0, 33.3 s at Lag 4, and 71.8 s at Lag 10.

The events on each trial were the same as in the first experiment, and instructions to participants were also the same. The 12 basic lists each included equal numbers of trials at each of the three lags, for each of the priming sentence types. Every basic list was repeated three times so that every item was presented once at each lag. In total, there were 36 separate priming lists.

Design. Every participant received one experimental picture in each of the 18 cells of the experimental design. The design crossed the factors of picture type (dative or transitive), prime form (target, alternative, or neutral sentence form), and lag (0, 4, or 10). Every item was presented to 72 participants in the 9 cells of the design formed by crossing the factors of priming form and lag. Picture type was a between-items factor.

Scoring. The participants' repetitions of the priming sentences and their descriptions of the experimental pictures were transcribed from the tapes of the experimental sessions and coded as in the first experiment. The 2,592 priming-sentence reproductions included 2,388 fluent repetitions of the priming sentences and an additional 181 structure-preserving repetitions for a total of 99% satisfactory reproductions of priming sentences. The remainder of the attempted reproductions were inadequate, and the trials on which they occurred were omitted from subsequent coding and analysis.

The coding of the picture descriptions from the trials with satisfactory prime reproduction yielded 406 actives and 610 passives from the 1,296 transitive trials. From an equivalent number of dative trials there were 452 prepositional datives and 591 double-object datives. There was 93% agreement in the use of these structural categories between one judge who scored all of the picture descriptions and a second who scored 80% of the descriptions. The discrepancies between them were examined and resolved by Zenzi M. Griffin.

The 510 utterances that did not fall into these structural categories were coded as "other" and omitted from the analyses. Taken together with unsatisfactory prime reproductions, 21% of all trials were omitted.

Analyses. As in Experiment 1, the dependent measures in the main analyses were the number of target (i.e., passive or double object) structures produced in describing the experimental pictures, represented as a proportion of all the coded sentence structures of a particular type (either transitive or dative). To reduce the number of cells with no observations, we paired participants who received the same experimental lists as what we term *participant twins,* each pair treated as a single participant for purposes of data analysis. After conducting this pairing, we replaced missing observations, using the procedure described by Winer (1971, p. 488), for 19 participant twins in 27 cells and for four items in 9 cells.

Separate ANOVAs were conducted in which participant twins and items were treated as random effects. The confidence intervals for planned and post hoc comparisons were calculated as before, and effects were again treated as significant when the probability associated with them was less than or equal to .05.

Results

Figure 3 displays the proportions of target structures produced at each lag when preceded by a target-structure sentence (primed), by an alternative-structure sentence (unprimed), or by an intransitive sentence (neutral). Overall, the proportions of target structures produced were .55 in the primed condition, .52 in the neutral condition, and .48 in the unprimed condition. The effect of priming was significant, $F_1(2, 140) = 3.77$; $F_2(2, 68) = 5.13$, and, despite the anomaly in the primed condition at Lag 4, the interaction with lag was not significant in the participants analysis, $F_1(4, 280) = 1.24$, and was only marginal in the items analysis, $F_2(4, 136) = 2.01, p < .10$. The 95% confidence interval for a planned pairwise contrast between the priming conditions at each lag is also shown in Figure 3. The primed and unprimed conditions differed from each other except at Lag 4 but from the neutral condition only at Lag 0.

The results for the individual sentence types are given in Table 3. More transitive than dative targets were produced in all conditions (.61 and .42, respectively), $F_1(1, 70) = 31.46$, $F_2(1, 34) = 7.64$, but the type of structure did not interact significantly with priming or with lag (all $F_1 < 1.04$; all $F_2 < 1$). No other main effects or interactions were significant.

