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Syntactic priming in English sentence production: Categorical and latency evidence from an Internet-based study

MARTIN CORLEY
University of Edinburgh, Edinburgh, Scotland

and

CHRISTOPH SCHEEPERS
Saarland University, Saarbrücken, Germany

To date, syntactic priming in sentence production has been investigated categorically, in terms of the probabilities of reusing particular syntactic structures. In this paper, we report a web-based replication of Pickering and Branigan (1998), Experiment 1, using a typed sentence completion paradigm that made it possible to record not only the responses made but also the response onset latency for each sentence completion. In conditions where priming occurred (as determined categorically), responses took less time when target completions were of the same type as preceding prime completions than when they differed. As well as validating Internet-based research by direct comparison with laboratory-based work, our findings strengthen the support for an architectural account of syntactic priming as envisaged by Pickering and Branigan.

The phenomenon of syntactic priming has now been well attested in a series of studies. When participants are given a message to produce that can be realized using more than one structure, they are likely to utter or write the form that they have most recently uttered (Bock, 1986), written (Pickering & Branigan, 1998), or heard (Branigan, Pickering, & Cleland, 2000). For example, participants are more likely to produce *The girl handed the paintbrush to the man* after *The rock star sold some cocaine to an undercover agent* (both contain prepositional object, or PO, structures). However, following a double object (DO) such as *The rock star sold an undercover agent some cocaine*, they are more likely to produce *The girl handed the man the paintbrush.* In such experiments, the first and second sentences are referred to as the *prime* and *target* respectively.

A series of studies (Bock & Loebell, 1990; Bock, Loebell, & Morey, 1992) has established that this tendency to repeat structure is best conceived of at the syntactic level. For example, primes such as *Mary brought a book to study* fail to elicit more PO targets, despite the superficial similarity between different syntactic forms. On the other hand, primes such as *Mary bought a book for John* do increase the number of PO targets containing prepositional phrases (PPs) beginning with *to*, even though the prime contains *for.* Another potential nonsyntactic explanation of structure repetition is ruled out by the fact that the thematic role played by the PP in the prime does not appear to have an effect: For example, *The widow drove the Mercedes to the church*—in which the PP denotes a location rather than a recipient—renders PO target responses more likely, even when the target PP specifies a recipient. There is some evidence, however, from languages with variable constituent ordering suggesting that the order of constituents in the prime may be reflected in target completions (Hartsuiker & Westenberg, 2000; Scheepers & Corley, 2000).

The arguments surrounding such findings tend to center around the architecture of the system responsible for language production. For example, Pickering and Branigan (1998) have followed Bock and Levelt (1994) in arguing that in the production lexicon, verbs have distinct *lemma* (approximately, syntacto-semantic) and *lexeme* (lexical form) representations. To account for syntactic priming, Pickering and Branigan assumed that on the lemma stratum, verbs are linked to "combinatorial" nodes, which express the constructions in which a verb can be used. A ditransitive verb such as <give> would have links to (at least) two of the available combinatorial nodes, representing <NP NP> (give the dog a bone) and <NP PP> (give the bone to a dog) combinations. Given standard assumptions about decaying activation, the priming of *The girl handed the paintbrush to a man* by *The rock star sold some cocaine to an undercover agent* is accounted for by suggesting that the <NP PP> node retains some activation, and thus reaches threshold more easily, when the second utterance is made.

Pickering and Branigan (1998) supported their model using a paradigm in which participants provide handwrit-

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ten completions for partial sentences (see also Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995). The prime sentences are pragmatically constrained in such a way that the most likely completion is of a given form, but the target sentences remain unconstrained (further details are given in the Method section below). In line with the model, participants are more likely to produce target sentences with the same syntactic structures as their primes. Moreover, the priming effect becomes stronger when the verb is repeated between prime and target (in Experiment 1, replicated below, different verb primes failed to elicit significant effects). Pickering and Branigan assume that activation from both lemma and combinatorial nodes contributes to the same verb effect.

