

Published in final edited form as:

Lang Cogn Process. 2006 November ; 21(7-8): 1011–1029.

## The functions of structural priming

Victor S. Ferreira and

University of California, San Diego, CA, USA

Kathryn Bock

University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, USA

### Abstract

*Structural priming* refers to speakers' tendency to produce sentences with previously heard or produced syntactic structures. We review arguments and evidence for three common accounts of the functions of structural priming. One is that structural priming enhances fluency. Only some (reaction time and fluency measure) evidence supports this view. A second account argues that structural priming stems from implicit learning of how features of meaning are linked to syntactic configurations. We describe evidence suggesting that structural priming exhibits effects characteristic of both learning and implicitness. A third account claims that structural priming is an aspect of coordination or *alignment* among interlocutors. Consistent with this, some evidence shows that structural priming involves a shorter-term component that is broadly sensitive to repeated bindings of wide-ranging types of knowledge. Together, these observations suggest that structural priming is likely a multifaceted force that reflects implicit learning and, possibly independently, alignment among interlocutors.

---

People tend to repeat themselves. They say things that they've heard themselves say before, and that they've heard others say before. They repeat specific words (Kubovy, 1977), sounds (Dell, Burger, & Svec, 1997), and the general framing or mental model of the subject under discussion (Garrod & Anderson, 1987; Garrod & Pickering, 2004). In short, though linguistic performance is quintessentially creative, it can also be surprisingly recapitulative.

Among all forms of repetition, one that has received much scrutiny in recent years is here termed *structural priming* (sometimes called *syntactic priming*). Structural priming refers to speakers' tendency to use current utterances that are similar in general form to sentences they have previously experienced. For example, speakers who previously produced (Bock, 1986) or heard (Bock, Dell, Chang, & Onishi, in press; Branigan, Pickering, & Cleland, 2000a) a *prepositional dative* structure like *The governess made [a pot of tea] [for the princess]* are likely to describe a subsequent picture with another prepositional dative like *The woman is showing [the dress] [to the man]*. In contrast, speakers who previously heard or produced a double-object structure like *The governess made [the princess] [a pot of tea]* are likely to describe a subsequent picture with another double-object like *The woman is showing [the man] [the dress]*. Structural priming is evident in naturalistic (Bock et al., in press; Gries, 2005; Szmrecsanyi, 2004, 2005; Weiner & Labov, 1983) as well as experimental (e.g., Bock, 1986) settings, and in utterances produced to communicate (e.g., Branigan et al., 2000a) or to support memory (e.g., Bock, 1986). Structural priming appears in the production of different kinds of structures, including transitives and datives (actives vs. passives or prepositional datives vs. double objects; e.g., Bock, 1986), the mention of the optional *that* (Ferreira,

---

Correspondence should be addressed to Victor S. Ferreira, Department of Psychology 0109, University of California, San Diego, La Jolla, CA, 92093-0109, USA. E-mail: ferreira@psy.ucsd.edu

Preparation of this paper was supported in part by National Institute of Health grants R01 MH-64733, R01 HD21011, and R01 MH66089, and National Science Foundation grant BCS 0213270.

2003a), particle placement (Konopka & Bock, 2005), different noun-phrase structures (Cleland & Pickering, 2003), and from one level of syntactic embedding to another (Branigan, Pickering, McLean, & Stewart, 2006). Structural priming has been observed in English (e.g., Bock, 1986), Dutch (e.g., Hartsuiker & Kolk, 1998), and German (e.g., Loebell & Bock, 2003; Scheepers, 2003). In sum, structural priming is a wide-ranging phenomenon, that manifests in different settings, different languages, and with different linguistic structures.

Most work on structural priming has aimed to establish its representational underpinning, and this work has led to the consensus that structural priming occurs because speakers tend to repeat syntactic structures from utterance to utterance. This conclusion follows from studies showing that the repetition of structure is not dependent on the repetition of different aspects of the contents of previous utterances. For example, structural priming is observed even when an initial *prime* sentence and a subsequent *target* sentence share no open-class words at all (nouns, verbs, adjectives; Bock, 1986), though the effect is larger when sentences do share open-class words (Pickering & Branigan, 1998). Structural priming is also observed between sentences that have similar syntactic structures but are semantically distinct, though it is not observed between sentences that have different syntactic structures but are similar in terms of prosody or superficial appearance (Bock & Loebell, 1990). Furthermore, structural priming is insensitive to whether prime and target sentences have similar or distinct inflectional or closed-class lexical content (Bock, 1989; Ferreira, 2003a; Pickering & Branigan, 1998). Speakers tend to repeat thematic (Chang, Bock, & Goldberg, 2003) and semantic assignments from sentence to sentence, such that when they produce sentences with an inanimate grammatical subject, they are likely to do so again (Bock, Loebell, & Morey, 1992; Griffin & Weinstein-Tull, 2003); however, speakers also repeat syntactic structures over and above these semantic-assignment priming effects (Bock et al., 1992).