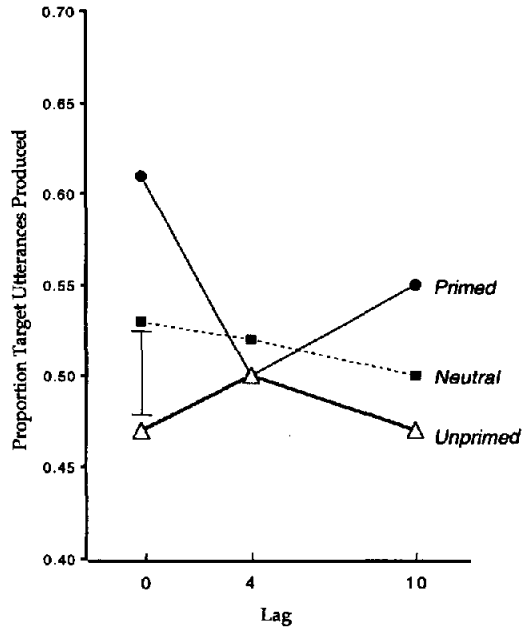

Figure 3. Structural priming across 0, 4, or 10 intervening sentences (lag) after structure-matching (primed), structure-mismatching (unprimed) priming sentences, or intransitive (neutral) priming sentences. The error bar represents the 95% confidence interval for a pairwise planned comparison (.048), as calculated from the error term for the interaction between prime type and lag in the analysis of variance by participants.

Lag 10 was roughly comparable with the magnitude at Lag 2 in Experiment 1 (see Figure 4).

Against a different benchmark, the intransitive primes, there was an overall reduction in the incidence of target sentences when the alternative structure was the prime at all three lags. At Lags 0 and 10 there was also a roughly corresponding increase in the incidence of targets when they were primed. This is analogous to Bock's (1986) result and, apart from the anomaly in the primed condition at Lag 4, suggests that the normal effect of the priming manipulation is to amplify the tendency to produce the primed structure.

A subsidiary goal of the experiment was to further assess the differences between the dative and transitive sentences in their responses to the priming manipulation. As in Experiment 1 and its pilot, the differences between the primed and the unprimed condition for datives were consistent across all three lags (see Table 2). Relative to the neutral condition, however, there was priming for the target structure only at the immediate and longest lags and for the alternative structure only at the immediate and intermediate lags. The transitives again exhibited substantial priming at the immediate lag, but at the longer lags the pattern became less stable. At Lag 4, passive targets were actually more likely to be produced in the unprimed than in the primed condition (the disappearance of priming at Lag 4 in the overall analysis, as shown in Figure 3, was chiefly due to the results for transitives). Then for the transitives at Lag 10, the difference between the primed and the unprimed condition reappeared, but relative to the neutral condition, only the

Discussion

Our primary goal in this experiment was to examine the persistence of priming over longer lags. Comparing the primed with the unprimed sentence structures, as we did in Experiment 1, there was reliable priming immediately after the presentation of the prime (at Lag 0) and after 10 intervening sentences of other kinds (Lag 10). In contrast, there was no evidence of priming after four intervening sentences, although the magnitude of the priming effect at

Table 3
Proportions of Target Syntactic Structures Produced After Target, Neutral, and Alternative Primes Over Three Lags (Experiment 2)

Utterance and priming form	Lag 0	Lag 4	Lag 10	*M*
Dative				
Prepositional dative (target)	.50	.43	.48	.47
Double-object dative (alternative)	.38	.36	.38	.37
Intransitive (neutral)	.45	.45	.37	.42
Transitive				
Passive transitive (target)	.72	.58	.62	.64
Active transitive (alternative)	.56	.63	.57	.59
Intransitive (neutral)	.61	.60	.63	.61

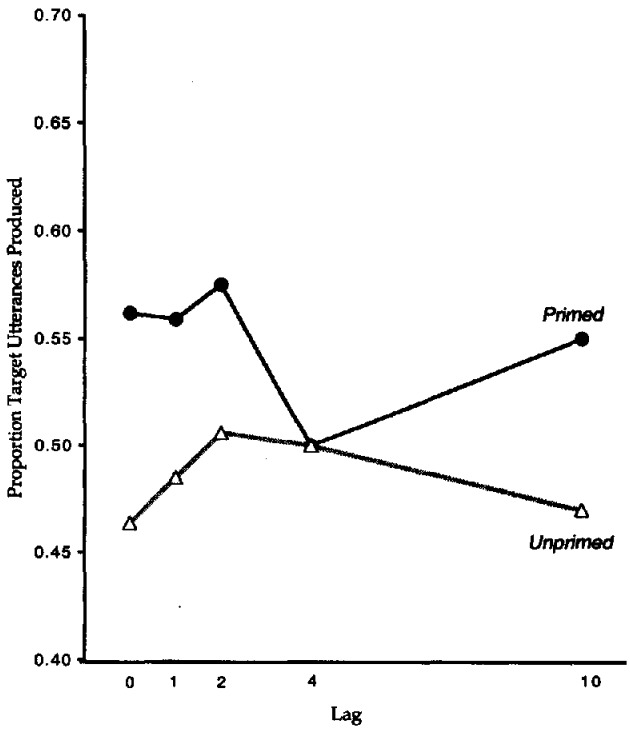

Figure 4. Overview of structural priming at lags spanning 0 to 10 intervening sentences.

alternative structure was responsible for the effect. In short, the priming patterns for the transitives were more complex than those for datives and, in most circumstances in the present experiments, were more fragile and shorter lived.