However, such findings may be open to alternative interpretations. For example, each of the studies can be seen as dialogues: either explicitly, between the participant and a stooge, or implicitly, between the experimenter and the participant, in speech or writing (see Branigan et al., 2000, for a similar argument). This interpretation leaves open the suggestion that participants are "collaborating" with their interlocutors, either strategically, or in a Gricean sense, to achieve effective communication. Where there is greater overlap between prime and target (in the sense of repeated verbs), the communicative advantages of structure repetition are greater. Such an alternative account remains neutral as to the *mechanism* for production.

Evidence consistent with an automatic priming mechanism such as that envisaged by Pickering and Branigan (1998) would be provided by a study demonstrating that the *time* to produce a target consistent with its prime is reduced (relative to that needed to produce an inconsistent target); in their model, reduced production latencies would follow from the fact that (combinatorial or lemma) nodes with residual activation would reach their thresholds earlier than nodes that have not been activated before. (That is, the mechanism responsible for structure repetition would, of necessity, entail reduced latencies for repeated structure.) A prediction of reduced production time for targets consistent with their primes could also be accommodated within a "communicative" account (e.g., a reduction in uncertainty over candidate syntactic structures might be predicted to lead to a quicker production process). However, making such a prediction would require the extension of Branigan et al.'s (2000) account as it currently stands. In principle, at least, their proposal could equally be extended to accommodate *higher* response latencies for structure repetition (e.g., by assuming that the decision to reuse a previous structure might sometimes conflict with "lower level" production mechanisms). Models based on implicit learning (e.g., Chang, Dell, Bock, & Griffin, 2000) are also currently underspecified with respect to latency predictions.

This study, therefore, focuses on the Pickering and Branigan (1998) model, with two specific aims. The first is to investigate the consequences of experimentation using the World-Wide Web. Using the web means that the participant group, as well as the conditions under which the experiment is carried out, are open to much greater variation than in traditional laboratory-based studies. Results replicating the findings in Pickering and Branigan would not only contribute to the validation of Internet-based research, but would also demonstrate that syntactic priming is a robust, highly replicable phenomenon.

The second aim is to test the latency predictions that follow directly from the Pickering and Branigan (1998) model. By requiring participants to type (rather than handwrite) their responses, the time needed to produce a sentence completion can be approximated by the time needed to press the first key of a sentence completion (we assume that a response is generated before typing commences). If syntactic priming is a consequence of residual activation in combinatorial or lemma nodes, we would expect target completions consistent with their primes to be faster to generate, in conditions where priming can be shown to occur. On the methodological side, it is of interest whether such latency effects can be established over the web at all.

METHOD

Participants

Sixty-six participants, all self-reported as native speakers of English, took part in an experiment administered via the World-Wide Web. The participants were attracted either by advertisements posted to Usenet newsgroups or by links from other websites. The average age of participants was 33 years (range 15–61). Participants were asked to indicate which dialect of English they spoke. Of the answers given, 38% identified the respondents as coming from the United States, 32% from the United Kingdom, and 6% from other English-speaking regions. The remaining answers were not specific enough to determine participants' provenance (e.g., 12 participants reported their dialects as "English"). Reported occupations ranged from mechanic to marketing director (33% of participants reported themselves as undergraduate or postgraduate students).

Materials

The materials were taken from Pickering and Branigan (1998), Experiment 1. Experimental items consisted of a prime sentence fragment followed by a target fragment. There were four variants of each prime fragment (see below), each consisting of a subject noun phrase (NP), a ditransitive verb, and an NP immediately following the verb. The second NP was either inanimate, making it more probable that participants would complete the sentence using a prepositional object (PO) construction (e.g., 1a and 1c), or animate, rendering a double object (DO) completion more likely (1b and 1d). The NPs used were always simple, consisting of determiner, optional adjective, and noun or noun compound.

(1a) The bank manager handed the cheque . . .

(1b) The bank manager handed the customer . . .

