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Patterns of experience with verbs affect long-term cumulative structural priming

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Recent studies of structural priming have demonstrated that although there is evidence of verb-based effects in short-term priming (e.g., stronger priming when verbs are repeated between prime and target sentences), such effects are absent in long-term priming. We present evidence that verb-based effects can be observed in long-term priming situations. This result has important implications for theoretical accounts of the mechanisms that give rise to structural priming and other such adaptation effects in language production.

Understanding the relationship between verbs and syntactic structures is one of the central issues in the study of language. This issue has had a prominent place in the study of linguistics (e.g., Goldberg, 1995), language acquisition (e.g., Tomasello, 2003), and language comprehension (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994). The relationship between verbs and syntactic structures has come to the fore in the study of language production, particularly with respect to structural priming (see, e.g., Chang, Dell, & Bock, 2006; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Kaschak & Borreggine, 2008). *Structural priming* refers to the tendency of speakers to repeat constructions across utterances (Bock, 1986). Although the hallmark of structural priming is that the tendency to repeat constructions occurs in the absence of the repetition of lexical items across utterances, it has been shown that structural priming effects are stronger when lexical items are repeated across utterances (Branigan, Pickering, & Cleland, 2000; Cleland & Pickering, 2006; Pickering & Branigan, 1998). That is, there appears to be a "lexical boost" in structural priming. Two recent studies have placed an important qualification on the lexical boost: Whereas the boost appears in short-term priming situations (e.g., when utterances are produced in immediate succession), it has not appeared in long-term priming situations (e.g., when utterances are separated by several intervening sentences; Hartsuiker et al., 2008; Kaschak & Borreggine, 2008).

Hartsuiker et al. (2008) presented participants with prime and target stems in both the spoken modality and the written modality. The prime and target sentences were either adjacent or separated by two, four, or six filler items. The main finding from Hartsuiker et al. is that whereas structural priming does not weaken substantively as the number of filler items between the prime and target sentences increases, the lexical boost decays rapidly under the same circumstances. This pattern was present in both the spoken and written modalities. Kaschak and Borreggine (2008) reported a similar lack of a lexical effect on structural priming in long-term cumulative priming situations. In their Experiment 2, participants produced double object and prepositional object constructions for two (target) verbs (e.g., *send* and *hand*). In some cases, the verbs were produced equally often in both the double object and preposition object constructions; in other cases, verbs were skewed toward one of the constructions (e.g., *send* was produced only in the double object, and *hand* was produced only in the prepositional object). The key finding of this experiment was that structural priming for utterances involving the target verbs was of essentially the same magnitude when the verbs were produced in both the double object and prepositional object constructions and when the verb was produced in one construction only. Although the overall conclusion from this experiment is that patterns of experience with the target verbs did not affect the priming observed for utterances using those verbs, there was one exception to this pattern: The verb *lend* displayed a very strong verb bias effect. Kaschak and Borreggine attributed the presence of a verb bias effect for *lend* to the relative oddity (for their participants, at least) of the past-tense form of the verb that was used in the materials (*lent*). They suggested that this oddity may have made the *lend* items stand out in the experiment and thereby had produced the verb bias effect. We return to this point later in this article.

There is much at stake in understanding the dynamics that produce lexical effects on structural priming. Pickering and Branigan (1998) and Chang et al. (2006) have offered the two major theories of structural priming. These theories differ in their predictions regarding the lexical boost. Whereas the mechanisms inherent in Pickering and Branigan's model provide a natural account of the short-lived nature of the lexical boost, simulations of Chang et al.'s model do not produce a lexical boost in either short-

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or long-term priming situations (although there may be mechanisms through which the lexical boost can be generated; see the Discussion). Thus, determining when and how the lexical boost arises is central to efforts to judge between the main theories of structural priming, and to the further development of such accounts. Understanding the dynamics of the lexical boost in structural priming is also important because the relatively short-lived nature of the lexical effect on structural priming is at odds with findings in both language comprehension (see MacDonald et al., 1994, for a review) and language production (Kaschak, 2007, Experiment 2) that long-range patterns of experience with verbs can affect syntactic processing and choices. Although it is possible that verb biases toward particular constructions are fixed during language acquisition (see Pinker, 1989, for a discussion), many extant theories of language processing posit that such biases are learned and therefore subject to change based on one's continuing linguistic experience (see MacDonald et al., 1994). If the mechanisms that give rise to structural priming are the same mechanisms that are responsible for language learning (see Chang et al., 2006, for a discussion), it is not clear how one acquires long-range lexical biases and how those biases change (and affect language performance), given that structural priming experiments suggest that information about patterns of experience with verbs within an experiment does not seem to persist long enough to affect performance on subsequent trials.