General Discussion

From one standpoint, the present effort to trace the time course of structural priming met with resounding failure. Over the intervals used in these experiments, there was no consistent decline in the magnitude of priming, although there were unstable changes at particular lags for particular sentence types, changes which may or may not be systematic. Setting these variations aside for the moment, the results suggest that structural priming may undergo no reliable degradation over a filled interval that includes as many as 10 interfering events. In contrast, the magnitude of semantic priming for single words decreases by 30% to almost 100% after just one intervening word in standard, explicit semantic priming tasks (e.g., Gough, Alford, & Holley-Wilcox, 1981; Joordens & Besner, 1992; McNamara, 1992), and verbatim memory for sentences is reliably disrupted in recall after a single intervening sentence or a 1.5-s interval (Jarvella, 1979; Potter & Lombardi, 1990). Recognition memory for sentence forms likewise deteriorates substantially after 7.5 s (Sachs, 1967, 1974).

From a different perspective, the findings make a strong argument for considering an explanation of structural priming in terms of learning rather than transient memory activation mechanisms. The implication of this claim is not simply that a change in performance persists, although it clearly does, but also that the change generalizes to new utterances involving different words. The relevant kind of learning appears to be implicit or procedural, inasmuch as it does not depend on specific intentions to replicate a sentence's structure in new words, does not require an effort to remember the priming sentence (Bock, 1986), and does not require explicit attention to the form of a priming sentence (Bock et al., 1992).

A more traditional indicator that structural priming may involve implicit or procedural learning comes from the absence of any clear dependence between direct and indirect measures of memory for sentence form. Following the logic of tests used to establish stochastic independence (Tulving & Schacter, 1990), the data from Bock et al. (1992) can be used to calculate the conditional probabilities of explicitly remembering a priming sentence's structure. In Bock et al. (1992), after speakers completed a priming session they received a forced-choice recognition memory test for the priming sentences. This made it possible to determine whether the effectiveness of the prime (as indicated by production of the primed form for the event description) was related to a speaker's ability to explicitly remember the priming sentence's syntactic form on the later recognition test.

These calculations revealed no evidence that priming facilitated subsequent recognition performance. The unconditionalized probability of correctly recognizing the priming sentence's form was .66. When the probability was calculated conditionalized on the prime's success in influencing the form of the picture description, the correct recognition rate changed only to .67. In addition, we calculated the conditional probability of priming given that the prime's form was explicitly remembered later, in the recognition test.[1] Again, the conditional probability of priming was the same as the unconditional probability of priming, .29 in both cases. Although these relationships constitute a notoriously weak test of independence between implicit and explicit memory performance (see Hintzman, 1991 for discussion), they offer some reassurance that any links between overt memory for the priming sentence and priming performance are likely to be subtle.

A different way to evaluate the learning hypothesis for structural priming is to attempt to simulate priming in a computational model that actually learns to produce sentences. Such a model can then be tested in an analog of the priming paradigm. Chang, Dell, Bock, and Griffin (2000; see also Dell, Chang, & Griffin, 1999) implemented a model that adapts the principles of parallel distributed processing to the circumstances of language production. The model explicitly incorporates a learning mechanism for priming, so that its priming performance depends on the same kinds of weight changes that are involved in its training. In other words, the mechanism of learning is identical to the mechanism of priming. Tests of a current model have shown that it reproduces most of the patterns of priming observed in previous work, as well as the persistence over trials found in the present experiments (Chang et al., 2000).

Some of the more specific questions raised by our findings have to do with apparent differences between sentence forms in their ability to prime or be primed and with variations in the persistence of priming that have been reported in the literature. We take up these questions in the next two sections.

How Do Transitives and Datives Differ?