(1c) The bank manager gave the cheque . . .

(1d) The bank manager gave the customer . . .

Target fragments consisted of a subject NP and a ditransitive verb (e.g., see below). Since no complement NPs were given, participants were free to complete these fragments as either PO or DO constructions.

(2) The junior surgeon handed . . .

Thirty-two sets of materials similar to those in (1) and (2) were used. For each material set, the target could be combined with each of four primes to form four prime–target pairs. The two factors manipulated across conditions were verb repetition (the prime contained the same verb as, or a different verb from, the target) and (likely) prime completion (PO or DO). The 32 sets of four prime–target pairs were arranged into four files so that eight exemplars of each condition occurred in each file, and only one pair from a particular prime–target set occurred in any file. To each of the four files, 64 filler sentence fragments were added (bringing the total number of sentences to be completed in each file to 128). These were of varying syntactic form, subject to the constraint that they contained no ditransitive verbs and were unlikely to be completed with PP constructions.

Procedure

The experiment was administered on the World-Wide Web using WebExp experimental software (Keller, Corley, Corley, Konieczny, & Todirascu, 1998).[1] When participants first entered the experimental site (via http://surf.to/experiments), they were presented with instructions explaining that their task was to complete the sentence fragments, using the "first completions that came to mind." They were informed that there were no right or wrong answers but that continuations had to be "acceptable" (which was defined as grammatically correct and reasonably plausible).

Clicking on a Start button started the WebExp Java applet. Participants were initially presented with a dialogue box asking them for their e-mail address, in addition to biographical information (age, profession, etc.). Once this information had been entered the experiment proper started: The software selected one of the four files of materials and randomized them, subject to the constraint that each group of four sentence fragments consisted of two fillers followed by a prime–target pair. Each sentence fragment was presented above a dialogue box into which participants could type their completions. In addition to recording the order of presentation and content of the completions, the software recorded the times taken to press the first key of a response and to press the Return key to complete a response (each accurate to within approximately 16 msec).[2] Once a response had been completed, the next fragment was displayed. Participants were unable to inspect previous fragments or completions.

At the end of the experiment, a "thank you" message appeared on the participant's browser, and an e-mail was dispatched to the address the participant had typed in. This thanked the participant and informed him/her that a debriefing would be sent to that address once the study was complete.

Information such as participants' e-mail addresses and other information that could be automatically requested from their browsers (such as the Internet address of the machine they were using) was recorded and used to ensure that participants didn't take part in the experiment twice.

Coding of Responses

Completed prime and target fragments were classified as PO, DO, or Other using the same criteria as Pickering and Branigan (1998, p. 638). Primes were scored on the basis of their actual completion; no account was taken of the original semantic constraints imposed. Thus a prime was scored as PO if its completion consisted of a recipient PP headed by *to*, and as DO if its completion consisted of an NP serving as the patient (or theme). All other completions (including phrasal verb completions such as [*The architect* <u>*handed*</u> *the latest plan*] <u>*over*</u> *to the builder*) were scored as Other. Target completions were scored as PO if the verb provided in the fragment was immediately followed by an NP acting as the patient (or theme) and then by a recipient PP headed by *to*. They were scored as DO if the continuation consisted of two NPs, the first of which specified a recipient and the second a patient or theme. The remaining target completions were coded as Other, including those PO or DO completions that were not reversible or formed part of a phrasal verb.

RESULTS

Data from 12 participants were excluded from further analysis. Seven participants completed either the prime or the target as Other in more than 90% of cases; 3 were adjudged to be too slow to respond, with median prime-to-target times (measured from the presentation of the prime fragment until the first keystroke in response to the target fragment) of more than twice the grand median of 18.4 sec. The final 2 participants were excluded because it was clear from their answers that they were not taking the study very seriously (e.g., 1 participant completed almost every sentence with the word *currants*). Of the resulting 1,728 cases (based on 54 participants), 52 (3%) were excluded because the prime-to-target times were more than 1.5 interquartile ranges either above the participant-specific 75th percentile or below the 25th percentile.