The present experiment was designed to unravel one component of this mystery by showing that one can observe long-term cumulative verb-based effects in a structural priming paradigm of the sort employed by Kaschak and colleagues (e.g., Kaschak & Borreggine, 2008; Kaschak, Loney, & Borreggine, 2006). Kaschak and Borreggine may have failed to observe verb-based effects on structural priming because the verb effects that accumulated through the experiment were hidden by strong priming between the individual prime and target sentences at the end of their experiments. We tested this idea by conducting a replication of Kaschak and Borreggine's Experiment 2 in which the target stems presented at the end of the experiment were not preceded by prime stems (unlike in the original experiment). If our hypothesis was correct, we expected a verb bias effect in this experiment. Such an outcome would be theoretically important, because it would suggest—contra the results of Kaschak and Borreggine (2008) and Hartsuiker et al. (2008)—that the learning mechanisms responsible for accumulating long-term verb biases (and other such lexical effects) are the same mechanisms operating to produce cumulative learning and priming effects in structural priming experiments.

METHOD

Participants

The participants were 40 introductory psychology students from Florida State University. They received course credit for their participation. As in previous studies, participants needed to meet performance criteria in the *bias* phase to be included in the data set. We aimed to have participants whose experience with each verb was skewed 100/0 in favor of one construction (with an overall split of 50/50 across all constructions). To ensure the integrity of this manipulation, we excluded any participants whose patterns of production strongly deviated from the intended proportions. We excluded participants who showed a skew weaker than 80/20 in favor of the target construction for a given verb, or participants who showed an overall skew stronger than 80/20 between the double object and prepositional object constructions. We also excluded any participants who did not produce at least one dative sentence for each of the target verbs in the *priming* phase. (Note: Along with the present study, we ran a replication of Kaschak & Borreggine's [2008] Experiment 2. See note 2 for details.)

Materials

Two sets of materials were constructed for this experiment (see Kaschak & Borreggine, 2008, Appendix B). Each set contained 20 pairs of prime stems for use in the bias phase, and 8 target stems for use in the priming phase. One member of each prime pair was designed to elicit the double object construction, and the other was designed to elicit the prepositional object construction. Target stems could be completed as either a double object or a prepositional object construction (Table 1 presents examples of prime and target stems). Set 1 used the target verbs *give* and *loan*, and Set 2 used *send* and *hand*. There were 134 filler stems that elicited a range of transitive and intransitive constructions. Filler stems did not contain any of the target verbs, and they could not easily be completed as a double object or prepositional object construction.

Procedure

Participants were randomly assigned to receive materials from Set 1 or Set 2, and within each set, an equal number of participants saw each verb (e.g., *send* or *hand*) as the double object biased verb and as the prepositional object verb (resulting in four possible combinations of material sets and assignment of verbs to be double object or prepositional object biased).

Participants were told that they would see the beginning of a sentence on the top of the computer screen, and that they should type a completion for the sentence in the box displayed below the stem. They entered their completion by pressing the "return" button,

Table 1
Structure of Trials in the Bias and Prime Phases of the Experiment

Bias Phase (10 prime stems for each verb)		
	DO Bias Verb (*send*)	PO Bias Verb (*hand*)
Sample primes:	*The teacher sent the student . . .* (DO)	*The man handed the book . . .* (PO)
	The architect sent the client . . . (DO)	*The captain handed his hat . . .* (PO)
	The pianist sent the audience . . . (DO)	*The child handed the toy . . .* (PO)
Priming Phase (4 target stems for each verb)		
	Send	*Hand*
Target:	*The mechanic sent . . .*	*The professor handed . . .*
Target:	*The spy sent . . .*	*The politician handed . . .*

Note—DO, double object; PO, prepositional object.

which triggered presentation of the next stem. Participants could not go back to previous trials. Participants completed 20 prime stems in the bias phase (10 for each verb), which alternated between the target verbs in the experiment. One of the verbs was produced entirely in the double object construction, and the other verb was produced entirely in the prepositional object construction. Participants completed 8 target stems (4 for each verb) in the priming phase. Prime stems (bias phase) and target stems (priming phase) were separated by 4 or 5 filler stems. Within the preceding constraints, the order of stems was randomized for each participant.