Differences between transitives and datives in the magnitude or reliability of priming have been reported in other research (Bock, 1986; Boyland & Anderson, 1998; Hartsuiker & Kolk, 1998a, 1998b; Saffran & Martin, 1997). The best attested outcome in normal speakers is that datives are more likely to yield priming than transitives: In Bock (1986, Experiment 1), the overall priming effects were .22 for datives compared with .08 for transitives, and in Bock and Loebell (1990, Experiments 2 and 3), the respective effects were .15 and .05. For comparable structures in Dutch, the respective effects (as calculated from Hartsuiker & Kolk, 1998b, Tables 2 and 3) were .06 and .02. Despite the fairly consistent 3:1 advantage for datives across these experiments, others have found more reliable priming for transitives, particularly passives, than for datives (Boyland & Anderson, 1998; Saffran & Martin, 1997).

Although the present experiments lacked the statistical power needed to detect reliable differences between the forms, the numerical trends were consistent with previous

[1] We thank Rose T. Zacks for suggesting this calculation.

findings of weaker and less reliable priming for transitives. In both experiments, priming for datives was evident at all lags, whereas priming for transitives in some cases approached zero (with the pilot data for Experiment 1 included, the overall priming effect was .10 for datives and .03 for transitives; see Table 2). Relative to the neutral intransitive condition in Experiment 2, both forms of datives yielded priming effects of .05; the effect was .02 for actives and .03 for passives.

As yet, virtually nothing can be said with confidence about the sources of these disparities, in part because there are many plausible hypotheses and few data to address them. Datives and transitives differ in the number of arguments they express (three compared with two), in the relative frequencies of their alternative forms (actives are much more frequent than passives, whereas prepositional and double-object datives are in better balance[2]), in the restrictiveness of the forms (almost all transitive verbs in English can occur in either the active or passive voice, whereas only a small set of verbs can be used as datives of any kind), in their likelihood of occurrence (samples of speech may be even less likely to include datives of any kind than the already rare passive; Hartsuiker & Kolk, 1998a), in speakers' awareness of the forms and the alternations between them (due to prescriptions against the use of passives by composition instructors), in the magnitude of the morphological changes that accompany the alternation (both alternations involve a reversal of arguments and the addition or subtraction of a preposition, but passives also involve a change in the verb form and the addition of an auxiliary), and so on.

Among all of these possibilities, only the role of relative frequency has been evaluated. Hartsuiker and Kolk (1998b) found no consistent relationship between the baseline frequencies of using alternative forms for describing events and the magnitude of form priming for the same events. We replicated this result using our norms and the data from Experiment 1. By comparing the priming effect sizes for individual items with differences in the items' normative tendencies to elicit the alternative sentence forms, we examined whether the magnitude or persistence of priming was correlated with the strength of the bias toward or against the primed form. None of the correlations at any of the three lags were noteworthy ($rs = -.06$, .11, and $-.04$, respectively), and they were even weaker than the $-.21$ reported by Hartsuiker and Kolk (which was likewise nonsignificant). It appears that variations in existing preferences for one form over another have little or no relationship to variations in the magnitude of priming.

The Persistence of Priming

Although our results are consistent with several previous observations of the persistence of priming over time (Bock & Kroch, 1989; Boyland & Anderson, 1998; Hartsuiker & Kolk, 1998b; Weiner & Labov, 1983), they diverge from the findings reported by Levelt and Kelter (1982) and Branigan et al. (1999). Levelt and Kelter found priming beyond a single intervening clause or sentence only when their participants were encouraged to explicitly remember the priming sentences. It is important to consider how and why these results differ. Two factors that may be discountable are differences between Dutch and English (persistence in Dutch has been reported by Hartsuiker & Kolk, 1998b, although under circumstances quite different from those in Levelt and Kelter's research) and differences in the need to explicitly remember the form of the priming sentences, because persistence of priming has been found both in experimental tasks that discourage efforts to remember the primes (see Bock & Kroch, 1989) and in conversations where no special effort to remember sentence forms would be expected (Estival, 1985; Weiner & Labov, 1983).

Beyond these two factors, two critical differences between the present studies and those of Levelt and Kelter may be the lexical dependence of the observed priming effects and the lexically specific nature of the responses. Levelt and Kelter examined whether speakers used a preposition in their answers to questions as a function of whether the question contained the same preposition. Consequently, the answers varied in the presence versus the absence of the preposition, which in turn created prepositional phrases or bare noun phrases. If repeating the preposition depended on memory for the preposition itself (as Levelt and Kelter argued), and not on priming of the structure in which it occurred, one would indeed expect the effect to disappear after a single intervening clause, in line with the time course of memory for specific words. Similar factors may contribute to the rapid dissipation of priming in Branigan et al. (1999), where the responses included repeated verbs.