Another question about structural priming that has received less attention and for which answers are not yet clear is a functional one: What is structural priming for? How might syntactic repetition or persistence serve linguistic processing or communication? Recent work has seen the emergence of three different ways of characterising the function of structural priming. One view is that priming enhances the fluency of communication by promoting faster speech onsets (Corley & Scheepers, 2002; Smith & Wheeldon, 2001) or more fluent formulation of utterances (Bock & Loebell, 1990). Another view describes structural priming as a shorter-term reflection of the longer-term process of learning how the syntactic constructions in a speaker's language map onto the features of meaning that they express (e.g., Bock & Griffin, 2000; Chang, Dell, Bock, & Griffin, 2000). A third view characterises structural priming as a link in a larger chain that promotes efficient and ultimately successful communication between interlocutors (Pickering & Garrod, 2004). Though fundamentally different, these accounts are in fact not mutually exclusive, a point to which we return at the end of this paper.

## STRUCTURAL PRIMING AS A VEHICLE OF FLUENCY

The Law of Exercise is one of the oldest principles of psychology. A typical consequence of practicing a skill is increased fluency, ease, or efficiency in performance, and it is simple to imagine that structural priming is a manifestation of this basic principle. Smith and Wheeldon (2001) explicitly proposed that priming serves to decrease speakers' processing effort, and thereby to make speaking easier, faster, and more fluent. In line with this, they showed that structurally primed noun-phrase structures were begun more rapidly than unprimed structures (see also Corley & Scheepers, 2002). Along similar lines, Bock and Loebell (1990) observed that when passive structures were the most frequently produced structures in an experimental session, they were produced more fluently than corresponding active sentences, despite the latter's greater overall frequency in the language.

Against this hypothesis about the functional utility of priming, however, is the observation that increased fluency due to priming is short-lived (Wheeldon & Smith, 2003), whereas priming itself is at least sometimes surprisingly long-lived (see below). Moreover, Szmrecsanyi (2004,2005) presents corpus analyses showing that speakers are actually *less* likely to use primed structures when messages are more complex, counter to the expectation that momentarily easier structures should be more likely to be deployed. This effect might be due to syntactic interference from the material that creates the greater complexity, though experimental work suggests that material in and around primed constructions does not systematically influence degree of priming (Bock, 1986; Branigan et al., 2006; Fox Tree & Meijer, 1999). Together, these observations suggest that additional accounts of syntactic priming are needed. We turn to two others in what follows.

## STRUCTURAL PRIMING AS IMPLICIT LEARNING

In general, *implicit learning* refers to the incidental tuning or adjustment of the tendencies of a processing system as a function of experience. Most often, implicit learning reflects the modification of relatively superficial perceptual or motor processes. The *stem completion* task illustrates implicit learning (Roediger & Blaxton, 1987; Tulving, Schacter, & Stark, 1982). In this task, participants read a list of words (e.g., *motel*). Sometime later, they are provided with ‘stems’ – a list of the first few letters of words (e.g., *mot*) – and are asked to complete the stems with the first words that come to mind. People are consistently likely to complete stems with words they originally read even when the same words are unlikely to be used by control participants (who tend to use higher frequency completions such as *mother*). Awareness of or *explicit* memory for the originally studied words is unnecessary for the phenomenon to arise. These results suggest that readers’ experience with words tunes the process of lexical access toward more efficient retrieval of those particular words; when the stem-completion task engages the lexical-retrieval process again, the tuned words are more likely to be retrieved and so be provided as responses.

Structural priming too might reflect the operation of an implicit-learning process. Here, the relevant processes are components of *grammatical encoding*, the processes that link features of ideas to be expressed (often termed *messages*) to syntactic configurations or constructions in the grammar of a language. That is, when comprehenders encounter linguistic expressions, one thing they must do is determine how the syntactic structures of those linguistic expressions map onto ‘who did what to whom’ – how the subject, verb, direct object, indirect object, and so forth in the sentence map onto the relationships among the entities, actions, and modifiers that are identified by the (open-class) lexical content of the expression. Analogously, when producers create linguistic expressions, they must determine how the relational content of their message-level representations can be expressed in terms of grammatical subjects, direct objects, indirect objects, modifiers, adjuncts, and so forth, and in what order. Structural priming, then, might reflect tuning of this aspect of grammatical encoding: Comprehending or producing a linguistic expression causes speakers to link certain syntactic configurations in certain orders to relational structures in their message representations. Having done so once, the grammatical-encoding process is tuned to compute those linkings of message structures and syntactic configurations again (Bock et al., in press).

