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Priming Prepositional-Phrase Attachment During Comprehension

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Strong evidence suggests that prior syntactic context affects language production (e.g., J. K. Bock, 1986). The authors report 4 experiments that used an expression–picture matching task to investigate whether it also affects ambiguity resolution in comprehension. All experiments examined the interpretation of prepositional phrases that were ambiguous between high and low attachment. After reading a prime expression with a high-attached interpretation, participants tended to interpret an ambiguous prepositional phrase in a target expression as highly attached if it contained the same verb as the prime (Experiment 1), but not if it contained a different verb (Experiment 2). They also tended to adopt the high-attached interpretation after producing a prime with the high-attached interpretation that included the same verb (Experiment 3). Finally, they were faster to adopt a high-attached interpretation after reading an expression containing the same verb that was disambiguated to the high-attached versus the low-attached interpretation (Experiment 4).

Keywords: syntax, parsing, syntactic priming, ambiguity resolution, alignment

Theories of language comprehension investigate the resolution of syntactic ambiguities in order to provide accounts of how people draw on sources of information such as syntactic simplicity (Frazier & Rayner, 1982), plausibility (e.g., Trueswell, Tanenhaus, & Garnsey, 1994), frequency (Trueswell, Tanenhaus, & Kello, 1993), or referential context (Altmann & Steedman, 1988) during parsing. To explain parsing data, traditional garden-path theory proposed that initial decisions are based on syntactic information alone (Frazier, 1987), whereas interactive theories proposed that a range of different sources of information are used immediately (MacDonald, Pearlmutter, & Seidenberg, 1994). However, there has been little consideration of the way in which parsing may be affected by the prior processing of sentences using syntactic structures that are related to one or another analysis of the ambiguous sentence. Likewise, most accounts of syntactic ambiguity resolution tend to pay attention to information related to the act of comprehension, and do not focus on information that can be extracted from acts of language production that precede the process of ambiguity resolution in comprehension. Our questions are therefore whether syntactic repetition facilitates language comprehension, both in terms of choice of analysis and in terms of its time-course, and whether comprehension can be facilitated by a prior act of production as well as by a prior act of comprehension.

We address these questions in relation to a particular syntactic ambiguity that has received considerable attention: expressions in which a prepositional phrase (PP) can modify the verb or the object noun, as in (1), taken from Rayner, Carlson, and Frazier (1983):

The spy saw the cop with binoculars. (1)

In one interpretation of this sentence, the spy is using the binoculars to see the cop. Here, the PP *with binoculars* modifies *saw*, and therefore "attaches" to the verb phrase (VP). We call this *VP attachment* or *high attachment*, because the VP is "high" in the phrase structure tree. On the other interpretation, the cop has the binoculars. Here, *with binoculars* modifies the noun phrase (NP) *the cop*. We call this *NP attachment* or *low attachment*, because the NP is "low" in the phrase structure tree.

Much research has addressed the question of how people decide between these two analyses during comprehension, and has used it as a way to investigate syntactic ambiguity resolution and sentence comprehension more generally. Traditional garden-path theory (Frazier, 1987) proposed that people make initial parsing decisions on the basis of the principle of minimal attachment, which says that the syntactically simplest analysis (defined in terms of nodes in a phrase structure tree) is initially adopted. In (1), the high-attached analysis is simpler. In accord with this, Rayner et al. (1983) found that locally ambiguous sentences requiring a low-attached analysis were harder to process than ones that did not. However, not all studies have confirmed this preference, with some showing that attachment preferences can be affected by factors such as thematic roles (Taraban & McClelland, 1988), lexical preferences (Britt, 1994), argumenthood (Schütze & Gibson, 1999), definiteness (Spivey-Knowlton & Sedivy, 1995), inclusion of *only* (Van Gompel, Pickering, & Traxler, 2001), and preceding discourse (Altmann & Steedman, 1988).

In this article, we investigate whether syntactic repetition is another such factor that may affect attachment preferences. We report four experiments that investigated the resolution of PP ambiguities like *The waitress prodding the clown with the umbrella*, in which participants matched such descriptions to pictures. We first asked whether prepositional-phrase attachment is affected by prior processing of utterances that are disambiguated to high or low attachment, using prime and target expressions that use the same verb. Our second experiment was the same as the first experiment, except that verbs were not repeated. We next asked whether prepositional-phrase attachment is affected by prior production of utterances containing a PP with a high or low attachment. Finally, we asked whether syntactic repetition affects the

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time course of ambiguity resolution. Our experiments investigated effects of syntactic repetition, but it is important to note that it is very hard to be certain whether any effects are due to the priming of syntactic information. For example, high- and low-attached expressions differ semantically, so that *The policeman prodding the doctor with the gun* contains a two-place relation between the policeman and the doctor when *with the gun* is attached low, but a three-place relation between the policeman, the doctor, and the gun (which acts as an instrument) when *with the gun* is attached high. We return to this issue in the General Discussion.

Syntactic Priming and Ambiguity Resolution

There are strong and reliable demonstrations of syntactic repetition in language production (see Pickering & Branigan, 1999). Following early evidence of repetition in corpora (Schenkein, 1980; Weiner & Labov, 1983), Bock (1986) demonstrated *syntactic priming* (also called *syntactic persistence* or *structural priming)* using a running recognition memory task, in which participants had to repeat sentences and describe pictures (ostensibly as a memory aid), and in a variant in which primes and targets were foils during the test phase of a study-test recognition procedure. Speakers were more likely to describe a picture using a passive if they had just repeated an unrelated passive than if they had just repeated an unrelated active. She also found syntactic priming for dative verbs like *give* (e.g., *gave the doctor a box* vs. *gave a box to the doctor*). Similar effects occur in other languages (Hartsuiker & Westenberg, 2000; Scheepers, 2003), in written sentence completion (Pickering & Branigan, 1998), spoken sentence completion (Branigan, Pickering, Stewart, & McLean, 2000), and sentence recall (Potter & Lombardi, 1998). They also occur for many different types of sentence (Ferreira, 2003; Griffin & Weinstein-Tull, 2003; Hartsuiker & Westenberg, 2000), and for complex NPs (Cleland & Pickering, 2003; Haywood, Pickering, & Branigan, in press). Priming has been found in aphasics (Hartsuiker & Kolk, 1998) and young children (Huttenlocher, Vasilyeva, & Shimpi, 2004; Savage, Lieven, Theakston, & Tomasello, 2003). Interestingly, priming affects response time as well as choice of response (Corley & Scheepers, 2002; Smith & Wheeldon, 2001; Wheeldon & Smith, 2003).

Alternative accounts in terms of lexical, semantic, or prosodic repetition do not appear able to explain the data. Repetition of closed-class items or event roles is not necessary for priming (Bock, 1989; Bock & Loebell, 1990), whereas repetition of metrical structure alone does not appear to cause priming (Bock & Loebell, 1990). Repetition of the verb is not necessary for priming to occur (Bock, 1986; Pickering & Branigan, 1998), though it is enhanced by verb repetition (Pickering & Branigan, 1998; cf. Cleland & Pickering, 2003).

Priming also occurs from language comprehension to language production, both in sentence recall (Potter & Lombardi, 1998) and in dialogue (Branigan, Pickering, & Cleland, 2000). Branigan, Pickering, and Cleland had a confederate and an experimental participant take turns describing cards to each other, and found that the form of the confederate's description affected the form of the experimental participant's subsequent description (see also Cleland & Pickering, 2003; Hartsuiker, Pickering, & Veltkamp, 2004).