It is clear that lexical repetition can enhance structural repetition (Pickering & Branigan, 1998), although it does not seem to be essential to it (Bock, 1989). One conjecture is that there may be two different factors at work in these effects. The activation of specific words in immediate memory may help to support the reactivation of a recently used structure, creating structural repetition. However, when sentences are generated from nonverbal message representations, messages that can be expressed in either of two alternative ways may tend to be formulated in terms of primed procedures, reflecting structural priming. Differences in structural persistence would then follow from differences in the time courses of (a) explicit memory for repeated words and (b) priming created by implicit structural learning. Obviously, the merits of this hypothesis remain to be examined.

Learning To Talk

We interpret our results as suggesting that structural priming can arise within a system that is organized for learning how to produce sequences of words, as a consequence of the learning processes themselves. Seen in this

[2] Franklin Chang (personal communication) recently carried out a rough count of sentence structures in the Brown corpus (Kucera & Francis, 1967) that used any of a small set of dative verbs (*gave, sold, offered,* etc.). For these verbs, the ratio of actives to passives was approximately 7:1, and the ratio of double-object datives to prepositional datives was approximately 2:1.

light, structural priming is a dynamic vestige of the process of learning to perform language. We call this process *learning to talk,* in the completely literal sense of *talk.* It is not learning language but learning to produce it. In this sense, learning to talk involves learning procedures—cognitive skills—for efficiently formulating and producing utterances. What structural priming suggests is that these procedures may undergo fine-tuning in every episode of adult language production. Similarly, structural priming in language comprehension (e.g., Mehler & Carey, 1967; Carey, Mehler, & Bever, 1970) might be interpreted as *learning to understand.*

A broader explanation for this kind of priming in language performance may be rooted in a general theory of learning and memory. For better or worse, the nervous system stores traces of actions, both covert cognitive processes and overt behaviors. Sometimes this retention leads to efficacy with practice; sometimes it leads to blunders with perseveration. Whether good or bad, there need be no specific linguistic motivation for the existence of structural priming.

There may, however, be specific linguistic consequences. In particular, it is interesting to speculate about whether such learning plays a part in children's language development. There is increasingly clear evidence that structural priming occurs in very young language users (Brooks & Tomasello, 1999; Whitehurst et al., 1974), and in rudimentary form, may even be discernible in the responses of infants (Marcus, Vijayan, Rao, & Vishton, 1999). In other linguistic domains, there is evidence for implicit priming of auditory word forms in both adults and toddlers (Church & Fisher, 1998). At a minimum, structural priming may help to broaden a child's ability to use known sentence structures for expressing new and different ideas. In other words, it supports generalization. What is less clear, and more central to traditional problems of language acquisition, is how these generalizations are constrained. Children's overgeneralizations of certain sentence structures do not appear to abate along the lines that current, influential theories of language acquisition would predict (as Bowerman, 1996, showed). Although structural priming by itself offers no clues to the solution of this puzzle, further research on dependencies between structural priming and lexical repetition may help to illuminate how experience with language interacts with developing language knowledge to explain changes in how children use language.

Conclusions

Our results suggest that structural priming persists over intervals that are fairly long by the standards of normal limitations on explicit memory for sentence form, either in recall (Bock & Brewer, 1974) or recognition (Sachs, 1967). More surprisingly, under the conditions of our experiments, there were no reliable declines in the strength of priming. These findings are consistent with an account of structural priming in terms of experience-dependent adaptations to the mechanisms of language production, mechanisms that are organized for producing sequences of words to express particular messages. We interpret these adaptations as a form of implicit learning.

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Appendix A

Experimental Pictures

Transitive-Eliciting Pictures

bee stinging man
*tornado destroying barn
*baseball hitting boy
wave engulfing woman
jack-in-the-box startling little girl
*rock breaking window
alarm clock awakening boy
dog chasing mailman
lightning striking church
*runaway bicycle approaching pedestrian
*crane demolishing building
missile attacking airplane
ambulance striking policeman
wind blowing off man's hat
whale swallowing man
train approaching woman tied to railroad tracks
cat biting veterinarian
truck bumping nurse
fire hydrant squirting fireman
shark attacking man
*avalanche approaching skiers
tank running over soldier
torpedo hitting ship
truck towing car

