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Long and Short Term Cumulative Structural Priming Effects

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Abstract

We present six experiments that examine cumulative structural priming effects (i.e., structural priming effects that accumulate across many utterances). Of particular interest is whether (1) cumulative priming effects transfer across language production tasks and (2) the transfer of cumulative priming effects across tasks persists over the course of a week. Our data suggest that cumulative structural priming effects do transfer across language production tasks (e.g., from written stem completion to picture description, and from picture description to written stem completion), but only when both tasks are presented in the same experimental session. When cumulative priming effects are established in one task, and the second (changed) task is not presented until a week later, the cumulative priming effects are not observed.

Keywords

language production; structural priming; implicit learning

Structural priming refers to the tendency for speakers and writers to repeat syntactic constructions across utterances (Bock, 1986, 1989). For example, a person who recently encountered the double object construction (DO; *Michael handed Meghan a toy*) is more likely to produce another DO to describe someone giving something to another person (*The sailor gave the captain the binoculars*) than to use a prepositional object construction to describe the same event (PO; *The sailor gave the binoculars to the captain*). Structural priming is a robust phenomenon. It can be observed in spoken (e.g., Bock, 1986) and written (e.g., Cleland & Pickering, 2006) production, with a range of syntactic constructions (e.g., Griffin & Weinstein-Tull, 2003; Hartsuiker & Kolk, 1998; Hartsuiker & Westenberg, 2000; Pickering & Branigan, 1998), in laboratory tasks (e.g., Bock, 1986; Branigan, Pickering, &

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¹Kaschak (2007) and Kaschak, Kutta, & Schatschneider (2011) employed partially overlapping sets of items. Three items were repeated across experiments, and the rest of the items in each experiment did not repeat.

²We report full models for the analyses across pairs of experiments rather than best fitting models because the presence (or absence) of the interaction effects is of theoretical import. As such it is instructive to compare the results across studies (even if the inclusion of the interaction terms does not improve model fit).

³We used a model fitting approach to this analysis because there were a large number of higher-order interactions that were not of major theoretical interest.

⁴The available evidence does not provide a ready explanation for this effect, but the tendency for our picture description task to elicit more DOs than the written completion task appears regularly with our materials. One possible explanation is that the pictures that we have selected have a bias (such as the location of the agent and recipient in the pictures) that leads to a higher likelihood of producing a DO description.

Cleland, 2000; Pickering & Branigan, 1998) and naturally occurring samples of speech (e.g., Gries, 2005; Weiner & Labov, 1983), in several languages (e.g., Hartsuiker & Kolk, 1998; Scheepers, 2003), and across languages within the same speaker (e.g., Hartsuiker, Pickering, & Veltkamp, 2004).

Many studies have used structural priming as a vehicle to explore language production (e.g., Bock & Griffin, 2000; Branigan et al., 2000), language comprehension (e.g., Branigan, Pickering, & McLean, 2005; Kaschak & Glenberg, 2004), and the relationship between production and comprehension (e.g., Bock, Dell, Chang, & Onishi, 2007; see Pickering & Ferreira, 2008, for a review). Interest in structural priming is driven by at least two theoretical concerns. First, the presence (or absence) of priming between individual prime and target sentences can be revealing with respect to the nature of the representations that underlie language use. For example, Bock et al. (2007) report that structural priming effects observed between language comprehension and production follow the same pattern as the structural priming effects observed within the language production of a single person. These data suggest that comprehension and production may trade on the same (or similar) processing mechanisms. Second, it has been proposed that structural repetition effects play a role in language acquisition (e.g., Brooks & Tomasello, 1999; Savage, Lieven, Theakston, & Tomasello, 2003) and language change (e.g., Chang, 2008). The tendency for speakers to repeat recently heard or produced constructions may serve to strengthen representations of a given structure (aiding the acquisition process; Tomasello, 2006), and (over time) may alter the long-range probabilities of using a given construction, thereby contributing to language change (e.g., Bock & Kroch, 1989; Chang, 2008). Examinations of structural priming thus have the potential to inform topics that are central to our understanding of language.

The current paper explores the nature of cumulative structural priming effects of the sort that have been reported by Kaschak and colleagues (Coyle & Kaschak, 2008; Kaschak, 2007; Kaschak & Borreggine, 2008; Kaschak, Loney, & Borreggine, 2006; see also Hartsuiker & Westenberg, 2000; Jaeger & Snider, 2008). Whereas most studies of structural priming assess priming between individual prime and target sentences, these studies examined structural priming effects that accumulate over many sentences. The experiments typically begin with a *Bias phase*, in which participants are induced to produce a certain proportion of DO and PO constructions (ranging from 100% DO productions to 100% PO productions). Then, the Priming phase of the experiment gives participants the freedom to produce either the DO or PO construction. The question of interest is how patterns of experience in the Bias phase affect the participants' choice of construction in the Priming phase. Kaschak and colleagues have demonstrated that experience in the Bias phase has a strong effect on production in the Priming phase (e.g., Kaschak et al., 2006; Kaschak, 2007), and that the effects of the Bias phase can be long lasting – participants show the effects of the Bias phase even when the presentation of the Priming phase is delayed for a week (Kaschak, Kutta, & Schatschneider, 2011).

Cumulative structural priming is of interest for at least three reasons. First, if studies of structural priming are going to be informative with respect to language acquisition and language change, it is necessary to observe how structural priming works over a broader scope of language use than the relationship between individual prime and target sentences.

Second, the temporal dynamics of structural priming represent an important point of contrast between the major theories of structural priming. Pickering and Branigan's (1998) residual activation account predicts that structural priming should be relatively short lived, whereas Chang, Dell, and Bock's (2006) implicit learning account predicts that structural priming should be a long lasting effect. Evidence for both claims has been reported (short-term effects reported by Branigan, Pickering, & Cleland, 1999; Levelt & Kelter, 1982; Wheeldon & Smith, 2003; long-term effects reported by Bock & Griffin, 2000; Kaschak, Kutta, & Schatschneider, 2011), and further refinement of our understanding of this issue is needed. Third, as argued by Kaschak, Kutta, & Schatschneider (2011), explorations of longterm cumulative priming can be informative about the nature of the memory representations that underlie structural priming (and other adaptations within the language system; e.g., Dell, Reed, Adams, & Meyer, 2000; Kraljic & Samuel, 2005).

Kaschak, Kutta, & Schatschneider (2011) performed a modification of Experiment 1 from Kaschak (2007). In the Bias phase of the study, participants engaged in a stem completion task of the sort introduced by Pickering and Branigan (1998). Participants saw stems such as:

1. Meghan gave Michael... (DO eliciting)
2. Meghan gave a toy... (PO eliciting)

Stem (1) was designed to elicit the DO construction (Meghan gave Michael ... a toy), and Stem (2) was designed to elicit the PO construction (Meghan gave a toy ... to Michael). Participants produced either 100% DO constructions in the Bias phase or 100% PO constructions in the Bias phase. A week later, participants returned to the laboratory to complete the Priming phase of the study. Participants saw stems such as (3):

3. The librarian handed...

These stems gave participants the freedom to produce either the DO or PO construction. Kaschak (2007) demonstrated that the Bias phase had a strong effect on the rate of production for the DO and PO constructions in the Priming phase, and Kaschak, Kutta, & Schatschneider (2011) demonstrated that this effect persisted when the Bias and Priming phases were separated by a week. Kaschak, Kutta, & Schatschneider's (2011) result was interpreted as evidence that the language production system tracks the probability of use for different syntactic structures in a context-sensitive manner. In the week between sessions of the experiment, participants likely encountered a relatively normal proportion of DO and PO constructions (Bock & Griffin, 2000, suggest that speakers of American English have a 2:1 bias in favour of the DO construction; see also Kaschak, Kutta & Jones, 2011). If the language production system tracked the probabilities of use for these constructions in a context-independent manner, this experience likely would have washed out the effects of the Bias phase, resulting in no cumulative bias effect being observed in the Priming phase. The fact that this result was not found suggests that participants experience with the DO and PO constructions in the experiment was remembered in a context-sensitive way, and that reinstating the context of the experiment a week later triggered the retrieval of the participants' experience within the Bias phase*resulting in the long-term persistence of the cumulative priming effect.