This idea of structural priming as implicit learning is somewhat counterintuitive. Relational knowledge represented at the message level and syntactic knowledge represented at grammatical encoding seem to be open-ended representations that are computed on the fly based on the current utterance being processed. How could the linking of such dynamic structures be subject to experience-based tuning?

One solution to this puzzle lies in imparting at least some additional structure to the relevant message-relational and syntactic levels. At the message-relational level, representational schemes such as those using event semantics (Chang, Dell, & Bock, 2006) or thematic roles (Fillmore, 1968; Jackendoff, 1972) might structure speakers' message-level representations of who did what to whom. At the syntactic level, aspects of the notion of syntactic construction or families of syntactic structures could similarly classify an otherwise open-ended syntactic vocabulary into phrasal categories consistent with structural representations in contemporary syntactic theories that call on context-sensitive grammars. Defined in this way, message-level role features that organise relational knowledge could be consistently mapped to syntactic constructions that organise syntactic knowledge. These mappings, which are semantically broad and multiply determined, but are also structurally strongly constrained, could then be subject to experience-based tuning.

One proposal along these lines comes from Chang (2002; see also Chang et al., 2006; Chang et al., 2000) in the form of models that explain structural priming in terms of error-based learning (Rumelhart, Hinton, & Williams, 1986). Learning occurs as the models come to represent the connections between abstract relational features of meaning and the word sequences that tend to convey those features. The models include a 'dual-path' architecture that creates a division of labour between the meaning representations and a sequencing system. The sequencing system in turn learns (via a simple recurrent network) to create dynamic structural frames for expressing words. This learning yields an ability to create structured sequences of words that are in important respects separable from specific meanings and can work independently of them. When the model is presented with input or produces meaningful output, the sequencing system undergoes error-based learning that causes changes in processing that yield a combination of meaning-independent and meaning-sensitive effects of structural priming.

### Structural priming as learning

Some current structural-priming results are consistent with this implicit-learning interpretation. Most relevant is evidence suggesting that structural priming reflects a form of learning because (a) it can cause relatively long-lasting changes to performance, and (b) it is sensitive to speakers' current state of knowledge. The clearest evidence of the longevity of structural priming comes from Bock and Griffin (2000). They had speakers repeat auditory prime sentences that either were alternating dative forms (prepositional datives vs. double-object datives, like *The governess made [a pot of tea] [for the princess]* vs. *The governess made [the princess] [a pot of tea]*) or were alternating transitive forms (passives vs. actives, like *One of the fans was punched by the referee* vs. *The referee punched one of the fans*). Then speakers repeated some number of auditory filler sentences that were neutral structures – intransitive structures like *Bob jogs every morning* or predicate-adjective structures like *Brandon and Brenda are similar*. Finally, speakers described target pictures that after dative primes could elicit dative (prepositional or double-object) descriptions, and that after transitive primes could elicit transitive (passive or active) descriptions.

Most importantly, Bock and Griffin (2000) manipulated whether speakers heard and repeated 0, 1, 2, 4, or 10 neutral sentences between the prime sentence and the target description. Note that 10 intervening neutral sentences constitutes a substantial interruption, both in terms of time (a minute or more) and in terms of processing events (with each neutral event involving hearing a sentence, repeating it back, and judging whether the sentence had been heard in the experiment before). Nonetheless, Bock and Griffin found that structural priming was about as robust when 10 neutral sentences intervened between prime repetition and target description as it was when no neutral sentences intervened between prime repetition and target description. Bock et al. (in press) observed this pattern again, even when participants only heard and did

not repeat the prime sentences (see also Bock & Kroch, 1989). So, structural priming has an important characteristic of implicit learning: It can be an enduring effect that survives across extensive amounts of intervening time and processing material (though see below for discussion of evidence suggesting that priming can sometimes be more short-lived). Developmental data, including evidence of priming in young children, are likewise consistent with this conception (Brooks & Tomasello, 1999; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Huttenlocher, Vasilyeva, & Shimpi, 2004).