Dative-Eliciting Pictures

*woman showing dress to man
boy giving valentine to girl
children showing picture to teacher
boy handing guitar to rock singer
girl throwing bone to dog
*librarian handing book to boy
children giving flowers to man
girl handing paintbrush to boy
mother giving ice-cream cone to son
*lawyer showing gun to judge
waitress handing menu to customer
boy giving apple to teacher
*nurse handing stethoscope to doctor
*nurse giving water to patient
girl tossing banana to boy
salesman showing car to customers
girl handing cup to boy
mother giving lunchbox to daughter
girl showing paper to boy
policeman writing traffic ticket for driver
girl handing plate to boy
boy passing pitcher to girl
girl giving bouquet to teacher
*waitress offering cocktails to men

Note. Asterisks indicate pictures that were used in Experiment 1 only.

(*Appendixes continue*)

Appendix B

Priming Sentences (for Target Forms Only)

Transitive Target Primes

A compromise is being suggested by the chairperson.
*The referee was punched by one of the fans.
*The returning astronauts were welcomed by a brief ceremony.
The building manager was mugged by a gang of teenagers.
A passerby was jostled by the drunk.
*The jogger wasn't tripped by the chain.
The car's windshield was struck by a brick.
The embassy staff isn't being evacuated by the government.
The film critic was charmed by the new children's movie.
*The mayor was observed by a reporter leaving the mobster's home.
*The players are being assisted by a union leader in organizing the strike.
The designer's favorite dress was worn by a bald fashion model.
The file was dropped by a clerk into the wastebasket.
A corpse was found by some hunters behind the ice cream plant.
An innocent bystander was grazed by the assassin's bullet.
The floors are cleaned by a janitor daily.
The potholes are being repaired by a crew from the Department of Transportation.
The front page of the newspaper was dominated by an article about a natural disaster.
The bicycle was forced off the road by a motorcycle.
The Lakers were beaten by the Bulls in four games.
*The valley's stillness was shattered by a gunshot.
The chess master was outsmarted by the computer.
A medieval manuscript was misplaced by the museum after the exhibit.
Thousands of acres of forest were destroyed by the fire in less than a week.

Dative Target Primes

*The corrupt inspector offered a deal to the bar owner.
The graduate students are baking a cake for the professors.
The lifeguard tossed a rope to the struggling swimmer.
The governess made a pot of tea for the princess.
The foundation is giving several million dollars to the university.
*A rock star sold some cocaine to an undercover agent.
The legislature is sending a bill legalizing capital punishment to the governor.
The management company is renting three suites of offices to the CIA.
The team owner told an offensive joke to the columnist.
*The cheerleader saved a seat for her boyfriend.
The dictator bought a Rolls Royce for the terrorist leader.
The waitress took a tray of appetizers to the customers.
*The credit card company mailed an application to the student.
*The indulgent mother promised a puppy to her daughter.
The judge awarded a hundred thousand dollars to the plaintiff.
The clerk issued an office key to the new typist.
The ambitious father taught the alphabet to his 3-year-old son.
The little girl read a short story to the old woman.
The driver sheepishly handed his license to the police officer.
The bored teen passed a note to the cute guy.
The toddler timidly fed a carrot to the rabbit.
The cocktail waitress served a martini to the tired executive.
Mozart wrote a song for his wife.
*The deadbeat tenant owed 6 months' rent to the landlord.

Neutral Primes (Experiment 2)

A flying saucer landed.
The young electrician fell down.
The vacationing family stayed together.
The angry customer stormed out.
The new television network struggled.
The unhappy artist sighed.
The reluctant volunteer slacked off.
The clerks giggled.
The duck hunters whispered.
The real estate agent blundered.
The successful businessman retired.
The young man shaved too often.
The defeated king barely escaped.
The company's problems multiplied.
The old women gambled every day.
The computer crashed.
The lost child cried.
The resourceful campers survived.
The clock isn't running.
The tightrope walker fell.
The moon is shining brightly.
The university went broke.
The audience didn't laugh.
Mister Rogers smiles frequently.
Fred Astaire and Ginger Rogers danced.
The thoroughbred galloped gracefully.
The bus driver sneezed suddenly.
The young couple strolled arm in arm.
The delicate vase shattered.
The kidnapped child escaped.
The shy kid always mumbled.
The hardworking nurse dozed off.
The nervous woman finally relaxed.
The dentist's patient yelped.
The overworked receptionist slept heavily.
The worn-out container leaked.

Note. Asterisks indicate items that were used only in Experiment 1.

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