The fact that an act of comprehension can prime an act of production suggests that it might be possible to prime an act of comprehension itself. However, there is surprisingly little evidence for effects of syntactic repetition on comprehension. Some early work suggested that auditory presentation of many sentences of a particular syntactic form facilitated processing of sentences with the same form (Mehler & Carey, 1967) and judging sentences as true or false with respect to pictures (Mehler & Carey, 1968), or affected the interpretation of ambiguous sentences (Carey, Mehler, & Bever, 1970). However, these results depended on a great deal of repetition, were based on one or two items, and may have been due to prosodic repetition (Dooling, 1974). Other studies showed facilitation of a second conjunct if it was syntactically or semantically similar to the first (Frazier, Munn, & Clifton, 2000; Frazier, Taft, Clifton, Roeper, & Ehrlich, 1984). In addition, people prefer answers that are syntactically congruent with their questions (Levelt & Kelter, 1982), repeated exposure to some types of "marginal" sentences increases their acceptability (Snyder, 2000), and children prefer one interpretation of an ambiguous relative clause following extensive exposure to that interpretation (Cuetos, Mitchell, & Corley, 1996). All of these experiments suggest that prior exposure to a stimulus, or multiple stimuli, with a particular syntactic structure may affect subsequent comprehension. In accord with this, Noppeney and Price (2004) found a decrease in left anterior temporal activation following stimuli with similar versus dissimilar syntactic structure, in a functional magnetic resonance imaging study. In addition, Trueswell and Kim (1998) found that comprehending an ambiguous sentence was affected by the preferred argument frame of a subliminally presented verb. Pickering and Traxler (2004) used eye-movement monitoring to investigate whether people would find a "reduced relative" ambiguity like *The manager proposed by the directors was a bitter old man* easier to process if it immediately followed another reduced relative. They found rapid effects of repetition, in that difficulty with the disambiguating phrase *by the directors* was reduced when the previous sentence had been a reduced relative, but only if the two sentences shared the same verb. This is the only study showing effects of the syntactic form of one sentence on the comprehension of the next.

In light of the limited evidence for effects of syntactic repetition on language comprehension, Experiment 1 involved a straightforward investigation of whether comprehending an expression that was disambiguated to either high or low attachment of a PP affected the resolution of an immediately following expression. The experiment required participants to select between two pictures. In the prime expression, one picture corresponded to either the high- or low-attachment interpretation of the expression, and the other picture did not correspond to either interpretation. In the target expression, each picture corresponded to one interpretation of the sentence. The experiment is therefore reminiscent of the picture-verification methods of Mehler and Carey (1968) and Carey et al. (1970), though it used a different ambiguity; used a considerable number of items; and, most important, did not involve multiple primes (5 in Carey et al., 1970).

Experiment 1

This experiment investigated whether syntactic priming occurs between two expressions in description–picture matching. We used expressions involving a PP whose attachment was ambiguous. For example, in the expression *the waitress prodding the clown with the umbrella*, the PP, *with the umbrella*, can attach high, with the meaning that the waitress used the umbrella to prod

the clown, or low, with the meaning that the waitress prodded the clown who had the umbrella. On each trial, participants first read an expression. They then saw two pictures and had to decide which picture (left or right) matched the expression. On prime trials, one picture corresponded to either the high- or low-attached interpretation, hence disambiguating the appropriate analysis of the prime expression; the other picture corresponded to neither interpretation. On target trials, one of the pictures corresponded to the high-attached interpretation and the other corresponded to the low-attached interpretation. Thus, the target pictures did not disambiguate the target expression: Participants could equally felicitously choose either picture. We investigated whether participants interpreted the target expression in the same way that they had interpreted the prime expression.

Method

Participants. Sixteen participants from the University of Edinburgh community were paid to participate. All the participants were native English speakers and had no reading difficulties.

Items. We constructed 24 sets of items (see Appendix). Each comprised a prime expression like (2) together with one picture that matched either the high- or the low-attachment interpretation of the expression and one picture that matched neither interpretation, and a target expression like (3) that was matched with pictures corresponding to each interpretation of the expression.

The policeman prodding the doctor with the gun. (2)

The waitress prodding the clown with the umbrella. (3)

In the high-attachment (HA) condition, the prime expression in (2) was matched with the two pictures at the top of Figure 1, corresponding to the high-attached interpretation and an alternative involving the same action but a different object (e.g., a policeman using a bat to prod a doctor). In the low-attachment (LA) condition, the pictures corresponded to the low-attached interpretation and an alternative involving the same action but a different object (e.g., a policeman prodding a doctor holding a bat). The target expression in (3) was matched with the two pictures at the bottom of Figure 1, corresponding to the high- and low-attached interpretations of the target expression.

The expression pairs used six verbs (*hit*, *hurt*, *injure*, *poke*, *prod*, *thump*) that could appear in ambiguous expressions for which both interpretations

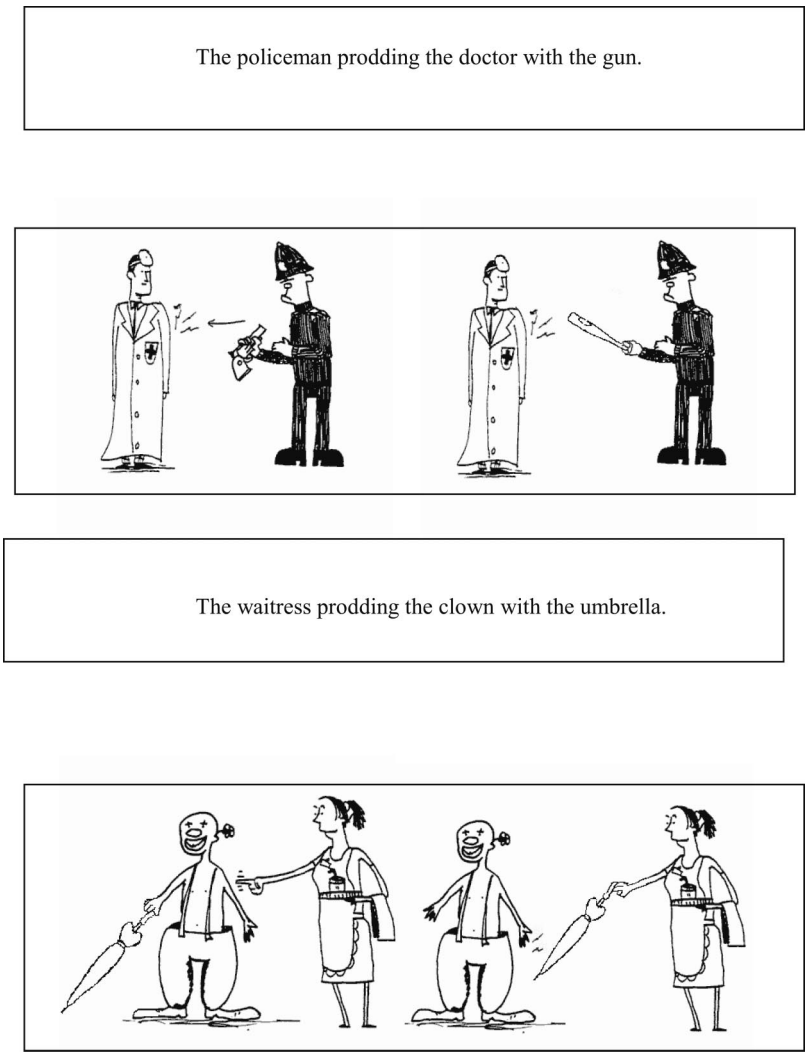

Figure 1. Example of a comprehension-to-comprehension trial (Experiment 1; high attached prime).

could be straightforwardly depicted. Prime and target expressions used the same verb (cf. Branigan, Pickering, & Cleland, 2000; Pickering & Branigan, 1998), but all three arguments were different.

In addition, we constructed 72 unambiguous filler expressions and pairs of pictures, one of which matched the expression. Fifty-four expressions used transitive verbs. In 18 of these, the agent and patient were reversed in the mismatching picture; in another 18, the agent was different; in the final 18, the patient was different. The remaining 18 expressions used intransitive verbs, and the mismatching picture had a different agent.