The experiments described below were designed to explore Kaschak, Kutta, & Schatschneider's (2011) claim that the long-term persistence of cumulative structural priming reflects a context-specific tracking of the probabilities of use for particular syntactic constructions. We are interested in two issues. First, to what extent does the cumulative priming effect accrued within one production task transfer to language production in another task? Crowder (1993; see also Craik, 2003) identifies context- and task-sensitivity as among the defining principles of memory, and examples of specificity effects in language processing have been observed (e.g., Goldinger, 1996, 1998), including an experiment that tested memory for sentences over the course of a week (Masson, 1984). Second, does the temporal delay between the establishment of the cumulative priming bias effect and the assessment of the effect in the Priming phase of the study affect the degree to which cumulative priming effects transfer across production tasks? Although the match between encoding and retrieval conditions has long been known to affect the success of memory retrieval (better match leading to better retrieval; see Crowder, 1993, for a review), it is also known that the importance of the encoding-retrieval match is affected by the delay between encoding and retrieval. As Read and Craik (1995) demonstrate, the longer the delay between encoding and retrieval, the more important the encoding-retrieval match is for successful memory retrieval.

The transfer of cumulative priming effects across production tasks has not received much scrutiny in the literature. Kaschak (2007) reports one experiment in which the cumulative priming effect accrued in a written stem completion task, and the Priming phase tested for the bias effect using a picture description task. The experiment showed that the cumulative priming effect did transfer across tasks. In addition, there are reports from studies of short-term priming effects (i.e., priming between individual prime and target sentences) suggesting transfer between written and spoken production (and vice versa; e.g., Cleland & Pickering, 2006) and between production and comprehension (e.g., Bock et al., 2007). These data point towards the conclusion that structural priming effects are robust enough to survive across greater or lesser changes in the demands of the production task. One goal of this paper is to replicate these patterns and strengthen this general conclusion within the cumulative priming paradigms that Kaschak and colleagues have explored. Using a combination of newly collected and previously published data, we will assess the degree to which cumulative priming effects transfer across tasks, and whether the transfer is symmetrical across tasks. That is, does one observe the same amount of transfer in moving from a written stem completion task to a picture description task as one does when moving in the opposite direction?

The second goal of this paper is to assess the extent to which cumulative priming effects persist across the course of a week when there is a change in task between the Bias and Priming phases of the study. Kaschak, Kutta, & Schatschneider (2011) demonstrated longterm persistence of the priming effect when the Bias and Priming phases used an identical written production task. Will the effect persist as strongly if the production task is changed between the Bias and Priming phases? One possibility is that participants are tracking the probability of use for the DO and PO constructions within the experiment context generally, and as such reinstating the general context of the experiment (i.e., returning to the same room, using the same computer as in the Bias phase, and so on) will be

sufficient to reinstate the cumulative priming effect. Alternatively, the tracking of patterns of use for the DO and PO constructions may be closely tied to the specific experimental task (e.g., written stem completion). As such, the cumulative priming effect may not be observed when participants return to the laboratory, but engage in a different language production task (e.g., picture description). The latter possibility would be reflective of a generally high degree of context specificity in how the language production system tracks experience with particular syntactic constructions.

EXPERIMENTS 1 AND 2

We began our exploration of the task-specificity of cumulative structural priming effects by conducting an analysis of previous data from our laboratory in an effort to verify that the strength of cumulative priming effects do not diminish over the course of a week when the same task is used during the Bias and Priming phases of the study. We did this by comparing the results of Kaschak's (2007) Experiment 1 (no delay between Bias and Priming phases) with the results reported by Kaschak, Kutta, & Schatschneider (2011); one week delay between Bias and Priming phases). The data from both experiments was analyzed using a mixed logit regression model predicting the log odds of producing a DO target completion in the Priming phase. Participants and items served as crossed random factors (with random intercepts) in the analysis, and Bias condition (DO Bias condition coded as 1 vs. PO Bias condition coded as 0), Delay (no delay before priming phase coded as 0 vs. one week delay before priming phase coded as 1), and the Bias condition \times Delay interaction were included as predictors.¹ Random slopes across items for these predictors did not improve model fit, and were therefore not included in the model. The results of the analysis are presented in Table 1. There was a strong effect of Bias condition ($p < .001$), demonstrating that participants in the DO Bias condition were more likely to produce a DO completion than participants in the PO Bias condition. There was no effect of Delay condition, and no evidence of a Bias condition \times Delay condition interaction ($ps > .7$). This result suggests that when the same task is used in the Bias and Priming phases of the study, cumulative priming effects show no sign of weakening over the course of a week.

Having demonstrated that there is little evidence for a decline in cumulative priming over the course of a week in a written production task, we next replicated this result using a different task. We employed a modification of the picture description task used in Kaschak's (2007) Experiment 3 (see also Bock, 1986). In the Bias phase of the study, participants alternated between describing pictures and reading sentences aloud. The sentences that were read aloud were used to bias participants towards the production of the DO or PO construction. In the Priming phase of the study, participants continued alternating between describing pictures and reading aloud, but now the pictures were designed so that they could be described using either the DO or PO construction. As in previous studies, we expected participants to produce more DO picture descriptions after having been biased towards the DO construction than after having been biased towards the PO construction. In Experiment 1, the Bias and Priming phases were presented within the same experimental session (as in Kaschak, 2007). In Experiment 2, the Bias and Priming phases were separated by a week (as in Kaschak, Kutta, & Schatschneider, 2011).

METHOD

Participants—Fifty undergraduate psychology students participated in Experiment 1, and an additional 50 students participated in Experiment 2. Within each experiment, 25 participants were in the DO Bias condition, and 25 participants were in the PO Bias condition.

Materials—For the Bias phase, there were 10 pairs of prime sentences designed to be read aloud (see Appendix 1). One member of each pair was a DO construction, and the other was a PO construction. There were also 12 filler sentences that were a mixture of transitive and intransitive constructions. We selected 21 filler pictures that were designed to elicit nondative transitive and intransitive constructions. The materials for the Priming phase were borrowed from those used in the Priming phase of Kaschak's (2007) Experiment 3 (see Appendix 3). There were five critical pictures (Kaschak's experiment used six pictures, but one picture was omitted due to an error) designed to elicit the production of either the DO or PO construction, as well as 19 filler pictures that elicited the production of active and passive transitive constructions, and intransitive constructions. There were an additional 12 filler sentences to be read aloud. The pictures used in this study were a subset of the items used by Bock (1986). Throughout the experiment, each picture had a verb printed on it, and participants were asked to use this verb in generating their description of the picture.

Procedure—Participants were randomly assigned to be in the DO or PO Bias condition, with the constraint that an equal number of participants were in each condition. Participants were told that they were going to flip through a binder in which each page contained either a single sentence or a picture. Participants were told that if they saw a sentence, they should read the sentence out loud. If they saw a picture, they were to use the verb listed on the picture to generate a one-sentence description of the picture. In the Bias phase, participants read aloud either 10 DO or 10 PO constructions, where each prime construction was separated by three filler items (a combination of filler sentences and filler pictures). The experimenter listened to the participants performing the task to ensure that all prime sentences were produced as intended. All participants completed this aspect of the task successfully. In the Priming phase, participants saw five target pictures that could be described as either a DO or PO construction, plus a number of filler pictures and filler sentences to be read aloud. As in the Bias phase, each target picture was separated by three filler items. In Experiment 1, the Bias and Priming phases were completed in immediate succession. In Experiment 2, after participants completed the Bias phase, they were told that the first phase of the study was over, and that they would need to be assigned a time to complete the second phase of the study. Participants were assigned a time slot approximately 7 days from the time of their participation in the Bias phase. All participants returned to the laboratory at least 7 days after completing the Bias phase, with the average delay being 7 days. Note that for all experiments involving a delay (Experiments 2, 4, and 6), participants returned to the same laboratory room and used the same computer as was used in the first session of the experiment (though the experimenter was not necessarily the same). On returning to the laboratory, participants completed the Priming phase. All responses were audio recorded and later scored according to the criteria described below.