The remaining data (1,676 valid cases) were analyzed as follows. First, syntactic priming was examined categorically (analogous to Pickering & Branigan, 1998, and other relevant studies) in order to check whether the original pattern of results could be replicated using a web-based experimental paradigm. Second, in conditions where categorical analyses showed that syntactic priming occurred, we tested effects in the corresponding target response onset latencies (measured as the time from the presentation of a target fragment until the first keystroke of its completion). The question behind these analyses was whether structure repetition is associated with faster response latencies (as predicted by architectural accounts of syntactic priming).

Categorical Analysis

The categorical analyses mirror those reported in Pickering and Branigan (1998). For each factor combination of verb repetition (same vs. different verb) and (actual) prime completion (PO vs. DO), we calculated the probabilities of PO and DO target completions relative to the total number of valid responses per condition (including Other responses). This was done separately across participants (for F_1 analyses) and items (F_2). Table 1 shows the average probabilities of each response type, from Pickering and Branigan (1998, Experiment 1) on the left-hand side, and from the present study on the right-hand side. An inspection of the descriptive data suggests that the studies obtained very similar results. This impression is borne out by a reasonably high correlation between experiments across the data points in Table 1 (Pearson $r = +.92$, $N = 8$, two-tailed $p < .001$).

Following Pickering and Branigan (1998), further analysis of the categorical responses was carried out using three-way analyses of variance (ANOVAs) including verb repetition, prime completion, and target completion as repeated measures factors.[3] As in Pickering and Branigan (p. 639), we found a reliable two-way interaction between prime completion and target completion [$F_1(1,53) = 8.49$,

Table 1
Probabilities of PO and DO Target Completions (by Verb Repetition and Prime Completion) for Pickering and Branigan (1998) and for the Present Experiment

	Pickering and Branigan (1998)				Present Experiment			
	Same Verb		Different Verb		Same Verb		Different Verb	
Prime	PO	DO	PO	DO	PO	DO	PO	DO
PO	.47	.29	.40	.35	.37	.27	.37	.32
DO	.22	.38	.25	.29	.22	.29	.23	.25

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

$p < .01$; $F_2(1,31) = 10.94, p < .01$], indicating an overall structure repetition effect. Planned comparisons confirmed that participants produced significantly more PO target completions following PO prime completions than following DO prime completions [$F_1(1,53) = 8.78, p < .01$; $F_2(1,31) = 15.10, p < .01$], and marginally more DO target completions following DO prime completions than following PO prime completions [$F_1(1,53) = 3.14, p = .082$; $F_2(1,31) = 3.45, p = .073$].

Testing the prime completion × target completion interaction at each level of verb repetition revealed that the overall syntactic priming effect was mainly due to the same-verb condition: in the different-verb condition, the interaction was at best only marginal by items [$F_1(1,53) = 1.14, p = .291$; $F_2(1,31) = 2.97, p = .095$], whereas in the same-verb condition, it was significant by both participants and items [$F_1(1,53) = 10.45, p < .01$; $F_2(1,31) = 9.19, p < .01$].[4]

Thus in this study, as in the study reported in Pickering and Branigan (1998), the bulk of the priming effect is due to conditions where the verb is repeated between prime and target. Note, however, that the three-way interaction—significant in Pickering and Branigan—failed to reach significance in our study (F_1, $F_2 < 1.5$). We believe that this is due to a weaker same-verb syntactic priming effect in our study (8.5% on average, as compared with 17% in Pickering & Branigan). We will return to this point in the discussion.

Finally, Pickering and Branigan (1998) reported a main effect of target completion (reliable by participants only) due to a slightly higher overall proportion of PO target completions. A comparable trend was found in our study [$F_1(1,53) = 3.39, p = .071$; $F_2(1,31) = 4.88, p < .05$].