Another set of observations pointing to the possibility that structural priming reflects a form of learning comes from the *inverse-preference* effect. In general, learning ought to be sensitive to the learner's current state of knowledge, such that when something is poorly known, it should be subject to greater learning, whereas when something is already well known, it should be subject to less learning. Formally, such asymmetries are the basis of computational accounts of the above-described error-based learning mechanisms (Chang, 2002; Chang et al., 2000; Chang et al., 2006; Rumelhart et al., 1986).

A number of observations in the literature suggest that structural priming exhibits an inverse-preference pattern (Bock, 1986; Bock & Griffin, 2000; Ferreira, 2003; Hartsuiker & Kolk, 1998; Hartsuiker, Kolk, & Huiskamp, 1999; Scheepers, 2003). Most of these have shown that structures that were in general less preferred or less common exhibited greater structural priming relative to a neutral baseline, whereas structures that were in general more preferred or more common exhibited less structural priming relative to a neutral baseline. Further evidence suggests that even the same structure exhibits greater syntactic persistence when it is produced in a context in which it is less preferred, compared to a context in which it is more preferred (Ferreira, 2003b). Other observations suggest that such inverse-preference effects too might be enduring. Specifically, Hartsuiker and Westenberg (2000) had Dutch speakers produce sentences with subordinate clauses, which in Dutch can be produced either with a participle-final or an auxiliary-final word order. Initial baseline measurements revealed that the participle-final word order was preferred to the auxiliary-final word order. Priming manipulations then revealed that relative to baseline, the more-preferred participle-final primes increased participle-final target production only weakly, whereas the less-preferred auxiliary-final primes decreased participle-final target production more strongly. When Hartsuiker and Westenberg assessed speakers' baseline preferences at the end of the experiment, after speakers had produced approximately equal numbers of each kind of prime structure, they found that speakers' baseline preferences reversed: the auxiliary-final word order was numerically preferred to the participle-final word order. This suggests that in the course of the experiment, the less-preferred auxiliary-final order accumulated more long-term priming than the more-preferred participle-final order.

Note that the sensitivity of learning to a structure's overall preference in the language addresses a potential cost of structural-priming-as-implicit-learning (Ferreira, 2003b). Specifically, the possibility that learning occurs every time a sentence is processed raises the concern that syntactic knowledge could become crystallised and inflexible, especially in light of baseline differences between structures. For example, active structures heavily outnumber passives in everyday language use, which might cause actives to effectively become overlearned and thus be used every time a speaker aims to express a transitive relational structure. However, the inverse-preference effect counteracts any such tendency: Because passive structures seemingly undergo more learning per processing event than actives (as a function of their degree of preference), inverse preference balances the more frequent learning that the active accrues.

### **Implicit versus explicit contributions to structural priming**

The evidence reviewed thus far suggests that structural priming can be long-lived and is sensitive to the knowledge state of the primed syntactic structures. Together, these observations



point to the conclusion that structural priming reflects learning. However, what is still uncertain is the degree to which structural priming is a form of *implicit* learning versus *explicit* learning (for a review of these forms of learning, see Squire, 1992). As noted above, implicit learning reflects the relatively specific tuning of a mechanism's processing tendencies – in this case, the mechanism responsible for linking the relational structures of speakers' messages to features of syntactic constructions. A different possibility is that structural priming partially or completely reflects explicit learning. By an explicit-learning account, structural priming might involve the encoding of utterances as 'facts' in long-term memory, complete with their conceptual, thematic, syntactic, lexical, and prosodic characteristics, all bound into a single episodic instance. This might be comparable to how other declarative knowledge is learned, for example, historical facts, or where one parked his or her car in the morning. Indeed, knowledge acquired through explicit learning could exhibit the features of learning that were attributed to structural priming in the previous section – explicit memories can be long-lived, and unusual explicit memories might be easier to remember than ordinary explicit memories.

In fact, based on current implicit-learning evidence, it is not obvious that structural priming could be an implicit-learning effect at all. This is because the signature effects of implicit learning are largely restricted to representational domains that are perceptual or motor in nature, such as stem completion (described above) and mirror drawing (where subjects trace shapes while viewing their actions in a mirror; see Milner, Corkin, and Teuber, 1968). Syntactic structure is neither as perceptual nor as motor in nature as these other representational domains, and so it is not obvious that structural priming, even if it is long-lived and is sensitive to a speaker's state of syntactic knowledge, could be a consequence of implicit learning of the kind revealed by tasks such as stem completion and mirror drawing. Another reservation is that implicit or procedural learning has been characterised as less relational than explicit, declarative learning (Cohen & Eichenbaum, 1993). Because syntax is nothing if not relational, this suggests that a nonrelational form of memory (implicit memory) may not be computationally capable of supporting structural priming. (Note that the conjecture that structural priming reflects implicit learning is different from the claim that syntactic processing in general might be implicit. Even if syntactic processing is implicit, it implies neither that such implicit processing leaves an enduring memory trace, nor that structural priming itself reflects sensitivity to any such memory trace.)