Procedure. The experimental items were placed into two lists, each comprising 12 items from each condition, such that one version of each item appeared in each list. The 120 expressions and pictures (24 prime, 24 target, and 72 fillers) were individually randomized, with the constraints that for each experimental item, the prime expression appeared immediately preceding the target expression, and that at least two fillers intervened between any two experimental items. Each expression and subsequent picture match was presented as an individual trial; participants were not informed of any relationship between prime and target trials.

Participants were told to match the correct picture to each expression that they read. They were asked to read each expression silently and, once they understood it, to press the space bar. When they pressed the space bar, or after 5,000 ms if they did not, the expression disappeared and two pictures immediately appeared on the screen. Participants had to decide which picture matched the previous expression by pressing the "a" key for the left-hand picture and the "l" key for the right-hand picture. For each list, the matching picture for the prime appeared on the right for half the trials and on the left for the other half. Similarly, the high-attached picture for the target appeared on the right for half the trials and on the left for the other half. Prime and target pictures were orientated right-to-left with respect to the position of agent and patient on half the trials, and left-to-right on the other half. All three of these counterbalancing manipulations were independent of each other.

The experimental files were presented and their responses recorded using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). The experiment began with a practice session consisting of four further fillers.

Design and data analysis. Each participant completed 24 targets, 12 in each of the two priming conditions (HA and LA). Each experimental item was presented to all 16 participants, with 8 participants seeing any one version of an item.

We first removed items on which a participant chose the wrong picture for the prime expression. We then coded the remaining responses according to whether the participant chose the high- or low-attached picture for the target expression. We computed the relevant proportions by dividing the number of HA target selections following HA primes by the sum of the number of HA primes (i.e., HA primes followed by HA and LA target selections), and the number of HA target selections following LA primes by the sum of the number of LA primes (i.e., LA primes followed by HA and LA target selections). We use this measure because it allows us to compare priming between conditions in cases when the primes completed correctly are not equivalent (see Pickering, Branigan, & McLean, 2002). These proportions were calculated for each participant and for each item. Analyses of variance (ANOVAs) were performed on these data, with separate analyses treating participants (F_1) and items (F_2) as random effects. The analyses were within-participants and within-items.

Results

Participants correctly identified the prime picture on 364 trials (95%). Of these, 188 (52%) were HA trials, and 176 (48%) were LA trials. In these 364 trials, participants chose 235 (65%) HA target pictures and 129 (35%) LA pictures.

Table 1 shows the proportions of HA and LA target responses in the two experimental conditions. The table shows an overall priming effect of 18%; that is, participants made 18% more target responses that were of the same type (HA or LA) as the prime response than target responses that were of the alternative type to the prime response. One-way ANOVAs on the HA target ratio revealed an effect of prime, $F_1(1, 15) = 7.45$, $p < .05$, partial $\eta^2 = .33$; $F_2(1, 23) = 16.2$, $p < .01$, partial $\eta^2 = .41$. An additional set of analyses was performed on the arcsine-transformed proportions of responses for both participants and items. Since the results of these additional analyses showed the same pattern of significant effects as those on the raw proportions for this experiment and Experiments 2 and 3, we do not report them.

Table 1
HA Target Proportions and Standard Deviations for Responses in Each Condition in Experiments 1–3 (on the Basis of Participant Analyses)

	HA prime		LA prime	
Experiment	*M*	*SD*	*M*	*SD*
1	.74	.17	.56	.21
2	.68	.17	.62	.17
3	.62	.33	.41	.35

Note. HA = high attached; LA = low attached.

A further analysis was carried out comparing data from the first and second halves of the experiment to examine whether there were differences in the priming effect through the course of the experiment. In the first half of the experiment, the HA target ratio was .74 following an HA prime and .59 following an LA prime; in the second half, the HA target ratio was .75 following an HA prime and .54 following an LA prime. There was a main effect of prime, $F_1(1, 30) = 8.27$, $p < .01$, partial $\eta^2 = .22$, but no effect of time (first vs. second half), nor an interaction (Fs <1).

Discussion

In Experiment 1, participants were presented with a structurally ambiguous prime expression that was disambiguated by a picture to either the high- or low-attachment interpretation. Participants were then presented with a target expression containing the same ambiguity, and they tended to interpret this expression in the same way that they had interpreted the prime expression. These results provide a clear demonstration that syntactic repetition can affect interpretation, in a way that confirms and extends the original work of Carey et al. (1970). In particular, our results show that participants' interpretation of an ambiguous expression is affected by prior presentation of a single disambiguated expression.

These results are explicable in a number of different ways. It is conceivable that there was more similarity between pictures that expressed the same attachment (e.g., pictures corresponding to high-attachment expressions were more similar to each other than to pictures corresponding to low-attachment expressions). This could explain our results if participants preferred to choose similar over dissimilar pictures. However, there is little reason to believe that this is the case. The main difference relates to which character holds the object (see Figure 1), but the orientation of the pictures was counterbalanced for the position of the agent and patient across prime and target, and the object appeared in different positions in different pictures (and see Experiment 4 for further evidence against this account). We can therefore exclude a nonlinguistic basis for the priming effect.

The results are compatible with representational or procedural accounts of priming. According to a representational account, comprehending or producing an expression leads to the activation of common representations associated with the structure of that expression. According to a procedural account, comprehending an expression leads to the activation of procedures specifically associated with comprehension. Most likely, these procedures would serve to map the form of the expression to an appropriate meaning. Similarly, producing an expression leads to the activation of procedures specifically associated with production, presumably mapping the meaning of the expression to an appropriate form. Clearly the results of Experiment 1 cannot distinguish these accounts. However, Branigan, Pickering, and Cleland (2000) found priming from comprehension to production using dialogue (see also Potter & Lombardi, 1998), similar to priming from production to production (Bock, 1986; Pickering & Branigan, 1998). These results support a representational account of priming and an underlying parity of representations for production and comprehension. Such an account makes clear sense for dialogue, in which interlocutors interleave production and comprehension (see Pickering & Garrod, 2004). We might therefore predict priming of description–picture matching to occur when the prime was overtly produced and did not itself use description–picture matching. Experiment 3 therefore tested whether this prediction is correct.

Before addressing this concern, we asked whether the priming affects representations that are independent of specific lexical items or whether they are localized to specific verbs. As Experiment 1 showed priming when verbs were repeated, it cannot distinguish these possibilities. In production, priming occurs when the verb is not repeated (Bock, 1986; Pickering & Branigan, 1998) or when it is repeated (Pickering & Branigan, 1998), though it is significantly stronger when it is repeated (Pickering & Branigan, 1998). Similar results hold when the prime is comprehended rather than produced (Branigan, Pickering, & Cleland, 2000). Comparable effects occur for NPs, with stronger priming occurring (e.g., of *the sheep that is red*) when the prime contains the same head noun as the target (*sheep*) than when it contains a different head noun (*knife*; Cleland & Pickering, 2003). These findings suggest that the syntactic representations used in production may be partly, but not entirely, localized to lexical items such as verbs.

Let us assume that the locus of priming is syntactic and can be expressed in terms of traditional phrase-structure analyses of high and low attachment (e.g., Frazier, 1987). Then, in the representational account of priming, a finding of nonlocalized priming would suggest that participants construct representations corresponding to VP[V NP PP] when comprehending a high-attached expression and VP[V NP[NP PP]] when comprehending a low-attached expression. These representations make no reference to the specific verb that has been used. If those representations have previously been constructed, and if activation of those representations did not decay immediately, priming should ensue. However, it is also possible that the process of constructing VP[V NP PP] or VP[V NP[NP PP]] during comprehension is dependent on having previously applied the same procedure during comprehension, in which case priming should not occur if the prime involved production rather than comprehension (see Experiment 3).