Response Latencies

To compensate for extreme value distortions, target response onset latencies (time to press first key of response following presentation of target) were trimmed prior to analysis. For each factor combination of verb repetition, prime completion, and target completion, cutoff values were defined as 1.5 interquartile ranges above the 75th percentile or below the 25th percentile. Data points exceeding these boundaries were replaced by the corresponding cutoff values. This affected 5.7% of the cases, equally distributed across conditions.

Other completions (for both primes and targets) were not included in the latency analyses because the range of (sometimes ungrammatical) structures in this category was not comparable to PO or DO responses. Data aggregation across PO and DO responses resulted in 23% missing data points across participants, and 16% across items. (Log-linear analyses established no systematic pattern in the distribution of missing observations across design cells, either by participants [all *p*s > .15] or by items [all *p*s > .22].) In order to perform within-participants/items ANOVAs, these missing cases were replaced by the appropriate participant (or item) mean plus the associated condition mean minus the grand mean. This procedure, originally proposed by Winer (1962), is designed to maximally preserve not only the variance across conditions but also interindividual differences between participants or items.

In the following, we will restrict our analyses to target response onset latencies for the same-verb condition because it was only in this condition that a reliable syntactic priming effect became manifest by response category.[5] Table 2 shows the mean latencies (averaged across participants and items after trimming and data substitution) by levels of prime completion, for cases where the target structure was the same or different from the prime.

As can be seen from the table, target response onset latencies were on average more than half a second faster when prime and target completions agreed in syntactic structure. Two-way repeated measures ANOVAs corroborated this picture with a reliable main effect of structure matching [$F_1(1,53) = 8.33, p < .01$; $F_2(1,31) = 14.18, p < .01$]. The main effect of prime completion did not approach significance, and nor did the interaction between prime completion and structure matching (all *F*s < 1).

The results were confirmed by analyses that did not rely on (partial) data estimation. There were 18 (33%) partic-

Table 2
Mean Target Response Onset Latencies and Standard Deviations (in Seconds) for the Same-Verb Condition

		Prime			
		PO		DO	
		M	*SD*	*M*	*SD*
Target	Match	4.20	1.82	4.37	1.92
	Mismatch	4.96	2.34	4.90	1.94

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

Table 3
Mean Target Response Onset Latencies and Standard Deviations (in Seconds) for the Same-Verb Condition, Based on Participants and Items With Complete Sets of Observations (No Data Substitution)

		Prime			
		PO		DO	
		M	*SD*	*M*	*SD*
Target	Match	4.04	1.52	4.24	1.79
	Mismatch	4.80	2.54	4.82	2.14

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

ipants and 23 (72%) items for which complete sets of observations (in the same-verb condition) were obtained after data aggregation. Table 3 shows the mean target response onset latencies considering only those cases, averaged across both subsamples.

A direct comparison between Tables 2 and 3 indicates a highly robust pattern of results (numerical differences between conditions were almost identical, in spite of the fact that the means in Table 3 are based on considerably smaller subsets of participants and items). It also verifies that the data substitution procedure did not result in any substantial distortions. The main effect of structure matching remained significant for the items subsample; the participants subsample was, apparently, too small to establish a clear effect [$F_1(1,17) = 1.83, p = .19; F_2(1,22) = 8.38, p < .01$].

DISCUSSION

The data reported in this paper have two important implications. The first one is methodological. We were able to show that syntactic priming effects obtained in a well-controlled laboratory setting can be replicated via the World-Wide Web. Our experiment therefore adds to a constantly growing body of evidence suggesting that psycholinguistic data collected over the Internet can stand up to results from traditional laboratory experiments (see also Keller, 2000, demonstrating web-based replications of magnitude estimation experiments). We have also demonstrated that syntactic priming is a robust phenomenon that manifests itself even where both the experimental setting and the choice of participants are relatively uncontrolled in comparison with a laboratory-based study.

The only notable difference between our results and those from Pickering and Branigan (1998) was the magnitude of (categorical) syntactic priming in the same-verb condition, which was about twice as high in Pickering and Branigan as in our study. There are at least two possible (mutually nonexclusive) explanations of this difference.