Until recently, just two observations spoke to possible implicit versus explicit memory contributions to structural priming. Both come from data reported in Bock et al. (1992). The first evaluated the supposition that if structural priming is implicit, there should be no relationship between speakers' explicit memory for prime sentences and the degree to which those prime sentences cause structural priming. Bock et al. (1992) assessed this prediction by determining whether primes that speakers explicitly remembered (as assessed by a multiple-choice recognition-memory test) caused more structural priming, and complementarily, whether primes that caused structural priming were better remembered. They observed no relationship between structural priming and explicit memory. Across the entire experiment, 29% of all prime sentences caused structural priming. If this priming were influenced by explicit memory, then prime sentences that were explicitly remembered should have been more effective primes, but they were not: 29% of the prime sentences that speakers explicitly remembered also caused structural priming. Complementarily, across the entire experiment, speakers explicitly remembered 66% of all prime sentences. If structural priming influenced explicit memory, then sentences that successfully caused priming should have been better remembered, but they were not: Speakers explicitly remembered 67% of the sentences that caused priming.

Another way to assess implicit versus explicit contributions to structural priming is to determine whether degree of priming is sensitive to task instructions that encourage subjects

to explicitly remember syntactic structure. In the Bock et al. (1992) structural priming procedure, two groups of speakers were tested in a running-recognition memory procedure, whereby speakers are asked after each sentence whether they had heard that sentence before in the session. One group was instructed to pay close attention to the wording of sentences, because they needed to distinguish whether current sentences were different from previous sentences even if they had (roughly) the same meaning (i.e., even if they were syntactic alternations). In essence, these instructions asked speakers to (explicitly) remember the syntactic structures of the presented sentences. The second group was instructed to remember meaning and not wording, so that syntactic structure was (as in everyday language use) only incidentally remembered. Bock et al. found that the subjects instructed to remember syntax showed greater structural priming (about a 12% difference) than subjects instructed to remember meaning (about a 5% difference). This suggests that structural priming is sensitive to explicit memory for syntax, which in turn is consistent with the possibility that structural priming might be due to explicit-memory functioning.

Less equivocal evidence that structural priming is an implicit-memory phenomenon comes in data from Ferreira, Bock, Wilson, and Cohen (2005). They assessed structural priming in a group of patients with *anterograde amnesia*. Anterograde amnesia is a memory condition that causes a severely impaired ability to encode new knowledge into explicit memory. At the same time, anterograde amnesia leaves implicit learning nearly intact. For example, if someone with anterograde amnesia is shown a list of words, later recognition memory ('indicate whether this word was on the previous list') or recall ('say all of the words from the previous list') performance will be much worse than that of a matched control. But when tested in a stem-completion task, the words from the previous list are as likely to emerge as completions as when a matched control is tested in the same task. Anterograde amnesia thus provides a powerful way to assess whether structural priming is based on implicit memory.

Ferreira et al. (2005) tested speakers with anterograde amnesia and matched control speakers in a structural priming paradigm similar to the one used by Bock and Griffin (2000). The procedure assessed both structural priming from and explicit memory for a set of prime sentences. Results showed that speakers with anterograde amnesia exhibited about the same amount of structural priming (an 8% effect) as matched controls (a 7% effect). Despite these comparable structural priming levels, speakers with anterograde amnesia exhibited a marked recognition memory impairment. Specifically, when speakers with anterograde amnesia discriminated prime sentences from a set of semantically and/or syntactically distinct foils, they showed a discriminability ( $d'$ ) score of 0.9, whereas control speakers showed a discriminability score of 1.8. Thus, the same prime sentences that caused about equivalent structural priming in speakers with anterograde amnesia and control speakers led to significantly poorer recognition memory in speakers with anterograde amnesia than in control speakers. In fact, when the structural priming and recognition memory measures of the speakers with anterograde amnesia were separately standardised with respect to control performance, speakers with anterograde amnesia exhibited impaired recognition memory (a  $z$ -score of  $-1.8$ ) but normal structural priming (a  $z$ -score of 0.1). This points to a dissociation between these forms of memory.