On the other hand, a finding of purely localized priming would support an account in which priming caused a short-term resetting of the biases associated with particular verbs. This would be compatible with evidence from language comprehension. Ambiguity resolution is greatly affected by the frequency of particular analyses, with participants preferring more frequent over less frequent analyses (e.g., Mitchell & Holmes, 1985; Trueswell et al., 1993; see MacDonald et al., 1994). Such preferences have presumably been acquired over a life-time of experience with the language. On this account, priming would cause a short-term change in a verb's bias to take a modifying PP. If priming in comprehension behaves similarly to priming in production, we should expect both localized and nonlocalized priming (e.g., Pickering & Branigan, 1998). We provide a first attempt to distinguish these possibilities in Experiment 2.

Alternatively, the priming in Experiment 1 may have been semantic, with priming of a three-place event schema on the high-attached analysis and a two-place event schema on the low-attached analysis. Such an account is also compatible with priming being localized, partly localized, or nonlocalized, and with priming being dependent on representations or (directional) procedures.

Experiment 2

Experiment 2 investigated whether priming occurred when prime and target involved different verbs. In other respects, it was identical to Experiment 1.

Method

Participants. Thirty-two additional participants from the same population were paid to participate.

Items. The experimental items were the same as in Experiment 1, except that the combination of prime and target expressions and associated pictures were rotated so that the verb differed between the prime and target (with each target verb being paired with four different prime verbs). Thus each item comprised a prime expression like (4) together with one picture that matched either the high- or the low-attachment interpretation of the expression and one picture that matched neither interpretation, and a target expression like (5) that was matched with pictures corresponding to each interpretation of the expression.

The policeman thumping the soldier with the gun. (4)

The waitress prodding the clown with the umbrella. (5)

The fillers were the same as in Experiment 1.

Procedure, design, and data analysis. These were the same as in Experiment 1.

Results

Participants correctly identified the prime picture on 749 trials (98%). Of these, 375 (50%) were HA trials, and 374 (50%) were LA trials. In these 749 trials, participants chose 486 (65%) HA target pictures and 263 (35%) LA pictures. Table 1 shows the proportions of HA and LA target responses in the two experimental conditions. Table 1 shows an overall priming effect of 6%. One-way ANOVAs on the HA target ratio revealed no effect of prime, $F_1(1, 31) = 2.18$, $p = .15$; $F_2(1, 23) = 2.18$, $p = .15$. Hence, there was no reliable indication of priming when the verb was not repeated from prime to target.

Comparison of Experiments 1 and 2

To determine whether priming was significantly stronger when the verb was repeated than when it was not repeated, we conducted

2 Verb (same vs. different verb) x 2 Prime (HA vs. LA prime) ANOVAs on the HA target proportions. Prime was within-participants and within-items; verb was between-participants and within-items (with an item being defined by the target expression). The ANOVAs revealed a main effect of prime, $F_1(1, 46) = 11.2$, $p < .01$, partial $\eta^2 = .20$; $F_2(1, 46) = 17.3$, $p < .001$, partial $\eta^2 = .27$, and an interaction between prime and verb, marginal by participants but significant by items, $F_1(1, 46) = 3.15$, $p = .08$, partial $\eta^2 = .06$; $F_2(1, 46) = 6.34$, $p < .05$, partial $\eta^2 = .12$. There was no effect of verb type (Fs < 1).

Discussion

Although there was a numerical tendency toward priming in Experiment 2, the effect was not significant (even though Experiment 2 had twice as many participants as Experiment 1). In contrast, the between-experiments comparison strongly suggested that priming is stronger when the verb is repeated than when it is not. We can therefore conclude that there is a localized component to priming. It would of course be premature to conclude that there is no nonlocalized priming in comprehension. The effect size in Experiment 2 is $d = .29$, which is regarded as small (Cohen, 1988). The power of the experiment to detect an effect of this size is .21. If the effect size were medium ($d = .50$), the power would still be relatively low (.52). Hence it is possible that nonlocalized priming does occur in comprehension but that we were unable to detect it in Experiment 2. However, we can be fairly confident that any such priming is fairly weak, at least when assessed with this experimental paradigm and type of expression.

Experiment 3

Experiment 3 asked whether description–picture matching can be primed by prior picture description. Such a finding would demonstrate that priming occurs when the processes involved in processing the prime and the target differ dramatically, in this case when processing the prime involves overt production, but processing the target does not. It would provide clear evidence for the representational account, in which common representations are activated during production and comprehension (Branigan, Pickering, & Cleland, 2000; Pickering & Garrod, 2004).

We therefore examined whether prior production of a expression with a high- or low-attached analysis increased the likelihood of assigning the same analysis to the next expression. The experiment used the same types of stimuli as in Experiment 1, but this time participants alternated between verbally describing pictures and choosing pictures that matched visually presented descriptions. On production (prime) trials, participants read a verb and then used that verb to describe a presented picture that depicted either an agent using an object to carry out an action on a patient (inducing a high-attached description), or an agent acting on a patient who was holding an object (inducing a low-attached description). On comprehension (target) trials, participants read a globally ambiguous expression that could be assigned either a high- or a low-attached interpretation, and then had to choose which of two presented pictures matched that description. As in Experiment 1, each picture was congruent with one of the alternative interpretations. Our dependent measure was again the proportion of trials on which participants selected the picture that matched the high-attached interpretation. If the priming found in Experiment 1 reflected the facilitation of syntactic rules or principles specific to comprehension, then producing a description with a particular structure should not influence the likelihood of interpreting a subsequent description as having the same structure. But if the priming in Experiment 1 arose from the facilitation of syntactic rules shared between comprehension and production, then prior production of a particular structure should make it easier to access that structure in subsequent comprehension.

Method

Participants. Sixteen additional participants from the same population were paid to participate. Six additional participants were excluded (see *Design and data analysis*).

Items. These were similar to Experiment 1, except that for prime trials, an appropriate verb was paired with a single prime picture. For example, the verb *prod* was paired with a picture of a policeman using a gun to prod a doctor in the HA condition (shown in Figure 2) and a picture of a policeman prodding a doctor who held a gun in the LA condition. The target trials were the same as in Experiment 1. In this case, the corresponding target expression was *The waitress prodding the clown with an umbrella*, and it was paired with pictures of a waitress using an umbrella to prod a clown, and a waitress prodding a clown who held an umbrella (see Figure 2). Half of the fillers were production trials (using the verb from the corresponding filler expression in Experiment 1), and half were comprehension trials.

Procedure. Two lists were prepared as in Experiment 1. The order of production and comprehension trials was randomized, with the constraint that a production prime trial always preceded a comprehension target trial. Participants were told that they would be taking part in a describing and matching task. If they saw a verb on the screen, they were to read it silently, press the space bar, and then use the verb to describe the picture on the screen. If they saw an expression on the screen, they were asked to read it and then make a picture-match decision, as in Experiment 1. If the participant did not press the space bar within 5,000 ms of the verb or expression appearing on the screen then the program moved on. Stimulus presentation and response recording were as in Experiment 1.

The experiment began with a practice session consisting of 12 production trials and 12 comprehension trials. For the production trials in this session, participants were given a fragment before each picture, which they used to generate a description. The practice session included two HA and two LA production trials. To push them toward producing an ambiguous expression, the fragment included the agent, the patient, and the preposition *with*. For example, if the picture in Figure 2 had been a practice item, it would have had the preceding fragment *The policeman prodding the doctor with. . . .* In addition there were four practice comprehension trials. The HA and LA production trials were included because pilot testing revealed that participants were unlikely to produce a HA or LA expression if they had not been exposed to the structure.

Design and data analysis. These were the same as Experiment 1, except that we removed items on which participants failed to produce a high-attached or low-attached expression for the prime. Prime descriptions were scored if they contained the agent, the appropriate verb, the patient, and a PP containing *with* and the object (in that order, and nothing else). Six participants were excluded because they completed fewer than five prime trials correctly in each prime condition.