First, note that in our experiment participants were not able to reinspect earlier trials (once Return had been pressed, a trial was irretrievably replaced by the next one), whereas in Pickering and Branigan (1998), participants could—at least theoretically—look up responses to earlier sentence fragments. Hence, the magnitude of syntactic priming reported in Pickering and Branigan may be artificially high, since the effect may not stem from residual activation of memory traces alone. Note that Branigan, Pickering, and Cleland (1999) have observed reduced syntactic priming effects over trials with several intervening items between prime and target (where participants are less likely to reinspect the relevant earlier prime completions).

A second possible reason for the reduced priming effect is that we obtained about 9% more Other completions (for both primes and targets) than in the Pickering and Branigan (1998) study. We believe that this is due to the greater variety of dialects spoken by our participants (recall that in Pickering & Branigan, all participants were from Britain). In particular, we think that different verb argument structure preferences across dialects might have resulted in a higher proportion of Other responses in our study (consider, e.g., *to post*, which is biased toward <agent, theme, recipient> in British English, but toward <agent, theme, location> in American English). Given that the experimental stimuli were originally designed by British natives to be tested on British natives, the higher proportion of Other responses in our study (resulting in a reduced syntactic priming effect) could therefore be explained by the fact that many of our participants spoke non-British dialects.

The second, theoretically more interesting, finding from the present study is that syntactic priming—which has previously only been established categorically via the probability of structure repetition over subsequent trials—has been shown to manifest itself in latency data. That is, we were able to demonstrate that structure repetition, where it takes place, is accompanied by systematically faster response onset latencies. Note that the latency differences were of the order of 500 msec; whereas WebExp and related approaches to data collection lend themselves well to the establishing of differences of this magnitude, the accuracy of the software is clearly not such that we would expect to be able to replicate more subtle findings such as lexical priming (where the effects are often of the order of 20 msec or less).

Despite latency differences of a magnitude that can be established over the web, the present study does not allow us to infer a causal link between structure matching and latency to complete a target given its design (where target responses were not independently manipulated by the experimenters). We simply note that they are correlated: Such a correlation between categorical priming on the one hand, and the time for planning a response on the other, finds a natural explanation in architectural accounts of syntactic priming such as that espoused by Pickering and Branigan (1998), where the two effects are mutual outcomes of the same mechanism (and causally indistinguishable). Other accounts of syntactic priming in sentence production (e.g., Branigan et al., 2000; Chang et al., 2000) are not incompatible with these findings, but do not offer a straightforward prediction of this kind of relationship as they stand.

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NOTES

1. WebExp is freely available to interested researchers from http://www.hcrc.ed.ac.uk/web_exp/.

2. The exact accuracy depended on the computer used by each participant, since the experiment was administered remotely over the Internet. However, experiments with a number of computers (and versions of Java) suggest that 16 msec is a conservatively high estimate.

3. Categorical data of this nature are most appropriately analyzed using hierarchical log-linear models (see Howell, 1997). In this paper, however, we have opted to report the same parametric analyses as Pickering and Branigan (1998) for easier comparison of the two experiments. Log-linear analyses bear out the findings reported below (a detailed summary can be found at http://www.ed.ac.uk/~martinc/CSloglin.html).

4. Simple contrasts in the same-verb condition (not reported in Pickering & Branigan, 1998) revealed a significantly higher proportion of PO target completions following PO prime completions than following DO prime completions [$F_1(1,53) = 9.84, p < .01; F_2(1,31) = 7.16, p < .05$], and a significantly higher proportion of DO target completions following DO rather than PO prime completions [$F_1(1,53) = 4.04, p = .05; F_2(1,31) = 5.62, p < .05$].

5. Analyses of target response onset latencies in the different-verb condition revealed gross differences between by-participants and by-items analyses, in line with the lack of a reliable categorical priming effect in this condition.

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