Scoring—All the experiments reported in this paper involve the use of written stem completion and/or picture description tasks. As such, we will lay out the scoring procedures for all aspects of the tasks here rather than describe them piece-meal across studies. The scoring for written stem completions was as follows. For prime stems (e.g., *Meghan gave Michael...*), completions were scored as a DO if the completion was a noun phrase incorporating the patient of the verb. Completions were scored as a PO if they began with a prepositional phrase using the word “to” that incorporated the beneficiary of the verb. For target stems (e.g., *The captain sent...*), completions were scored as a DO if they contained two noun phrases, the first denoting the beneficiary of the verb, and the second denoting the patient of the verb. Completions were scored as a PO if they consisted of a noun phrase denoting the patient of the verb and a prepositional phrase using the word “to” that denoted the beneficiary of the verb. Target picture descriptions were scored using the same criteria, except that these descriptions also contained the subject of the sentence. All other completions, including completions containing a verb particle (*Meghan gave the toy back to Michael*) and completions that were nonreversible (e.g., a PO completion that would not produce a grammatical DO completion: *The girl gave it to her mom*), were scored as “other”.

Design and analysis—All experiments were analyzed in the following manner. First, trials on which an “other” response was made were excluded from the analysis, resulting in a binary dependent variable (DO response coded as 1, PO response coded as 0). The log odds of producing a DO target completion (stem completion or picture description, depending on the study) was predicted with a mixed logit regression analysis (Jaeger, 2008). Analysis was done with the HLM statistical software (Raudenbush, Bryk, Cheong, & Congdon, 2004). Participants and items were crossed random factors in the model. Intercepts were allowed to vary for both participants and items. For individual experiments, the only additional predictor in the analysis was Bias condition (DO Bias coded as 1, PO Bias coded as 0). When analyzing data across experiments (e.g., comparing Experiments 1 and 2), Delay (No delay coded as 0, Week delay coded as 1) and the Bias condition \times Delay interaction were added to the model. We ran all models with random intercepts only, and repeated the analyses including random slopes by items for Condition (and, where appropriate, Delay). Random slopes did not add to model fit in any of our analyses (and produced essentially the same results as the analyses without random slopes), and so were not included in the models reported here. Raw and estimated proportions of DO responses are presented in the tables describing the results of each experiment. Estimated proportions are presented in the text. For Experiments 1 and 2, participants produced “other” responses on 1% of the trials.

RESULTS

The results of the mixed logit analyses predicting the log odds of producing a DO target picture description for Experiments 1 and 2 are presented in Table 2.

Experiment 1—Replicating the result of Kaschak’s (2007) Experiment 1, there was an effect of Bias condition ($p < .01$). Participants in the DO Bias condition were more likely to

produce a DO picture description (0.92) than participants in the PO Bias condition (0.73). That is, there was a cumulative priming effect.

Experiment 2—Replicating Kaschak, Kutta, & Schatschneider’s (2011) result, there was an effect of Bias condition ($p = .02$). Participants in the DO Bias condition were more likely to produce a DO picture description (0.96) than participants in the PO Bias condition (0.81). Thus, the cumulative priming effect seen in Experiment 1 persists for at least one week.

Analysis across experiments—We conducted an analysis to determine whether the Bias condition effects in Experiments 1 and 2 were statistically different. Regression results are presented at the bottom of Table 2. There was an overall effect of Bias condition ($p < .01$), but the effect of Delay ($p = .43$) and the Bias condition \times Delay interaction ($p = .91$) were not significant. The lack of a Bias condition \times Delay interaction suggests that the Bias effect in Experiment 2 was not statistically different from the effect observed in Experiment 1.

DISCUSSION

The results of Experiment 1 and 2 replicate the outcome of Kaschak’s (2007) Experiment 1 and Kaschak, Kutta, & Schatschneider’s (2011) study. Effects of Bias condition in the picture description task were present both when the Priming phase immediately follows the Bias phase, and when the Priming phase is delayed by a week. This finding supports the claim that when the same task is used for the Bias and Priming phases of the experiment, cumulative structural priming effects persist for at least one week.

EXPERIMENTS 3 AND 4

Experiments 1 and 2 provide support for Kaschak, Kutta, & Schatschneider’s (2011) main claim: cumulative priming effects can persist for at least one week when the same task is used in the Bias and Priming phases. Experiments 3 and 4 assess whether cumulative priming effects persist in a similar way if different tasks are used in the Bias and Priming phases of the study. We did this by conducting experiments parallel to Kaschak’s (2007) Experiment 3, in which participants performed a written stem completion task in the Bias phase of the study, and a modification of the picture description task from Experiments 1 and 2 in the Priming phase.

Experiment 3 replicates Kaschak’s (2007) Experiment 3. The original study demonstrated a cumulative priming effect: participants were more likely to produce a DO picture description when the Bias phase elicited 100% DO responses than when it elicited 100% PO responses. The present replication was motivated by the fact that the original experiment had a small sample size (12 participants in each Bias phase condition), and that the production task used for the Priming phase resulted in participants producing a high proportion (over 40%) of “other” responses. Our concern is that both of these factors might distort the size of the observed cumulative priming effect. As one goal of this paper is to compare the cumulative priming effects observed with different language production tasks to each other, it was our sense that a replication of Kaschak’s (2007) experiment that had a larger sample size and took measures to reduce the number of “other” responses produced would be

needed. The major methodological change between this experiment and Kaschak's (2007) experiment is that the pictures used in the picture description task were presented with a verb (e.g., give or hand) that the participant needed to include in their description (as in the present Experiments 1 and 2). The specification of the verb for each description was intended to reduce the number of "other" responses produced in the study. Furthermore, as the 100% DO and 100% PO Bias conditions are the critical ones for observing the cumulative priming effect, these are the only conditions from the original study that were replicated.

Experiment 4 used the same paradigm as Experiment 3, except that the Bias and Priming phases were performed a week apart. If Kaschak, Kutta, & Schatschneider's (2011) claims are correct, a cumulative priming effect should be observed in Experiment 3, but not Experiment 4.

METHOD

Participants—80 undergraduate psychology students participated in Experiment 3, and an additional 80 students participated in Experiment 4. Within each experiment, 40 participants were in the DO Bias condition, and 40 were in the PO Bias condition.

Materials—For the Bias phase, there were 20 pairs of prime stems, where one member of each pair disposed participants to produce a DO completion (*The swimmer handed the diver...*) and the other disposed participants to produce a PO completion (*The swimmer handed the towel...*). These stems are presented in Appendix 2. An additional 80 filler stems were constructed for use in the experiment. These stems elicited a range of transitive and intransitive constructions, and were structured so that they could not easily be completed as a DO or PO construction. The materials for the Priming phase were the same as those used in the Priming phase of Experiments 1 and 2, except that (1) the picture that was mistakenly omitted from those studies was restored (i.e., there were 6 target pictures, rather than 5), (2) the filler sentences to be read aloud were omitted (i.e., only pictorial stimuli were used), and (3) all elements of the experiment were presented via computer (rather than a binder, as in Experiments 1 and 2).