Results

Participants correctly produced the prime expression structure on 323 trials (84%). Of these, 151 (47%) were HA trials, and 172 (53%) were LA trials. In these 323 trials, participants chose 167 (52%) HA target pictures and 156 (48%) LA pictures. There was

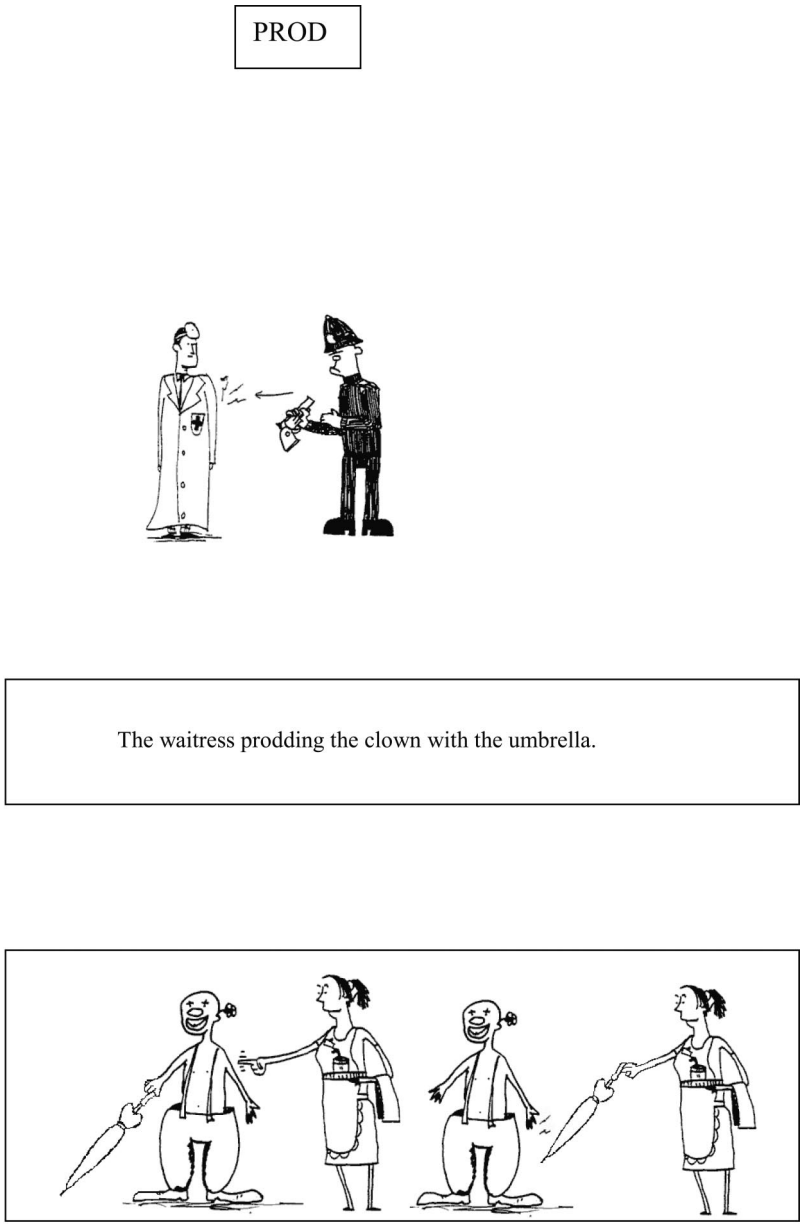

Figure 2. Example of a production-to-comprehension trial (Experiment 3; high attached prime).

a 21% priming effect (see Table 1). In other words, participants made 21% more target responses that were of the same type (HA or LA) as the prime response than target responses that were of the alternative type to the prime response. One-way ANOVAs on the HA target ratios revealed an effect of prime, $F_1(1, 15) = 6.19$, $p < .05$, partial $\eta^2 = .29$; $F_2(1, 23) = 17.8$, $p < .001$, partial $\eta^2 = .44$.

Comparison of Experiments 1 and 3

To determine whether description–picture matching is differentially affected by prior description–picture matching versus prior picture description, we conducted 2 Prime Task (description–picture matching vs. picture description) × 2 Prime (HA vs. LA prime) ANOVAs on the HA target proportions. Prime was within-participants and within-items; prime task was between-participants and within-items. The ANOVAs revealed a main effect of prime, $F_1(1, 30) = 13.2$, $p < .01$, partial $\eta^2 = .31$; $F_2(1, 46) = 33.8$, $p < .001$, partial $\eta^2 = .42$, and a main effect of prime task, significant by items only, $F_1(1, 30) = 2.58$, $p = .12$, partial $\eta^2 = .08$; $F_2(1, 46) = 7.93$, $p < .01$, partial $\eta^2 = .15$. If this effect of prime task is reliable, it suggests that participants are more likely to produce an HA response following description–picture matching (65%) than following picture description (52%). There was no interaction (Fs < 1). Hence the 21% production-to-comprehension priming effect found in Experiment 3 does not differ significantly from the numerically smaller (18%) comprehension-to-comprehension priming effect found in Experiment 1.

Discussion

In Experiment 3, participants described pictures that involved either an agent using an object to act on a patient, or an agent acting on a patient who was holding an object, leading them to produce descriptions that involved a PP with a high- or low-attached interpretation. Participants were then presented with a target expression containing an ambiguous PP, and they tended to interpret this expression as having the same attachment as they had produced in their description for the prime picture. These results demonstrate that prior production of a particular structure influences subsequent picture matching for an ambiguous expression in which one possible interpretation has that structure. These results are therefore compatible with the representational account of priming, in which the processing of complex expressions involves representations that are common to production and comprehension.

However, it is difficult to be certain that any act of production does not involve some comprehension processes. If such processes were particularly strong, they might produce priming effects under a procedural account. In Experiment 3, participants may have monitored their own production of the prime expression using the comprehension system, given that most researchers assume an important role for comprehension-based monitoring (Hartsuiker & Kolk, 2001; Levelt, 1989; Postma, 2000). Might priming from production to comprehension actually be due to comprehension-based monitoring? In theory, such an account could hold for production-to-production priming (Bock, 1986). That is, facilitation apparently caused by the repeated production of a particular structure might actually arise partially or wholly from comprehension-to-production priming (Branigan, Pickering, and Cleland, 2000), based on the action of the self-monitor. Although we cannot entirely rule out such an account, it is unlikely that overt production would prime picture matching to the same extent that picture matching would prime picture matching, because the amount of comprehension monitoring during production is likely to be less than the amount of comprehension that takes place in a task that requires comprehension. In fact, there was no suggestion in the data that picture matching primed picture matching to a greater extent than did picture description, as such a procedural account would predict. As the combined analysis demonstrated, the two experiments showed comparable levels of priming (and indeed, the priming effect was numerically greater following picture description than following picture matching). This argues against a procedural account based on comprehension-based monitoring and provides further support for a representational account.

The combined analysis also suggested that participants may have been more likely to choose HA descriptions following description–picture matching than following picture description. If this difference is reliable, a possible explanation resides in the fact that in Experiment 1, 52% of correct primes were high attached, whereas in Experiment 3, 47% were high attached. It is therefore possible that this slight difference produced a tendency for participants to choose high-attached targets in Experiment 1 to a greater extent than in Experiment 3.

Experiment 4

Experiments 1 and 3 demonstrated that participants were more likely to interpret an expression in a manner that was syntactically congruent with a prior syntactic structure that they had either comprehended or produced (so long as the verb was repeated). That is, prior processing of a particular syntactic structure during comprehension or production increased the likelihood of adopting that analysis during subsequent comprehension. One might therefore expect that priming might have an effect on the time taken to comprehend an utterance. Smith and Wheeldon (2001; Wheeldon & Smith, 2003) found that response latencies to produce a conjoined expression (e.g., *the spoon and the car move up*) were shorter following prior presentation of the same construction, and Corley and Scheepers (2002) found similar effects for the production of dative alternations, using materials comparable to those of Pickering and Branigan (1998).