Scoring

The prime and target stem completions were scored as "double object," "prepositional object," or "other" on the basis of the criteria outlined by Kaschak and Borreggine (2008).

Design and Analysis

For the bias and priming phases, we computed the proportion of double object and prepositional object constructions produced overall and for each verb. The proportions were computed by dividing the number of double object or prepositional object constructions produced by the total number of double object and prepositional object constructions produced. This computation ignored trials on which "other" responses were produced.

The proportion of double object, prepositional object, and other stem completions from the priming phase of the experiment was analyzed across participants (F_1) and items (F_2), using a factorial ANOVA with counterbalance list (four lists: *give*/*loan*, with *give* as the double object bias verb; *give*/*loan*, with *loan* as the double object bias verb; *send*/*hand*, with *send* as the double object bias verb, and *send*/*hand*, with *hand* as the double object bias verb) as a between-participants factor and verb bias (double object bias vs. prepositional object bias) as a within-participants factor. Verb bias was a within-items factor. Counterbalance list was included as a factor only in the analysis by participants. Because they are of little theoretical interest, we do not report effects involving counterbalance list below. Our method of calculating the proportion of double object and prepositional object constructions resulted in complementary proportions. Consequently, we report only the analyses conducted on the proportion of double object constructions produced, and report only the proportion of double object constructions produced in the text below.

RESULTS

The data from the bias phase show that we were able to control the participants' rates of production of the double object and prepositional object constructions overall (51% double object, 49% prepositional object) and for the target verbs (participants produced the intended construction for the verb 100% of the time). Overall, "other" responses occurred on 28% of the target completions in the priming phase, with 30% of the target completions in the double object bias condition being "other" responses, and 26% of the target completions in the prepositional object bias condition being "other" responses. Analysis of the proportion of "other" responses revealed no effect of verb bias [$F_1 < 1$; $F_2(1,15) = 1.46$, $p = .24$].

Analysis of the proportion of double object constructions produced in the priming phase of the experiment revealed a main effect of verb bias [$F_1(1,36) = 4.71$, $p = .037$; $F_2(1,15) = 5.48$, $p = .03$]. Participants produced more double object target completions for the double object bias verb ($M = .50$, $SD = .44$) than for the prepositional object bias verb ($M = .35$, $SD = .39$). In other words, this experiment showed a verb bias effect, in that biasing a verb toward a particular construction in the bias phase increased the probability that participants would use that construction when completing target stems involving that verb in the priming phase.[1] This outcome stands in contrast to the results obtained by Kaschak and Borreggine (2008, Experiment 2), who observed no verb bias effect.[2]

DISCUSSION

We began this article by discussing a mystery surrounding the absence of verb-based effects in long-term structural priming: Why are verb-based effects on structural priming absent in long-term cumulative priming situations, when long-range experience with verbs has been shown to affect syntactic processing and syntactic choices in other sorts of language comprehension and language production studies? Our data take a step toward resolving this mystery by showing that verb-based effects can be observed in long-term cumulative priming experiments. It appears that the absence of such effects in earlier studies (e.g., Kaschak & Borreggine, 2008) is due to the fact that strong priming between individual prime and target sentences can override the verb-bias effects that accrue during the experiment.

Our data have important theoretical implications. Pickering and Branigan (1998) proposed that priming is the result of the residue of activation that both spreads between nodes representing individual verbs and nodes representing grammatical rules that govern the construction of particular sentence types and resides in the individual nodes themselves. This model can explain the data observed here and in Kaschak and Borreggine (2008) if one assumes that language production experience results in long-term changes to the strength of the links between verbs and combinatorial nodes. These changes serve as the mechanism through which both long-term structure-based adaptations and long-term verb adaptations arise. The "residual activation" mechanism explains how the long-term verb-based adaptations can be overridden by the presence of prime sentences before the critical target sentences. The success of this account depends on finding an appropriate balance between the strength of the long-term changes in the links between verbs and combinatorial nodes, and the strength of the short-term activation that drives short-term priming effects. It is our hope that the present results will spur such theoretical development.