The observation of intact structural priming in amnesic patients despite their impaired explicit memory strongly suggests that at least a component of the structural priming effect reflects implicit learning. This agrees with the evidence described above showing a dissociation between implicit and explicit memory for sentences (Bock et al., 1992). The contrary observation, that of greater structural priming observed when speakers were told to attend to the wordings of sentences (Bock et al., 1992) might either reflect an attentional effect (the message-to-syntax links that are subject to implicit learning might have been subject to greater strengthening due to heightened attention to syntax irrespective of explicit learning), or an

additional explicit-memory contribution to structural priming (in fact, the possibility that structural priming might be multifaceted in this manner will be addressed further below). Evidence that at least a component of the structural priming effect reflects the operation of implicit memory, when combined with the evidence described in the previous section suggesting that structural priming has properties of learning in general (it is long-lived and is sensitive to the state of speakers' syntactic knowledge), suggests that structural priming has both features of implicit learning – it's implicit, and it's learning.

## STRUCTURAL PRIMING AS ALIGNMENT

Recently, Pickering and Garrod (Garrod & Pickering, 2004; Pickering & Garrod, 2004) more formally developed a notion initially suggested by Branigan et al. (2000a), that structural priming might implement an important dialogue function. Branigan et al.'s initial observation was that not only is structural priming evident in dialogue – from 'prime' sentences that a speaker hears from an interlocutor to 'target' sentences that the speaker says back to his or her interlocutor – but the numerical size of the priming effect is substantially larger than the structural priming effects that have been revealed in standard (memory-based isolated production) structural-priming paradigms (Bock, 1986; Bock & Griffin, 2000; Ferreira et al., 2005). Pickering and Garrod synthesised this general idea into the construct of *alignment*. The claim is that during dialogue, interlocutors strive to align their representations of the current situation at hand (their *situation models*). Representations in situation models, in turn, are systematically related to the lexical and syntactic devices that interlocutors use to describe them. This implies that if interlocutors align on lexical and syntactic levels, using the same words and structures to describe comparable aspects of the situation, alignment at the situation model is more likely as a result. In short, structural priming may directly reflect communication among interlocutors, by revealing the correspondence of their respective representations of (ultimately) the situation at hand.

The implicit learning and alignment views of structural priming are often placed in opposition to one another. However, the two accounts are not mutually exclusive. In fact, what could be taken as the central claims of the two views are strikingly complementary: Structural priming as implicit learning claims that when speakers link a relational structure (represented in a message) to a particular syntactic configuration, the tendency to link those two again becomes stronger (i.e., there is learning); priming is one manifestation of that strengthening. Structural priming as alignment claims (or can be taken to claim) that the links between syntactic configurations and the relational structures represented in situation models allow primed (aligned) syntactic configurations to promote priming (alignment) of relational structures (represented in situation models). Drawing a correspondence between messages and situation models, we see that both explanations for structural priming rely on the notion that representations between distinct levels (messages/situation models and syntax) are strengthened as a function of use. The implicit learning account formalised by Chang et al. (2006) emphasises that such strengthening reflects the gradual acquisition of the relevant knowledge, whereas the alignment account emphasises that a consequence of such strengthening, the binding of representations, can promote communication among interlocutors.

In fact, it is straightforward to posit an evolution (in a nongenetic sense) from structural-priming-as-implicit-learning to structural-priming-as-alignment and vice versa. This evolution emphasises the development and use of knowledge relationships that form the bedrock of *bootstrapping* accounts of language acquisition, both syntactic bootstrapping (Landau & Gleitman, 1985) and semantic bootstrapping (Pinker, 1989). The general idea is that as we accumulate linguistic experience, implicit learning mechanisms strengthen the knowledge relationships between relational structures represented in our messages/situation models and



the syntactic configurations made available to us through our grammar. This is how we learn message-to-syntax relationships. With the strengthening of a message-to-syntax link comes increased use of that link – persistence due to priming. This implies that priming in the form of repetition of a particular syntactic configuration can be used to infer the presence of a particular message structure in the interlocutor who exhibits the priming. This inference is presumably tacit, and according to Pickering and Garrod (2004), automatic. Thus, if interlocutors become sensitive to repetition within a particular dialogue context (a ‘situation’, in the sense of the situation model used by Pickering and Garrod), the repeated structure or material can support communication of one aspect of the subject matter at hand, namely the relational meanings under discussion.