Experiment 4 therefore investigated whether repeating structure affected response times for target expressions in comprehension after comprehension of a prime expression. The prime was the same as in Experiment 1, but the target did not include pictures matching both interpretations of the target expression. Instead, one picture matched one interpretation and the other matched neither interpretation (see Figure 3). Hence, participants were forced to adopt either a high- or a low-attached interpretation. On the basis of Experiment 1, we predicted that participants would tend to interpret the target expression in the same way (high or low attachment) as they had interpreted the prime expression. We assumed that the process of comprehending involves constructing syntactic and semantic representations that correspond to the different linguistic analyses of the expression, and investigated whether priming can affect the way in which the processor eventually settles on a particular analysis. For these purposes, it does not matter whether this process takes place in serial (e.g., Frazier, 1987) or in parallel (e.g., MacDonald et al., 1994). If the target picture matched the interpretation assigned to the target expression, comprehension should be straightforward, but if the picture did not match this interpretation, participants would find it more difficult to reach the appropriate interpretation when they saw the picture.

Method

Participants. Sixteen additional participants from the University of Edinburgh community were paid to participate. All the participants were native English speakers and had no reading difficulties.

Items. The items were the same as Experiment 1, with the exception that in the target trials, only one of the pictures in the matching part of the trial was an acceptable match for the target expression. The nonmatching card differed from the match by having a different object. The fillers were identical to those used in Experiment 1.

Procedure. The procedure was identical to Experiment 1.

Scoring. Response times for each picture-matching trial were recorded. However, if a participant failed to correctly identify the matching prime picture, the response times for that item were removed. If a participant failed to correctly identify a matching target picture, the response time for that item was removed from the target picture responses only.

Design and data analysis. Each participant completed 24 items, 6 in each of the conditions defined by the prime (HA vs. LA prime) and Target (HA vs LA target). Each experimental item was presented to all 16 participants, with 4 participants seeing any one version of an item.

Response times were recorded for target picture choice and prime picture choice. We first excluded trials on which participants failed to correctly identify the prime picture (17 trials), and then excluded target trials on which participants failed to correctly identify the target picture (7 target trials). For the remaining trials, any response time over 8,000 ms was

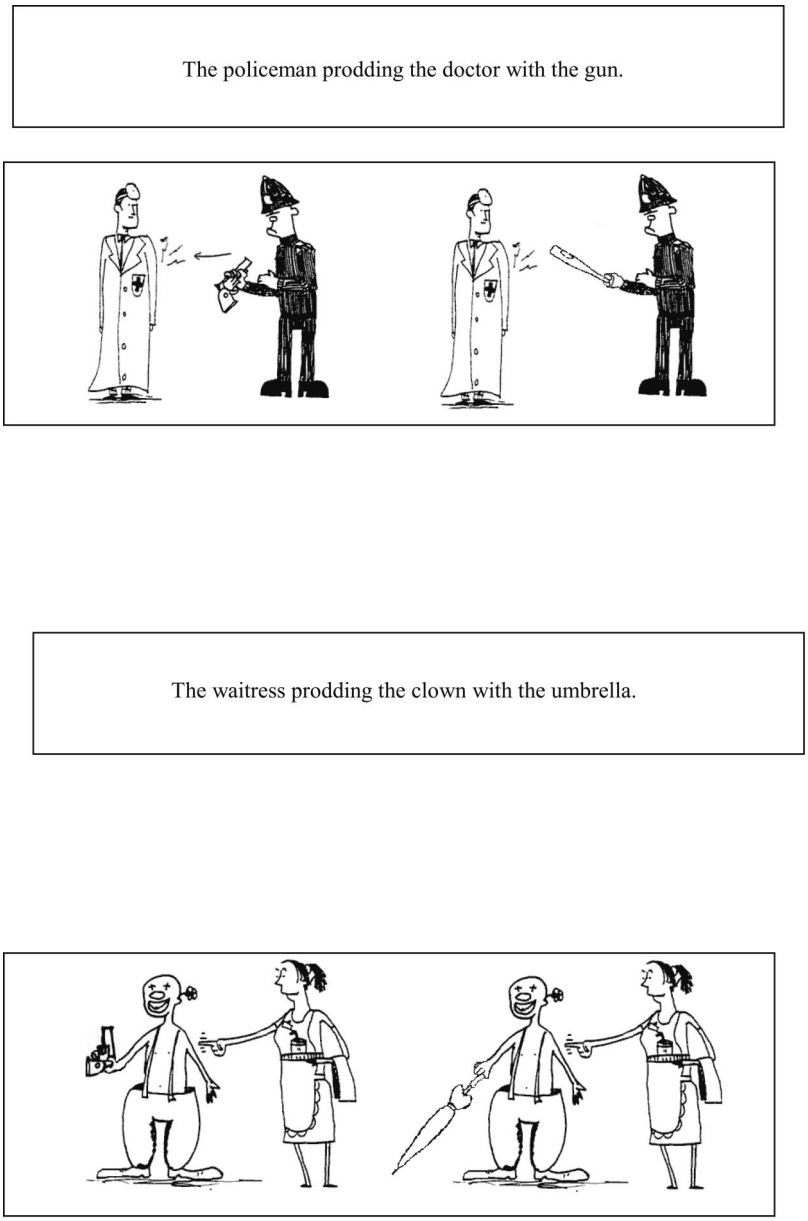

Figure 3. Example of a comprehension-to-comprehension trial (Experiment 4; high attached prime, low attached target).

excluded (5 prime trials, 4 target trials). In the participants analysis, we then replaced any datum more than 2 standard deviations above or below the grand mean of a participant by the cut-off value (3 prime trials; 4 target trials). In the items analysis, we replaced any datum more than 2 standard deviations above or below the grand mean of an item by the cut-off value (4 prime trials, 4 target trials).

Results

Participants correctly identified the prime picture on 367 trials (96%). Five prime trials with responses over 8,000 ms were also excluded. Of these 362 trials, 360 (98%) target pictures were correctly identified. Four of these target trials with responses over 8,000 ms were excluded.

Table 2 shows the mean and standard deviations for the response times in the four conditions for both the target pictures and the prime pictures. It shows that responses to the target pictures were 300 ms faster when they were preceded by congruent primes. In accord with this, ANOVAs on the target picture times revealed that the interaction was significant, $F_1(1, 15) = 10.7$, $p < .01$; $F_2(1, 23) = 5.49$, $p < .05$. There were no main effects of prime or target (Fs < 1).

To determine whether there was a preference for high or low attachment in the absence of priming, we also conducted ANOVAs on the prime picture times. These revealed an effect of prime, $F_1(1, 15) = 17.3$, $p < .01$; $F_2(1, 23) = 4.61$, $p < .05$, with responses to high-attached primes being faster than responses to low-attached

Table 2
Means and Standard Deviations in Milliseconds for Response Times in Each Condition in Experiment 4 (on the Basis of Participant Analyses)

	HA target		LA target		Overall mean	
Pictures	*M*	*SD*	*M*	*SD*	*M*	*SD*
Target Prime						
HA	2,138	843	2,508	853		
LA	2,438	923	2,209	746		
Prime Prime						
HA	2,262	840	2,207	745	2,235	793
LA	2,632	872	2,387	749	2,510	811

Note. HA = high attached; LA = low attached.

primes. There was also an effect on the prime picture times of target, significant only by items, $F_1(1, 15) = 2.83$, $p = .11$; $F_2(1, 23) = 4.75$, $p < .05$, and no interaction (Fs < 2.5). (As the target had not been seen at this point, any effect of target must be spurious.)