Chang et al.'s (2006) model proposes that structural priming arises from implicit learning in the language production system. Their model allows for learning based around both lexical items (including verbs) and particular constructions, but keeps these types of learning separate. As a result, previously reported simulations of the model did not produce a lexical boost in structural priming. This outcome is at odds with the results of our experiment. Nonetheless, it is worth pointing out that Chang et al.'s model is capable of learning distributional information relevant to the behavior of individual verbs. It is possible that this aspect of the model allows the constructional bias patterns for individual verbs to change on the basis of one's experience within the experiment, and thereby

produces the verb bias effect seen here. A detailed simulation of the model will likely be necessary in order to determine whether experience with verbs in our experiment produces the patterns of language production that we have seen from our participants. Importantly, and counter to proposals that structural priming and the lexical boost are produced by different sorts of memory mechanisms (implicit and explicit memory mechanisms, respectively; see Chang et al., 2006), our results suggest that both structural and lexical bias effects can be produced by similar mechanisms.

Earlier, we noted that Kaschak and Borreggine (2008) found that one verb (*lend*) showed a verb bias effect that was not overridden by the presence of prime sentences in the priming phase of the experiment. Kaschak and Borreggine argued that this result was produced by the relative oddity of the form of *lend* that was used in the experiment—namely, *lent*. They suggest that participants may have explicitly noticed this verb form in the experiment, and that explicit memory for prior experiences producing sentences with this verb produced the strong verb bias effect. Although our data suggest that a two-process account (involving contributions of explicit and implicit memory) may not be necessary in order to account for both lexical and structural bias effects in structural priming, it may be that both explicit and implicit modes of memory retrieval shape the production of sentences under different circumstances (see, e.g., Chang et al., 2006; Hartsuiker et al., 2008). Very little work has been done to examine the different ways that memory for prior linguistic experiences may affect the production of subsequent utterances. It is our sense that making progress on this front will be an important step in building and refining theories of structural priming, language production, and language learning.

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NOTES

1. Although we interpret this effect to be a result of the biases established during the bias phase, it is likely that the production of the target stems themselves also contributed to the established biases.

2. It is possible that the difference in outcome between our experiment and Kaschak and Borreggine's (2008) study occurred because Kaschak and Borreggine assessed verb bias effects between participants, whereas we assessed verb bias effects within participants. To rule out this possibility, we replicated Kaschak and Borreggine's result in a within-participants design of the sort employed in the present experiment. Simultaneous with the execution of the experiment reported in this article, we performed a replication of Kaschak and Borreggine's Experiment 2. This replication was identical to the present experiment in all respects except that (as in Kaschak and Borreggine's study) prime stems were placed before each of the target stems in the priming phase. The prime stem always used the same verb as did the following target stem, but it used the construction opposite the one toward which the verb had been biased. For example, if the verb *give* had been biased toward the double object construction, the prime stems for this verb in the priming phase used the prepositional object construction. As in Kaschak and Borreggine's study, the prime stems overrode the verb bias established during the bias phase of the experiment. Participants produced more double object target completions for the prepositional object biased verbs (whose target stems were preceded by double object primes; $M = .37$) than for the double object biased verbs (whose target stems were preceded by prepositional object primes; $M = .22$). This difference was significant in the analysis by items, and marginally significant in the analysis by participants [$F_1(1,36) = 3.31$, $p = .077$; $F_2(1,15) = 19.55$, $p < .001$]. In other words, participants' target completions followed the construction of the prime stem that immediately preceded the target stem, rather than the long-term pattern of bias developed for that verb within the experiment. A combined analysis of the experiment presented in this article and the replication reported here shows that this reversal of the verb bias effect is significant, as evidenced by a verb bias (double object bias vs. prepositional object bias) $\times$ experiment (main experiment from this article vs. replication of Kaschak & Borreggine, 2008) interaction [$F_1(1,72) = 7.85$, $p < .001$; $F_2(1,15) = 17.66$, $p = .001$].

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