From this evolution, it is a small step to a more independent structural-priming-as-alignment mechanism. Consider how we develop nonsyntactic strategies that communicate effectively, say, using particular patterns of intonation that capture attention, or using particular patterns of gesture that convey scalar properties. Presumably, such strategies develop because we are (tacitly) sensitive to the systematic relationships between particular behaviours (intonation, gesture) and their communicative consequences (capturing attention, conveying scalar properties). Eventually, the sensitivity to these systematic relationships becomes instantiated as a (tacit) strategy, whereby we use the behaviours themselves to achieve the communicative effects. So too might we be sensitive to the relationship between priming (i.e., the seeming overrepresentation of a linguistic feature in a particular context) and the prevalence of the corresponding message structures (a relationship which, according to the structural-priming-as-implicit-learning account, should not only exist, but ought to be systematic as well). This sensitivity begets a tacit strategy whereby priming between interlocutors can be used as a device to better infer relational meaning and thereby achieve more successful communication. Viewed in this way, structural-priming-as-implicit-learning may play a critical role in structural-priming-as-alignment by explaining why representations of meaning and representations of syntactic form might be systematically related to one another in the first place. Indeed, this kind of account can be seen in Pickering and Garrod’s (2004) explanation for *routinisation*, a longer-term (e.g., learning-based) representation and use of lexical and phrasal devices that carry relatively specific meanings (see also Kuiper, 1996).

This latter ‘small step’ carries an important implication: If structural-priming-as-alignment has its own at least partially independent processing mechanism, then structural priming might have multiple underlying cognitive bases. In particular, it may be that structural priming has both a longer-term manifestation, critical to its function as a reflection of implicit learning, and a shorter-term manifestation, critical to its function in alignment. Interestingly, a number of observations in the structural priming literature point to the possibility that structural priming has multiple cognitive bases. Suggestive evidence is reviewed next.

### **The multiplicity of structural priming**

Though Bock and Griffin (2000) presented evidence that structural priming can be long-lived, other observations show that priming can be quite transient. For example, Levelt and Kelter (1982) showed that a priming-like pattern in spoken production, involving the repetition of words and structures, disappeared after a single clause. Similarly, Branigan, Pickering, and Cleland (1999) found that with written production, processing even one intervening neutral sentence causes structural priming to diminish. However, Branigan, Pickering, Stewart, and McLean (2000b) showed that under similar circumstances with spoken production, structural priming was robust over longer intervals. Exactly what conditions cause structural priming to be shorter- or longer-lived is presently unclear; for present purposes, what is important is that these different time courses point to a complex structural priming effect with more than one cognitive basis.

A second set of observations that points to the multiplicity of structural priming is the evidence from production-latency investigations reviewed above. That is, a number of reports have shown that on trials where speakers exhibit structural priming, they begin their utterances more quickly than on trials where they do not exhibit structural priming (Corley & Scheepers, 2002; Smith & Wheeldon, 2001). As noted above, however, such production-latency effects of structural priming are markedly short-lived: Wheeldon and Smith (2003) observed that when one neutral trial intervened between prime and target sentences, the production-latency benefit is eliminated. They argue that because the production-latency effect is more short-lived than the structure-choice effect, that the effects likely have different cognitive bases, one shorter term (which could underlie alignment effects) and the other longer term (which could underlie implicit-learning effects).

Also relevant is that nonsyntactic factors appear to influence the likelihood of syntactic repetition. That is, the magnitude of structural priming is affected by whether speakers repeat content words from prime to target sentences (Pickering & Branigan, 1998), or even whether the content words in prime and target sentences are semantically similar to one another (Cleland & Pickering, 2003). The order of adjectives in speakers' utterances (e.g., 'stripy orange circle' vs. 'orange stripy circle') is also subject to persistence (Haywood, Pickering, & Branigan, 2003), even though the syntactic differences between such structures is not obvious. And the magnitude of structural priming can be independently boosted by whether speakers are able to repeat semantic or thematic assignments between prime and target sentences (Bock et al., 1992; Chang et al., 2003).

Conceivably, a basic syntactic repetition effect may reflect the operation of a longer-lived, implicit learning mechanism, whereas in the shorter term, the binding of specific contents (lexical, semantic, or thematic) and positions in specific structures triggers the repetition of structure. Because these shorter-term effects involve multiple cognitive dimensions, it is reasonable to suppose that they rely more heavily on explicit-memory processes. Consequently, the influences that trigger the shorter-term effect should have a shorter time course, dissipating over intervening events. Konopka and Bock (2005) observed a pattern of this kind with respect to the influence of open-class lexical repetition between prime and target sentences. Like Pickering and Branigan (1998), they obtained larger structural-priming effects when prime and target sentences shared main verbs. This lexically enhanced priming was observed when no neutral trials intervened between prime and target sentences. However, when neutral trials separated the prime and target sentences, the levels of structural priming were the same regardless of whether the verbs repeated.