Discussion

Experiment 4 demonstrated that participants were faster to respond to pictures that disambiguated the target expression in the same way as the prime expression. It provides further evidence for priming effects in comprehension, and additionally shows that priming affects speed of response as well as choice of analysis. Note also that the object entity appeared in the same location in both target pictures (e.g., if the object entity was on the far right in one target picture, it would also be on the far right in the other target picture), so an explanation of priming in terms of the relative spatial location of entities is not possible.

The results are important in demonstrating that priming affects response times as well as response choice. On one account, priming affects the initial choice of analysis, causing participants to be more likely to analyze the target in the same way that they had just analyzed the prime. Such an account would accord with "variable choice" theories of parsing, in which initial choice of analysis depends on a range of different factors (MacDonald et al., 1994; Trueswell et al., 1994; Van Gompel et al., 2001). Priming would therefore constitute one such factor, and might correspond to a short-term analog of frequency effects (cf. Trueswell et al., 1993). However, the results are also compatible with a "fixed choice" theory, in which people always adopt a particular analysis during initial processing. According to garden-path theory (Frazier, 1987), people would initially adopt the high-attached analysis (as a consequence of the principle of minimal attachment). Priming might facilitate the process of adopting this analysis during initial processing, and might facilitate the process of adopting the low-attached analysis during reanalysis.

General Discussion

We reported four experiments that investigated whether comprehension is influenced by syntactic repetition. In all four experiments, participants were presented with globally ambiguous expressions involving a PP that could be interpreted as modifying the verb (high-attached) or modifying the direct object (low-attached). In Experiment 1, participants were more likely to adopt an interpretation when they had just read a prime expression that was disambiguated to the same interpretation than when it was disambiguated to the other interpretation. However, Experiment 2 did not find a comparable effect when the verb was not repeated from prime to target. In Experiment 3, participants were more likely to adopt an interpretation when they had just produced a prime expression with the same interpretation than when they had just produced a prime expression with the other interpretation. In Experiment 4, they were faster to adopt an interpretation when they had just read a prime expression that was disambiguated to the same interpretation than when they had just read a prime expression that was disambiguated to the other interpretation.

Previous experiments have demonstrated syntactic repetition effects in language production following production or comprehension of a sentence with a particular structure. Our experiments demonstrate that syntactic repetition effects can also occur in picture matching. Both after picture matching and after producing an expression with a particular structure, subsequent comprehension of an expression with the same structure was facilitated. Hence, ambiguity resolution is affected by syntactic repetition after previous comprehension and production of a particular structure. A number of previous studies have shown effects of syntactic repetition based on the prior presentation of multiple stimuli with a particular syntactic structure (e.g., Cuetos et al., 1996; Mehler & Carey, 1967, 1968; Snyder, 2000). Our experiments show that prior presentation of a single stimulus can also influence language comprehension.

Our results also show that facilitation for repeated comprehension of expressions with the same structure occurs between expressions that share no open-class lexical overlap, apart from the repetition of the verb. We can therefore conclude that localized (i.e., verb-specific) syntactic repetition effects occur in comprehension. However, we did not find significant effects when the verb was not repeated. In this respect, the results contrast with findings of syntactic repetition effects in production, in which effects occur without verb repetition (e.g., Bock, 1986; Pickering & Branigan, 1998). However, the significant increase in priming that occurs as a result of verb repetition does accord with results from production (Branigan, Pickering, & Cleland, 2000; Pickering & Branigan, 1998).

One possibility is that priming in comprehension does not occur in the absence of verb repetition. These effects may then reflect a temporary alteration in the biases associated with particular verbs. According to this account, prior comprehension or production of a verb in conjunction with a high- or low-attached PP temporarily increases the high- or low-attached prepositional-phrase bias associated with that verb. Such an account is in keeping with theories of language comprehension that emphasize the sensitivity of language users to statistical regularities associated with heads (MacDonald et al., 1994; Trueswell et al., 1993).

Alternatively, it may be that priming without verb repetition is weak and difficult to detect, given that studies of production have shown priming with verb repetition to be at least twice as strong as priming without verb repetition (Branigan, Pickering, & Cleland, 2000; Pickering & Branigan, 1998; cf. Cleland & Pickering, 2003, for comparable results with head nouns). On the basis of our

results, we cannot draw a definitive conclusion about the existence of nonlocalized (non-verb-specific) repetition effects.

Our experiments show priming in the processing of complex expressions. They are clearly explicable in terms of syntactic priming. However, it is possible that the locus of the effects is semantic rather than syntactic, because the high- and low-attached analyses differ in their meaning. The high-attached analysis involves a relationship between the action denoted by the verb and three entities, one of which is an instrument. In contrast, the low-attached analysis involves a relationship between the action denoted by the verb and two entities, one of which is described by a possessive relation. After interpreting an expression as involving three entities, or producing that expression in response to a picture, a participant might be more likely to interpret a subsequent expression in a way that also involves three entities. Alternatively, participants might be primed to interpret the PP as expressing an instrumental or possessive relation. This would constitute a form of priming of thematic roles.

Evidence from production suggests that some abstract semantic priming does occur. For example, Watson, Pickering, and Branigan (2004) found that participants who had interpreted an expression with respect to a particular reference frame (e.g., relative to the perspective of the speaker) tended to use the same reference frame in their next utterance. Both Griffin and Weinstein-Tull (2003) and Cleland and Pickering (2003) found that semantic similarity enhanced syntactic priming, and Chang, Bock, and Goldberg (2003) found that the order of thematic roles can be primed. However, there is less evidence for semantic priming at levels directly relevant to the current experiments. Most important, Bock and Loebell (1990) found that differences in thematic roles between prime and target did not affect syntactic priming. For example, a passive containing a PP referring to the agent of the event (e.g., *stung by a bee*) was primed equally well by a sentence containing a PP referring to a location (e.g., *standing by a lamppost*) as by another passive. In addition, Pickering et al. (2002) found only very weak indications of priming of number of arguments in post hoc analyses.

If comprehension is analogous to production in this respect, abstract semantic priming is unlikely to be as important as syntactic priming. Whereas semantic priming might occur in the absence of syntactic differences, it is probably less likely in situations where the interpretations differ syntactically as well as semantically. In fact, the directionality of processing provides some further support for this claim. Whereas production presumably involves the conversion of a semantic representation into a syntactic one, comprehension presumably involves the conversion of a syntactic representation into a semantic one. It is therefore more likely that syntactic choices take place before semantic choices during comprehension. However, comprehension may involve top-down influences from semantics (e.g., MacDonald et al., 1994), and so it is possible that semantic influences could take place before critical aspects of syntactic processing.

A further argument against a purely semantic account is that the expressions in our experiments involved descriptions for entities rather than sentences. The two interpretations of, say, *The policeman prods the doctor with the gun* differ with respect to whether they focus on the nature of the action (how the prodding was done) or the specification of the referent (which doctor is being described). But the two interpretations of *The policeman prodding the doctor with the gun* both focus on the denotation of a particular complex noun phrase (specifying which policeman is being described). So it is at least arguable that the semantic difference between the two interpretations was minimized in our experiments.[1]

Finally, Branigan, Pickering, and Cleland (2000) found syntactic priming from comprehension to production. Because participants produced sentences whose denotation was unaffected by the syntactic form that they used, the effects are unlikely to have a semantic origin. But the *prime* was comprehended, so it appears that syntactic priming does occur as a result of comprehension. In sum, all of these arguments suggest that priming in our experiments was at least partly syntactic, but they are not conclusive.