Procedure—Participants were randomly assigned to be in the DO or PO Bias conditions, with the constraint that an equal number of participants appeared in each condition. They were told that they were going to see a series of sentence stems, and that they should complete each one so that they made a grammatical English sentence. After typing in their completion, participants hit the RETURN key on the keyboard to move on to the next stem. In the DO Bias condition, participants completed 20 DO-eliciting prime stems. In the PO Bias condition, participants completed 20 PO-eliciting prime stems. Throughout the Bias phase, 4 or 5 filler stems separated each critical prime. On completion of the Bias phase, participants were transitioned to the Priming phase by being told that they were going to engage in another task that involved picture descriptions. Participants were told that they would see a series of pictures one by one, and that they were to use the verb printed on the top of the picture to generate a single-sentence description of the event being depicted. Participants typed their response into the appropriate box on the computer screen before

moving on to the next picture. There were 3 or 4 filler pictures between each of the 6 critical items. The order of the pictures was the same for each participant. After participants in Experiment 4 completed the written Bias phase, they were told that the first phase of the study was over, and that they would need to be assigned a time to complete the second phase of the study. Participants were assigned a time slot approximately 7 days from the time of their participation in the Bias phase. All participants returned to the laboratory at least 7 days after completing the Bias phase, with the average delay being 7 days. On returning to the laboratory, participants completed the picture description Priming phase.

Scoring—Prime stem completions from the Bias phase and target picture descriptions from the Priming phase were scored as described earlier.

Design and analysis—The responses in the Bias phase were examined to ensure that performance fell within an appropriate range of performance for the given condition. The proportion of DO and PO constructions produced by each participant was calculated by dividing the number of responses of each type by the total number of DO and PO constructions produced (i.e., trials on which “other” responses were produced were not used in this calculation). In both Experiments 3 and 4, participants produced the intended construction over 97% of the time (Note: in Experiment 3, participants produced “other” responses on 8% of the Bias phase trials; in Experiment 4, the figure was 6%). In the Priming phase, we excluded all trials (9% in Experiment 3, 9% in Experiment 4) on which participants produced an “other” response. Data from the Priming phase were subsequently analyzed as in Experiments 1 and 2.

RESULTS

The results of the mixed logit analyses predicting the log odds of producing a DO target picture description for Experiments 3 and 4 are presented in Table 3.

Experiment 3—Replicating the result of Kaschak’s (2007) Experiment 3, there was an effect of Bias condition ($p < .001$). Participants in the DO Bias condition were more likely to produce a DO picture description (0.90) than participants in the PO Bias condition (0.65). That is, there was a cumulative priming effect.

Experiment 4—The effect of Bias condition was not significant in Experiment 4 ($p = .23$). Although participants in the DO Bias condition were somewhat more likely to produce a DO picture description (0.84) than participants in the PO Bias condition (0.77), this difference was not significant.

Analysis across experiments—We conducted an analysis to determine whether the Bias condition effects in Experiments 3 and 4 were statistically different. Overall, there was an effect of Bias condition ($p < .001$). Critically, there was also an interaction of Bias condition and Delay ($p = .04$). This result suggests that the cumulative priming effect observed in Experiment 4 was significantly weaker than that observed in Experiment 3.

DISCUSSION

Consistent with Kaschak, Kutta, & Schatschneider's (2011) proposal, Experiments 3 and 4 suggest that whereas cumulative priming effects transfer across tasks when the Bias and Priming phases are presented in succession, cumulative priming effects do not persist across a week when different tasks are used in the Bias and Priming phases. The results of these experiments are consistent with findings in the memory literature suggesting that the importance of the encoding retrieval match for memory performance is heightened when a delay intervenes between the encoding and retrieval sessions (e.g., Read & Craik, 1995). When there is little delay between encoding and retrieval (or, in our case, between Bias and Priming phases), memory for performance within the encoding (Bias) phase of the study is accessible even when the nature of the retrieval (Priming) phase of the study involves a change in task. As this delay increases, retrieval of patterns of performance in the Bias phase depends on the reinstatement of the same task within the Priming phase (as in Kaschak, Kutta, & Schatschneider, 2011). Put another way, the degree of context-specificity in tracking the probabilities of use for different constructions becomes greater across time. We return to this point in the General discussion.

EXPERIMENTS 5 AND 6

Experiments 3 and 4 demonstrated that cumulative structural priming effects generalise across language production tasks when both tasks are presented in a single experiment session, but that the generalisation across tasks does not appear to persist across the course of a week. To draw more definitive conclusions about how cumulative priming effects persist (or not) across time, it is necessary to get a broader look at the conditions under which the long range persistence effects can be observed. Experiments 5 and 6 are therefore designed to replicate and extend the findings of Experiments 3 and 4 by demonstrating that cumulative priming effects can transfer across different sets of tasks. Instead of looking for transfer from written stem completion to picture descriptions, these experiments look for transfer from the picture description task to written stem completion.

METHOD

Participants—Sixty undergraduate psychology students participated in Experiment 5 (30 in the DO Bias condition, 30 in the PO Bias condition), and 57 different undergraduate psychology students participated in Experiment 6 (30 in the DO Bias condition, 27 in the PO Bias condition).

Materials—The Bias phase used the same materials as the Bias phase of Experiments 1 and 2. The Priming phase used the same materials as the Priming phase of Kaschak, Kutta, & Schatschneider's (2011) experiment. There were 20 target stems (e.g., The captain sent...) intended to allow participants to produce either the DO or PO construction, plus 50 filler stems that elicited a range of transitive and intransitive constructions (and that were difficult to complete as a DO or PO). Each participant saw a random subset of 6 of the 20 critical target stems. Thus, each participant saw a slightly different set of critical items in the Priming phase of the experiment. Critical items from the Bias and Priming phase are presented in Appendix 4.

Procedure—Participants were randomly assigned to be in the DO or PO Bias conditions. The procedure for the Bias phase was identical to that of Experiments 1 and 2, except that pictures and sentences to be read aloud were presented via computer. Responses to the pictures were typed into the computer. The experimenter listened to the participants' reading of the prime sentences to ensure that they produced the sentences as intended. All participants successfully completed this aspect of the task. Bias phase items were presented in the same fixed order for all participants. At the conclusion of the Bias phase, participants were told that they would be engaging in another task in which they would see a series of sentence stems on the computer. They were told to complete each stem in such a way that they made a grammatical English sentence. Participants completed six critical target stems, which were separated by four or five filler stems. At the conclusion of the Bias phase, participants in Experiment 6 were assigned a time to return to the laboratory for the Priming phase of the study. Participants were assigned return dates at least 7 days after the Bias phase. The average length of delay between phases of the study was 7 days.

Scoring—Target stem completions were scored as described earlier.

Design and analysis—Target stem completions from the Priming phase were analyzed as in the previous experiments. Participants produced “other” responses on 21% of the target trials in Experiment 5, and on 25% of target trials in Experiment 6.

RESULTS

The results of the mixed logit analyses predicting the log odds of producing a DO target stem completion for Experiments 5 and 6 are presented in Table 4.

Experiment 5—Replicating the result of Kaschak's (2007) Experiment 3 and the current Experiment 3, there was an effect of Bias condition ($p < .01$). Participants in the DO Bias condition were more likely to produce a DO stem completion (0.62) than participants in the PO Bias condition (0.30). That is, there was a cumulative priming effect.

Experiment 6—The effect of Bias condition was not significant in Experiment 6 ($p = .33$). Although participants in the DO Bias condition were somewhat more likely to produce a DO stem completion (0.47) than participants in the PO Bias condition (0.39), this difference was not significant.

Analysis across experiments—We conducted an additional analysis to determine whether the Bias condition effects in Experiments 5 and 6 were statistically different. Overall, there was an effect of Bias condition ($p < .01$). The interaction of Bias condition and Delay was marginally significant ($p = .10$). This result suggests that the cumulative priming effect observed in Experiment 6 was somewhat (though not quite statistically) weaker than that observed in Experiment 5.

DISCUSSION

The results of Experiments 5 and 6 support the conclusions drawn from Experiments 3 and 4. Cumulative priming effects transfer across tasks when the Bias and Priming phases are

presented in immediate succession, and are weaker when the Bias and Priming phases are separated by one week.

ANALYSIS ACROSS EXPERIMENTS

Based on the six experiments presented here, plus the results of Kaschak (2007) and Kaschak, Kutta, & Schatschneider (2011), it appears that cumulative priming effects transfer across language production tasks when the tasks are presented in the same experiment session (Kaschak, 2007; Experiments 1, 3, and 5 here), but not when a week intervenes between the Bias and Priming phases. Cumulative priming persists for at least one week when the same task is used in the Bias and Priming phases (Kaschak, Kutta, & Schatschneider, 2011; Experiment 2 here), but not when tasks change across phases of the study (Experiments 4 and 6 here). One concern about these conclusions is that there are differences across the experiments in terms of the methodology and materials that are employed. For example, the picture description Bias phases have fewer critical sentences than the written stem completion Bias phases, potentially weakening the cumulative priming effect and reducing the possibility of observing effects after a delay of one week (see Kaschak, Kutta, & Jones, 2011). We acknowledge that differences between the experiments may affect the performance of our participants, but it is our sense that such effects do not undermine the main conclusions drawn across experiments. Both the picture description and written stem completion Bias phases have been shown to lead to immediate and long-lasting cumulative priming effects, and both the picture description and written stem completion Priming phases have been used to demonstrate immediate and long-lasting cumulative priming. Thus, the differences between tasks do not seem to affect our ability to observe cumulative priming. It is only when tasks switch between the Bias and Priming phases, and a delay exists between the phases that the cumulative priming effect is attenuated.

Whereas we do not feel that the differences between tasks played a major role in shaping the critical patterns observed in our data, we decided to pursue two further analyses to address this issue more fully. To get a broader picture of the way that cumulative priming effects operate under different conditions, we present the odds ratios (and associated 95% confidence intervals) generated from a number of cumulative priming experiments (Kaschak's (2007), Experiment 1, Kaschak, Kutta, & Schatschneider's (2011), experiment, and the six experiments reported here) in Table 5. Two things stand out when looking at the results. First, although there is some variability in the size of the odds ratios seen in the "no delay" experiments, Experiment 2, and Kaschak, Kutta, & Schatschneider's (2011) experiment, the confidence intervals suggest that the effects are generally uniform. That is, the effects are of a similar magnitude when the Bias and Priming phases use the same task (regardless of the delay between phases of the experiment), and when different combinations of Bias and Priming phase tasks are employed within a single-session experiment. Second, the two experiments in which the task changes between the Bias and Priming phases of the study, and there is a delay between the two phases, show a different profile. The odds ratios for both of these experiments are within the confidence intervals of only one of the experiments showing a cumulative priming effect (Experiment 2, which seems to have a wide confidence interval compared to the other studies), and the confidence intervals surrounding the odds ratios for the changed-task delay experiments do not include the odds

ratios for any of the other experiments. Thus, it appears that the cumulative priming effects are different in the two changed-task delay experiments, and that cumulative priming effects do not persist strongly over a week when the language production task changes between the Bias and Priming phases.

To tackle this issue in a different way, we performed a combined analysis of the experiments involving a delay of one week (Kaschak, Kutta, & Schatschneider, 2011; Experiments 2, 4, and 6 here). We performed a mixed logit analysis predicting the log odds of producing a DO target stem or target picture response. The analysis included participants and items as crossed random factors with random intercepts. We included the following predictors: Bias condition (DO bias = 1, PO bias = 0), Match (Priming phase uses the same task as the Bias phase = 1, Different tasks = 0), Task type (Written stem completion = 1, Picture description = 0), and the Bias \times Match interaction. Other interactions were not included in the model, as they did not improve model fit.³ Random slopes are not included, as they did not improve model fit. The results are presented in Table 6. The Bias condition effect was not significant ($p = .15$), which is not surprising given that half of the studies included in the analysis did not show a Bias effect. There was an effect of Task type ($p < .001$), indicating that participants in the stem completion tasks were less likely to produce a DO response than participants in the picture description tasks.⁴ Critically, there was an interaction of Bias condition and Match, indicating that the Bias condition effect is different in the matching conditions (same task in Bias and Priming phases) than in the nonmatching conditions (different task across phases of the experiment). The lack of interactions with Task type suggests that this pattern is the same whether one is dealing with the stem completion task or the picture description task. This analysis strengthens the claim that cumulative priming effects persist for a week when the same task is used in the Bias and Priming phases, but not when tasks change across phases of the study.

GENERAL DISCUSSION

The experiments described in this paper were designed to answer two questions. First, do cumulative structural priming effects transfer across language production tasks? The answer to this question is affirmative. Experiment 3 (as well as Kaschak, 2007, Experiment 3) showed transfer of cumulative priming effects from a stem completion Bias phase to a picture description Priming phase, and Experiment 5 showed transfer of cumulative priming effects from a picture description Bias phase to a stem completion Priming phase. Second, do cumulative priming effects transfer across tasks when the Bias and Priming phases are separated by one week? The results of Experiments 4 and 6 suggest that such transfer does not occur. The effects of the Bias condition were not observed in transfer from a stem completion task to a picture description task, or from a picture description task to a stem completion task, when the Priming phase was delayed by one week. It is worth pointing out that Experiments 4 and 6 both showed a hint of the Bias effect (i.e., more DO responses following the DO Bias condition), suggesting that it may be inaccurate to say that the Bias effect does not transfer at all; rather, it may be that the effect is merely attenuated (not eliminated). Experiments 1 and 2 replicated the results of Kaschak (2007), Experiment 1, and Kaschak, Kutta, & Schatschneider (2011), demonstrating that cumulative priming can be observed with a picture description task, and that these effects persist over the course of a

week. These data lend support to the general conclusion that whereas cumulative priming effects transfer across tasks within a single experiment, cumulative priming effects only persist across time when the same task is used in the Bias and Priming phases of the study.

The results of these studies are consistent with the idea that the language production system tracks the probabilities of use for particular syntactic constructions in a task specific manner. Simply reinstating the general context of the experiment (in terms of location, computers, and the like) does not appear to be enough to reinstate the effects of the Bias phase across the course of a week. Rather, it appears that the same language production task needs to be employed in the Bias and Priming phases of the experiment for long-range Bias effects to be observed. The patterns observed here are consistent with reports from the memory literature suggesting that the match between learning/ encoding conditions and retrieval conditions is more important as the lag between encoding and retrieval increases (e.g., Craik, 2003; Read & Craik, 1995).

Why is it that cumulative priming effects transfer across tasks in experiments with no delay between the Bias and Priming phases, but not in experiments in which a delay is introduced between phases of the experiment? We do not have a definitive answer to this question, but offer the following speculation. The results of several experiments (Coyle & Kaschak, 2008; Kaschak, 2007; Kaschak & Borreggine, 2008; Kaschak et al., 2006) suggest that at the end of the Bias phase of the experiment, we have successfully manipulated the likelihood of participants' producing a DO or PO construction. When the same task is used in the Priming phase (and there is no delay before the Priming phase) the Bias effect carries over directly to the Priming phase of the study. When the task changes (and there is no delay before the Priming phase), there is less match between the Bias and Priming phases, but this is offset by the fact that no experience with the DO and PO constructions has intervened between the Bias and Priming phases. Thus, the adaptation that has occurred in the language production system during the Bias phase is still in effect to influence production in the Priming phase. When a week-long delay intervenes between the Bias and Priming phases, participants will have a lot of linguistic experience (including experience with the DO and PO constructions), and this experience will likely work against the biases established within the experiment. As such, observation of a bias effect after a delay of one week depends on the participant retrieving memory of their patterns of use for the DO and PO constructions from the experiment a week before. It is more likely that this will occur when the same task is used in the Bias and Priming phases, and as such the bias effect can be observed a week later when the same task is used in the Bias and Priming phases, but not when the task switches between phases.