A different question is the extent to which some of our effects might not have arisen from comprehension processes, but instead from covert production processes associated with processing the prime. (We have already addressed the issue of whether overt production could involve comprehension-based monitoring in the discussion of Experiment 3.) This might occur because language comprehension routinely draws on some of the mechanisms of language production (e.g., Townsend & Bever, 2001). Alternatively, they might be specifically used during description–picture matching. According to this latter account, when participants read the prime expression, they established a semantic representation of the prime expression that corresponded to either the high- or low-attached analysis. When they subsequently saw the two pictures they were to choose between, they generated the prime expression again, on the basis of this semantic representation. In that case, initial comprehension of the prime would involve the activation of syntactic rules; these rules would then be activated again during regeneration of the prime (see Potter & Lombardi, 1998). Hence, both comprehension and covert production processes could contribute to the initial activation that subsequently leads to priming.

Although an account in which expression–picture matching involves a significant contribution from production is logically possible, such an account is not generally entertained within the literature using variants of this task. This is most apparent within the cognitive neuropsychological literature, in which sentence–picture matching is regarded as a standard test of comprehension (e.g., Caramazza, Basili, Koller, & Berndt, 1981; Caramazza & Zurif, 1976; Grodzinsky, 1989; Martin & Blossom-Stach, 1986). Notably, Caramazza et al. presented the sentence immediately before the pictures (as we did), to stop their patient from eliminating pictures on the basis of partial information. Most relevant, its results are regularly used to motivate distinctions between production and comprehension in aphasics (e.g., Grodzinsky, 2000), and there is good evidence that patients whose matching task results suggest agrammatic comprehension do not necessarily produce agrammatic speech (e.g., Martin & Blossom-Stach, 1986; see Martin, 2001, p. 350). It therefore seems unlikely that our results reflect production processes associated with covert production of the prime expression.

It would be much harder to explain the effect of priming on the target expressions in terms of production processes during picture matching on the target. The priming effect could not have been due to ambiguity about how to describe the chosen picture, because the high-attachment description was not compatible with the low-

[1] We thank an anonymous reviewer for this observation.

attachment picture, and the low-attachment description was not compatible with the high-attachment picture. This contrasts with Bock (1986), in which the target picture could be described in the two relevant ways (e.g., active or passive). So the priming could not have affected the choice of which structure to use, but rather must have affected the process of choosing which picture to describe. The locus of priming must be in the comprehension of the target expression, because any production priming must have taken place after picture selection.

Our results are therefore compatible with the representational model, in which both production and comprehension activate common representations that are concerned with the processing of complex expressions, and which are most likely at least partly syntactic in nature. These common representations are efficacious in priming and affect both comprehension and production. When a particular structure is processed, during either production or comprehension, the rule associated with it is activated and is thereby facilitated for subsequent reuse in either production or comprehension (Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995). This account accords with theories of language production, in which syntactic and semantic information are generally assumed to be common to production and comprehension (e.g., Levelt, Roelofs, & Meyer, 1999), and with approaches that assume a unified architecture for production and comprehension (e.g., Kempen, 2000).

One implication of these findings is for language processing in dialogue. Some theories of dialogue invoke such common coding (or representational parity) to account for the way in which interlocutors can straightforwardly switch between speaking and listening (Pickering & Garrod, 2004). Thus facilitation for comprehension of a particular structure should occur whenever that structure has been previously encountered, irrespective of whether this encounter involved production or comprehension. Pickering and Garrod argued that successful dialogue occurs when interlocutors align their situation models, and that the process by which this occurs is largely automatic. Specifically, alignment at one level of representation leads to further alignment at other levels of representation (e.g., lexical repetition enhances syntactic priming in dialogue; Branigan, Pickering, & Cleland, 2000).

Such alignment might occur if interlocutors simply use the same syntactic or semantic rules that they have just heard (i.e., comprehension-to-production priming). But a much stronger tendency for alignment will occur if interlocutors produce and comprehend syntactic or semantic structure in the same way as they have previously produced and comprehended it. For example, the tendency to repeat one's own choices (Bock, 1986) only facilitates alignment if people also have the tendency to perseverate in their patterns of comprehension; otherwise, the choice to use a particular structure would be restricted to a single speaker and would not "transmit" to the other speaker (cf. Garrod & Anderson, 1987). Likewise, the tendency for a speaker to comprehend an interlocutor in the same way that the speaker has just produced structure leads to both speakers making the same choices. The existence of all four sources of priming leads to a "spiraling" effect, whereby one interlocutor's actions affect the other's, whose actions in turn affect the first's. The finding that priming affects the time course of comprehension (Experiment 4) strengthens this conclusion, because it suggests that well-aligned interlocutors are likely to understand each other's contributions more efficiently as well. In conclusion, our experiments demonstrate that people can be primed in how they interpret prepositional-phrase ambiguities. These findings provide support for the existence of priming effects in language comprehension, and strongly suggest that they are at least partly syntactic in nature.

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Appendix

Item List

The expression before the first slash is the prime for Experiments 1 and 4; the expression between the slashes is the prime for Experiment 2. In Experiment 3, the prime verb was the base form of the verb used in the expression before the first slash (i.e., *hit*, *hurt*, *injure*, *poke*, *prod*, *thump*). The expression after the second slash was the target in Experiments 1–4. Expressions were paired with pictures (see text).

1. The teacher hitting the swimmer with the gun./The teacher prodding the swimmer with the umbrella./The nun hitting the monk with the ball.
2. The artist hitting the clown with the ball./The nun hurting the doctor with the gun./The cowboy hitting the soldier with the book.
3. The chef hitting the burglar with the bat./The artist poking the clown with the gun./The policeman hitting the dancer with the hammer.
4. The policeman hitting the sailor with the hammer./The teacher injuring the swimmer with the hammer./The artist hitting the pirate with the gun.
5. The policeman thumping the soldier with the gun./The chef injuring the boxer with the gun./The teacher thumping the clown with the book.
6. The artist thumping the monk with the book./The pirate hurting the dancer with the bat./The chef thumping the sailor with the gun.
7. The cowboy thumping the pirate with the hammer./The artist prodding the monk with the key./The policeman thumping the swimmer with the ball.
8. The nun thumping the dancer with the bat./The waitress poking the boxer with the key./The artist thumping the burglar with the hammer.
9. The artist poking the clown with the gun./The teacher hitting the swimmer with the gun./The waitress poking the doctor with the banana.
10. The teacher poking the soldier with the banana./The cowboy injuring the clown with the sword./The artist poking the pirate with the gun.
11. The policeman poking the dancer with the hammer./The teacher hurting the monk with the sword./The waitress poking the burglar with the key.
12. The waitress poking the boxer with the key./The cowboy thumping the pirate with the hammer./The policeman poking the monk with the umbrella.
13. The policeman prodding the doctor with the gun./The policeman thumping the soldier with the gun./The waitress prodding the clown with the umbrella.
14. The waitress prodding the burglar with the hammer./The pirate injuring the sailor with the bat./The artist prodding the dancer with the key.
15. The artist prodding the monk with the key./The artist hitting the clown with the ball./The teacher prodding the boxer with the banana.
16. The teacher prodding the swimmer with the umbrella./The chef hurting the burglar with the hammer./The policeman prodding the soldier with the gun.
17. The pirate injuring the sailor with the bat./The waitress prodding the burglar with the hammer./The chef injuring the swimmer with the gun.
18. The cowboy injuring the clown with the sword./The nun thumping the dancer with the bat./The teacher injuring the sailor with the hammer.
19. The teacher injuring the swimmer the hammer./The teacher poking the soldier with the banana./The pirate injuring the burglar with the sword.
20. The chef injuring the boxer with the gun./The policeman hitting the sailor with the hammer./The cowboy injuring the doctor with the bat.
21. The nun hurting the doctor with the gun./The policeman prodding the doctor with the gun./The chef hurting the dancer with the sword.
22. The pirate hurting the dancer with the bat./The artist thumping the monk with the book./The nun hurting the clown with the hammer.
23. The chef hurting the burglar with the hammer./The policeman poking the dancer with the hammer./The pirate hurting the boxer with the bat.
24. The teacher hurting the monk with the sword./The chef hitting the burglar with the bat./The cowboy hurting the swimmer with the gun.

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