The finding of task specificity in the long-term persistence of cumulative priming raises the issue of whether explicit memory or strategic processes are involved in the persistence of the effect. We did not measure explicit memory for sentences encountered during the Bias phase, and did not question participants about the strategies that they might have employed. As such, we cannot definitively rule out the possibility that the persistence of cumulative priming is driven by explicit memory for sentences encountered during the Bias phase, or by some other strategic processes. In other published and unpublished studies from our laboratory that use similar methods, we asked participants whether they were aware of the

cumulative priming manipulation. Participants rarely, if ever, had any idea about the syntactic manipulations that were employed. As the current studies use methods similar to the previous work from our laboratory, we think it is unlikely that awareness of our manipulations or task-related strategic processing is driving these effects. This is not to say that when participants encounter a given target stem or target picture during the Priming phase, they do not occasionally explicitly remember a sentence produced earlier in the experiment*whether it is from earlier in the Priming phase or from the Bias phase. Our intuition is that we sometimes experience this sort of memory retrieval when producing language in our daily lives (e.g., in a given context, we may be reminded of an utterance that we produced previously, and this shapes our subsequent utterances). As such, it is possible that long-range effects of previous experience on subsequent language production receive contributions from both implicit and (under some circumstances) explicit memory processes.

The data reported here have implications for our understanding of structural priming. It has been suggested that structural priming is the result of implicit or procedural learning within the language production system (e.g., Chang et al., 2006; Ferreira, Bock, Wilson, & Cohen, 2008), and the results of our studies are generally consistent with this claim. Implicit learning studies have shown long lasting effects similar to those reported by Kaschak, Kutta, & Schatschneider (2011; e.g., Allen & Reber, 1980; Kolers, 1976), but (as seen here) the demonstration of these effects over long stretches of time depends on the match between the initial conditions of learning and the later test of the persistence of learning (e.g., Kolers, 1976). Though much remains to be understood about the ways that different memory mechanisms contribute to structural priming (see Hartsuiker, Berolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; and Chang et al., 2006, for a discussion of the role of explicit and implicit memory in structural priming), our results suggest that there is almost certainly an implicit learning component to the observed priming effects.

Our data contribute to a growing body of literature suggesting that language comprehenders (e.g., Dell et al., 2000; Farmer, Fine, & Jaeger, 2011; Kaschak, 2006; Kaschak & Glenberg, 2004; Kraljic, Brennan, & Samuel, 2008; Kraljic & Samuel, 2005; Wells, Christiansen, Race, Acheson, & MacDonald, 2009) and producers (e.g., Jaeger & Snider, 2008; Kaschak, 2007) can readily adapt to the probabilistic structure of their linguistic environment. We see an affinity between these observations and other findings showing that individuals frequently adapt their behaviour to that of their conversational partners (e.g., Brennan & Clark, 1996; Pickering & Garrod, 2004). Adults seem to be quite capable of adjusting their patterns of language use within a specific context (e.g., a conversation, or an experiment). Beyond this general conclusion, the task-specific nature of long-term cumulative priming suggests that such effects may be driven (at least in part) by something other than adaptations to purely abstract syntactic representations. Performance of our experimental tasks may result in adaptations to abstract syntactic representations as well as memory for the procedures involved in the process of going from the information presented on any given trial (whether it be a sentence stem or a picture) to the production of a full sentence (see Kolers & Roediger, 1984, for evidence for the storage of this sort of procedural memory). From the perspective of a dual-representation view such as this one, our data suggest that adaptations to abstract syntactic representations may not be as long lasting as memory for

the processing work that went into turning the linguistic or pictorial input provided to the participants into an appropriate response for the task.

An alternative way to handle the task-specific nature of long-term cumulative priming may be to propose that representations of syntactic knowledge are themselves procedural in nature (in the sense of Kolers & Roediger, 1984). Kaschak and Glenberg (2004) proposed that syntactic representations may contain not only elements of linguistically-relevant information, but also elements of the processing work (such as the processing required to go from viewing a picture to generating a sentence describing that picture) that goes into handling that linguistic information. A proceduralist approach to syntactic representation (or, as Kaschak & Glenberg, 2004, called it, an *episodic-processing* approach) is consistent with functional linguistics approaches (such as Construction Grammar; Goldberg, 1995; Kaschak & Glenberg, 2000; Kay & Fillmore, 1999) which hold that representations of syntactic constructions contain information about the structure, function, and pragmatics of particular sentence types (i.e., not only abstract syntactic information, but also information about conventional uses and interpretations for a given construction). Although it is our sense that the data at hand suggest that memory for the processing operations employed during task performance play an important role in facilitating longterm cumulative priming effects, the current set of observations do not allow us to adjudicate between the dual-representation and single-representation approaches to integrating syntactic knowledge with other sorts of procedural knowledge that are presented here.

Finally, our data have implications for extant theories of structural priming (e.g., Chang et al., 2006; Pickering & Branigan, 1998). Our claim that the effects seen here reflect implicit learning and (perhaps) a proceduralist approach to syntax are in keeping with the spirit of Chang et al.'s (2006) model of structural priming. However, it is presently unclear whether the architecture of their model would capture the task-specificity of the transfer effects seen in our delay conditions. A similar assessment can be made of Pickering and Branigan's (1998) model. Whereas our cumulative priming effects are consistent with the general architecture of their model, it is less clear how the task-specificity of the transfer effects in the delay conditions would be implemented in their model. One possibility might be to add a "procedural" component to the model to account for the processing differences that occur across different production tasks. On a broader level, it is worth noting that both approaches to structural priming are essentially single-mechanisms theories (Chang et al., 2006 use error-driven implicit learning; Pickering & Branigan, 1998, use activation between nodes representing lexical and syntactic information). Although more work needs to be done to understand the learning and memory mechanisms at play in our studies, we believe that it is not unreasonable to expect that some combination of implicit and explicit processes are involved in producing long-range priming effects. To the extent that these effects are driven by a combination of memory processes, it will be necessary to revise extant models of structural priming to reflect the multiplicity of mechanisms involved (see Reitter, Keller, & Moore, 2011, for an example of a model that incorporates multiple memory mechanisms).

In conclusion, our data suggest that cumulative structural priming effects developed in the Bias phase of these experiments transfers across language production tasks – provided the second (changed) language production task is presented in the same experimental session.

Whereas it is clear that we have only begun to explore the task-specific and temporal parameters of long-range structural priming effects, we nonetheless believe that an exploration of these elements of structural priming effects will be rewarded by a deeper understanding of the ways that different memory mechanisms contribute to speakers' tendency to repeat syntactic constructions across utterances.

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Appendix 1

Prime sentences from the picture description Bias phases. DO versions are presented first.

1. The girl handed the boy a paintbrush/The girl handed a paintbrush to the boy
2. The boy tossed the girl a ball/The boy tossed a ball to the girl
3. The children showed the teacher a picture/The children showed a picture to the teacher
4. The salesman showed the couple a car/The salesman showed the car to the couple
5. The nurse gave the patient some water/The nurse gave some water to the patient
6. The man passed the woman a pitcher of water/The man passed a pitcher of water to the woman
7. The boy handed the singer a guitar/The boy handed the guitar to the singer
8. The girl handed the teacher the flowers/The girl handed the flowers to the teacher
9. The woman threw the dog a bone/The woman threw a bone to the dog
10. The server gave the man a menu/The server gave a menu to the man

Appendix 2

Prime stems used in the Bias phase of experiments using the written stem completion task. DO eliciting prime is listed first.

1. The swimmer handed the diver/The swimmer handed the towel
2. The good looking bartender gave the girls at the bar/The good looking bartender handed free drinks
3. The millionaire gave the struggling artist/The millionaire loaned the valuable painting
4. The unhappy customer sent the business owner/The unhappy customer handed the long fax
5. The woman sent the insurance company/The woman handed the claim
6. The builder handed his new client/The builder loaned the blueprints

7. The lecturer loaned the professor/The lecturer lent the book
8. The architect sent the president of the company/The architect gave the model of the building
9. The grandmother handed the little girl/The grandmother gave the big present
10. The photographer loaned the editor/The photographer sent the finished proofs
11. The researcher sent the experienced surgeon/The researcher sent the detailed results
12. The happy child gave her father/The happy child handed the coloring book
13. The captain handed the old sailor/The captain handed the spare life jacket
14. The eager boyfriend handed his girlfriend/The eager boyfriend gave the box of flowers
15. The secretary gave the manager/The secretary handed the invoice
16. The mean neighbor lent the woman next door/The mean neighbor gave a nasty note
17. The travel agent lent the young fan/The travel agent handed the last ticket
18. The ship's captain handed the admiral/The ship's captain lent her travel log
19. The mother handed the hungry toddler/The mother gave the expensive toy
20. The young couple sent the IRS investigator/The young couple sent their mortgage payment

Appendix 3

Scene descriptions and target verbs for the pictures used in the Priming phases involving the picture description task.

1. Boy handing a Valentine to a girl – HANDED
2. Librarian giving book to a patron – LOANED
3. Student handing teacher an apple – GAVE
4. Waitress offering drinks to partygoers – OFFERED
5. Children handing flowers to a man – HANDED
6. Man reading a book to a child – READ

Appendix 4

Target stems from the Priming phase of studies employing the written stem completion task.

1. The politician sent
2. The librarian lent
3. The famous novelist sent
4. The consultant loaned

5. The mailman gave
6. The kidnapper sent
7. The pianist sent
8. The fisherman gave
9. The investigator lent
10. The policeman handed
11. The worker lent
12. The businessman sent
13. The runner handed
14. The woman gave
15. The fireman handed
16. The diver handed
17. The writer gave
18. The owner lent
19. The artist handed
20. The repairman loaned

References

- Allen R, Reber AS. Very long-term memory for tacit knowledge. *Cognition*. 1980; 8:175185.
- Bock JK. Syntactic persistence in language production. *Cognitive Psychology*. 1986; 18:355387.
- Bock JK. Closed-class imminence in sentence production. *Cognition*. 1989; 31:163186.
- Bock K, Dell GS, Chang F, Onishi K. Structural persistence from language comprehension to language production. *Cognition*. 2007; 104:437458.
- Bock JK, Griffin ZM. The persistence of structural priming: Transient activation or implicit learning? *Journal of Experimental Psychology: General*. 2000; 129:177192.
- Bock, JK.; Kroch, AS. The isolability of syntactic processing. In: Carlson, GN.; Tanenhaus, MK., editors. *Linguistic structure in language processing* Dordrecht. The Netherlands: Reidel; 1989.
- Branigan HP, Pickering MJ, Cleland AA. Syntactic priming in written production: Evidence for rapid decay. *Psychonomic Bulletin and Review*. 1999; 6:635640.
- Branigan HP, Pickering MJ, Cleland AA. Syntactic coordination in dialogue. *Cognition*. 2000; 75:B13–B25. [PubMed: 10771277]
- Branigan HP, Pickering MJ, McLean JF. Priming prepositional phrase attachment during comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 2005; 31:468481.
- Brennan SE, Clark HH. Conceptual pacts and lexical choice in conversation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1996; 22:14821493.
- Brooks PA, Tomasello M. Young children learn to produce passives with nonce verbs. *Developmental Psychology*. 1999; 35:2944.
- Chang F. Implicit learning as a mechanism of language change. *Theoretical Linguistics*. 2008; 34:115122.
- Chang F, Dell GS, Bock K. Becoming syntactic. *Psychological Review*. 2006; 113:234272.

- Cleland AA, Pickering MJ. Do writing and speaking employ the same syntactic representations? *Journal of Memory and Language*. 2006; 54:185-198.
- Coyle JM, Kaschak MP. Patterns of experience with verbs affect long-term cumulative structural priming. *Psychonomic Bulletin and Review*. 2008; 15:967-970.
- Craik, FIM. Commentary. In: Bowers, JS.; Marsolek, CJ., editors. *Rethinking implicit memory*. New York, NY: Oxford University Press; 2003.
- Crowder, RG. Systems and principles in memory theory: Another critique of pure memory. In: Collins, AF.; Gathercole, SE.; Conway, MA.; Morris, PE., editors. *Theories of memory*. Hillsdale, NJ: Lawrence Erlbaum Associates; 1993. p. 139-161.
- Dell GS, Reed KD, Adams DR, Meyer AS. Speech errors, phonotactic constraints, and implicit learning: A study of the role of experience in language production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 2000; 26:1355-1367.
- Farmer, T.; Fine, AB.; Jaeger, TF. Implicit context-specific learning leads to rapid shifts in syntactic expectations. In: Carlson, L.; Hoelscher, C.; Shipley, TF., editors. *33rd Annual Meeting of the Cognitive Science Society*. Austin, TX: Cognitive Science Society; 2011.
- Ferreira VS, Bock K, Wilson MP, Cohen NJ. Memory for syntax despite amnesia. *Psychological Science*. 2008; 19:940-946.
- Goldberg, AE. *Constructions: A construction grammar approach to argument structure*. Chicago, IL: University of Chicago Press; 1995.
- Goldinger SD. Words and voices: Episodic traces in spoken word identification and recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1996; 22:1166-1183.
- Goldinger SD. Echoes of echoes? An episodic theory of lexical access. *Psychological Review*. 1998; 105:251-279.
- Gries ST. Syntactic priming: A corpus-based approach. *Journal of Psycholinguistic Research*. 2005; 34:365-399.
- Griffin ZM, Weinstein-Tull J. Conceptual structure modulates structural priming in the production of complex sentences. *Journal of Memory and Language*. 2003; 49:537-555.
- Hartsuiker RJ, Bernolet S, Schoonbaert S, Speybroeck S, Vandervorst D. Syntactic priming persists while the lexical boost decays: Evidence from written and spoken dialogue. *Journal of Memory and Language*. 2008; 58:214-238.
- Hartsuiker RJ, Kolk HHJ. Syntactic persistence in Dutch. *Language and Speech*. 1998; 41:143-184.
- Hartsuiker RJ, Pickering MJ, Veltkamp E. Is syntax separate or shared between languages? *Psychological Science*. 2004; 15:409-414.
- Hartsuiker RJ, Westenberg C. Word order priming in written and spoken sentence production. *Cognition*. 2000; 75:B27-B39. [PubMed: 10771278]
- Jaeger TF. Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*. 2008; 59:434-446.
- Jaeger, TF.; Snider, N. Implicit learning and syntactic persistence: Surprisal and cumulativity. In: Love, BC.; McRae, K.; Sloutsky, VM., editors. *Proceedings of the 30th Annual Conference of the Cognitive Science Society*. Washington, DC; Cognitive Science Society; 2008.
- Kaschak MP. What this construction needs is generalized. *Memory and Cognition*. 2006; 34:368-379.
- Kaschak MP. Long-term structural priming affects subsequent patterns of language production. *Memory and Cognition*. 2007; 35:925-937.
- Kaschak MP, Borreggine KL. Is long-term structural priming affected by patterns of experience with individual verbs? *Journal of Memory and Language*. 2008; 58:862-878.
- Kaschak MP, Glenberg AM. Constructing meaning: The role of affordances and grammatical constructions in sentence comprehension. *Journal of Memory and Language*. 2000; 43:508-529.
- Kaschak MP, Glenberg AM. This construction needs learned. *Journal of Experimental Psychology: General*. 2004; 133:450-467. [PubMed: 15355149]
- Kaschak MP, Kutta TJ, Jones JL. Structural priming as implicit learning: Cumulative priming effects and individual differences. *Psychonomic Bulletin and Review*. 2011; 18:1133-1139.

- Kaschak MP, Kutta TJ, Schatschneider C. Long-term cumulative structural priming persists for (at least) a week. *Memory and Cognition*. 2011; 39:381388.
- Kaschak MP, Loney RA, Borreggine KL. Recent experience affects the strength of structural priming. *Cognition*. 2006; 99:B73–B82. [PubMed: 16115618]
- Kay P, Fillmore CJ. Grammatical constructions and linguistic generalizations: The What's X doing Y? *Construction. Language*. 1999; 75:133.
- Kolers PA. Reading a year later. *Journal of Experimental Psychology: Human Learning and Memory*. 1976; 2:554565.
- Kolers PA, Roediger HL. Procedures of mind. *Journal of Verbal Learning and Verbal Behavior*. 1984; 23:425449.
- Kraljic T, Brennan SE, Samuel AG. First impressions and last resorts: How listeners adjust to speaker variability. *Psychological Science*. 2008; 19:332338.
- Kraljic T, Samuel AG. Perceptual learning for speech: Is there a return to normal? *Cognitive Psychology*. 2005; 51:141178.
- Levelt W, Kelter S. Surface form and memory in question answering. *Cognitive Psychology*. 1982; 14:78106.
- Masson MEJ. Memory for the surface structure of sentences: Remembering with and without awareness. *Journal of Verbal Learning and Verbal Behavior*. 1984; 23:579592.
- Mitchell DB. Unconscious priming after 17 years: Invulnerable implicit memory? *Psychological Science*. 2006; 17:925929.
- Pickering MJ, Branigan HP. The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language*. 1998; 39:633651.
- Pickering MJ, Ferreira VS. Structural priming: A critical review. *Psychological Bulletin*. 2008; 134:427459.
- Pickering MJ, Garrod S. Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences*. 2004; 27:169226.
- Raudenbush, SW.; Bryk, AS.; Cheong, YF.; Congdon, R. HLM 6: Hierarchical linear and nonlinear modeling. Lincolnwood, IL: Scientific Software International; 2004.
- Read D, Craik FIM. Earwitness identification: Some influences on voice recognition. *Journal of Experimental Psychology: Applied*. 1995; 1:618.
- Reitter D, Keller F, Moore JD. A computational cognitive model of syntactic priming. *Cognitive Science*. 2011; 35:587637.
- Savage C, Lieven E, Theakston A, Tomasello M. Testing the abstractness of children's linguistic representations: Lexical and structural priming of syntactic constructions in young children. *Developmental Science*. 2003; 6:557567.
- Scheepers C. Syntactic priming of relative clause attachments: Persistence of structural configuration in sentence production. *Cognition*. 2003; 89:179205.
- Tomasello, M. Acquiring linguistic constructions. In: Kuhn, D.; Siegler, R., editors. *Handbook of child psychology*. New York, NY: Wiley; 2006.
- Weiner EJ, Labov W. Constraints on the agentless passive. *Journal of Linguistics*. 1983; 19:2958.
- Wells JB, Christiansen MH, Race DS, Acheson DJ, MacDonald MC. Experience and sentence comprehension: Statistical learning and relative clause comprehension. *Cognitive Psychology*. 2009; 58:250271.
- Wheeldon LR, Smith MC. Phrase structure priming: a short lived effect. *Language and Cognitive Processes*. 2003; 18:431442.

Comparison of Kaschak (2007) Experiment 1, and Kaschak, Kutta, & Schatschneider (2011).

Table 1

Mixed logit analysis results						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	-0.97	0.43	-2.25	451	.03	0.38
Bias condition	1.68	0.41	4.07	451	<.001	5.38
Delay condition	0.19	0.57	0.33	451	.74	1.21
Bias × Delay	-0.12	0.65	-0.19	451	.85	0.88
Proportion of DO responses						
	Raw means		Estimated means			
	DO bias	PO bias	DO bias	PO bias	DO bias	PO bias
Kaschak (2007)	0.66	0.33	0.73	0.20		
Kaschak, Kutta, & Schatschneider (2011)	0.66	0.34	0.68	0.32		

Table 2

Mixed logit models from Experiments 1 and 2.

Mixed logit analysis results						
<i>Experiment 1</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	0.99	0.37	2.69	245	.008	2.68
Bias condition	1.50	0.52	2.87	245	.008	4.47
<i>Experiment 2</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	1.48	0.41	3.59	246	.001	4.41
Bias condition	1.64	0.69	2.39	246	.02	5.16
<i>Combined analysis</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	1.03	0.39	2.61	491	.01	2.79
Bias condition	1.51	0.57	2.65	491	.009	4.54
Delay condition	0.41	0.52	0.79	491	.43	1.51
Bias × Delay	0.10	0.85	0.12	491	.91	1.10
<i>Proportion of DO responses</i>						
Raw means			Estimated means			
	DO bias	PO bias	DO bias	PO bias	DO bias	PO bias
Experiment 1	0.91	0.70	0.92	0.73	0.73	0.81
Experiment 2	0.94	0.76	0.96	0.81	0.96	0.81

Table 3

Mixed logit models from Experiments 3 and 4.

Mixed logit analysis results						
<i>Experiment 3</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	0.64	0.59	1.09	436	.28	1.90
Bias condition	1.51	0.38	3.99	436	<.001	4.54
<i>Experiment 4</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	1.19	0.57	2.10	432	.036	3.30
Bias condition	0.44	0.37	1.21	432	.23	1.56
<i>Combined analysis</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	0.62	0.58	1.08	868	.28	1.87
Bias condition	1.53	0.38	4.05	868	<.001	4.61
Delay condition	0.59	0.36	1.65	868	0.10	1.80
Bias × Delay	-1.07	0.53	-2.03	868	.04	.34
<i>Proportion of DO responses</i>						
	Raw means	Estimated means				
	DO bias	PO bias	DO bias	PO bias	DO bias	PO bias
Experiment 3	0.83	0.62	0.90	0.65		
Experiment 4	0.79	0.72	0.84	0.77		

Table 4

Mixed logit models from Experiments 5 and 6.

Mixed logit analysis results						
<i>Experiment 5</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	-0.84	0.38	-2.21	284	.03	.43
Bias condition	1.33	0.44	3.06	284	.003	3.80
<i>Experiment 6</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	-0.44	0.33	-1.32	256	.19	0.64
Bias condition	0.33	0.37	0.88	256	.38	1.39
<i>Combined analysis</i>						
Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	-0.88	0.38	-2.32	540	.02	0.42
Bias condition	1.36	0.42	3.27	540	.002	3.89
Delay condition	0.37	0.42	.87	540	.38	1.44
Bias × Delay	-0.98	0.59	-1.65	540	.10	0.37
<i>Proportion of DO responses</i>						
	Raw means	Estimated means				
	DO bias	PO bias	DO bias	PO bias	DO bias	PO bias
Experiment 5	0.64	0.39	0.62	0.30	0.30	0.30
Experiment 6	0.47	0.43	0.47	0.39	0.39	0.39

Table 5

Odds ratios and confidence intervals for across experiments.

Phase 1 task	Phase 2 task	Delay?	Odds ratio	CI lower bound	CI upper bound
Writ stem	Writ stem	No	5.74	2.31	14.23
Writ stem	Writ stem	Yes	4.54	2.00	10.31
Writ stem	Pict descript	No	4.55	2.16	9.56
Writ stem	Pict descript	Yes	1.56	0.76	3.19
Pict descript	Writ stem	No	3.80	1.61	8.95
Pict descript	Writ stem	Yes	1.39	0.67	2.89
Pict descript	Pict descript	No	4.47	1.60	12.51
Pict descript	Pict descript	Yes	5.16	1.34	19.92

Note: The above statistics come from the following sources. Writ stem/Writ stem, no delay = Kaschak (2007), Experiment 1; Writ stem/Writ stem, Delay = Kaschak, Kutta, & Schatschneider (2011); Writ stem/Pict descript, no delay = current Experiment 3; Writ stem/Pict descript, delay = current Experiment 4; Pict descript/Writ stem, no delay = current Experiment 5; Pict descript/Writ stem, delay = current Experiment 6; Pict descript/Pict descript, no delay = current Experiment 1; Pict descript/Pict descript, delay = current Experiment 2.

Table 6
Mixed logit model comparing results of experiments with delayed priming phases.

Predictor	Coefficient	SE	t-value	df	p-value	Odds ratio
Intercept	1.21	0.44	2.78	1,124	.006	3.36
Bias condition	0.39	0.27	1.45	1,124	.15	1.47
Match	-0.35	0.30	-1.17	1,124	.24	0.70
Bias \times Match	1.15	0.45	2.56	1,124	.01	3.15
Task type	-1.66	0.48	-3.44	1,124	.001	0.19