This suggests that multiple mechanisms can contribute to structural priming. Shorter-term effects may be broadly sensitive to disparate kinds of repetition that occur between prime and target sentences, whereas longer-term effects may more specifically reflect structural learning. This follows from the proposed functional taxonomy: Dynamic, shorter-term effects, sensitive to the kinds of repetition that flag coordination among interlocutors, are suitably flexible supports for alignment; repetitions of the relational mapping from message structures to syntactic configurations reflect a longer-term learning of message-to-syntax relationships that support communication more broadly.

## SUMMARY AND CONCLUSIONS

The evidence reviewed here suggests the following: Structural priming has characteristics of learning in general, in that it can be long-lived (Bock & Griffin, 2000) and shows evidence of sensitivity to the state of a speaker's knowledge of the learning domain (e.g., Ferreira, 2003b; Hartsuiker & Westenberg, 2000). Structural priming also appears to be due to implicit learning, being as robust in speakers with anterograde amnesia as it is in matched controls,

despite the profound recognition memory impairments of the amnesic speakers for the very same prime sentences. More speculatively, structural priming may consist of several component effects, one based on shorter-term memory that appears at short prime-target lags and the other based on longer-term memory that appears at long prime-target lags. This possibility is suggested by a variety of evidence in the structural priming literature showing that in general, structural priming is a multifaceted effect.

This evidence makes a convincing case that structural priming reflects implicit learning, exhibiting the characteristics of other implicit learning effects (for a complete presentation of the ways in which structural priming looks like implicit learning, see Bock & Griffin, 2000). Such implicit learning can be seen as a mechanism by which speakers come to connect and strengthen their knowledge that specific relational structures encoded in message representations can be expressed by specific syntactic configurations in their grammar. The evidence is also consistent with the claim that structural priming supports normal communicative functions, whereby some of the bindings that enter into priming are exploited to allow interlocutors to more confidently infer the representation of particular message structures during dialogue. The possibility that structural priming has several processing bases, some that are short-lived and underlie alignment effects and others with longer-term consequences, is tentatively suggested by the different time-courses of lexically enhanced and lexically independent structural priming.

In sum, the issues discussed in this paper help shed light on why language users might be so surprisingly recapitulative: The repetition of linguistic features – the features of everyday conversational interaction – may reflect the workings of basic learning processes, and at the same time provide important communicative benefits. It is this effective learning and communicative facility that ultimately allows the creative linguistic capacity in humans to be successfully learned, and then effectively used.

## References

- Bock JK. Syntactic persistence in language production. *Cognitive Psychology* 1986;18:355–387.
- Bock JK. Closed-class immanence in sentence production. *Cognition* 1989;31:163–186. [PubMed: 2721134]
- Bock JK, Dell GS, Chang F, Onishi KH. Persistence structural priming from language comprehension to language production. *Cognition*. in press
- Bock JK, Griffin ZM. The persistence of structural priming: Transient activation or implicit learning? *Journal of Experimental Psychology: General* 2000;129(2):177–192. [PubMed: 10868333]
- Bock, JK.; Kroch, AS. The isolability of syntactic processing. In: Carlson, GN.; Tanenhaus, MK., editors. *Linguistic structure in language processing*. Dordrecht: Kluwer; 1989. p. 157-196.
- Bock JK, Loebell H. Framing sentences. *Cognition* 1990;35:1–39. [PubMed: 2340711]
- Bock JK, Loebell H, Morey R. From conceptual roles to structural relations: Bridging the syntactic cleft. *Psychological Review* 1992;99:150–171. [PubMed: 1546115]
- Branigan HP, Pickering MJ, Cleland AA. Syntactic priming in written production: Evidence for rapid decay. *Psychonomic Bulletin and Review* 1999;6(4):635–640. [PubMed: 10682206]
- Branigan HP, Pickering MJ, Cleland AA. Syntactic co-ordination in dialogue. *Cognition* 2000a;75(2):B13–B25. [PubMed: 10771277]
- Branigan HP, Pickering MJ, McLean JF, Stewart AJ. The role of global and local syntactic structure in language production: Evidence from syntactic priming. *Language and Cognitive Processes* 2006;21:974–1010.
- Branigan HP, Pickering MJ, Stewart AJ, McLean JF. Syntactic priming in spoken production: Linguistic and temporal interference. *Memory and Cognition* 2000b;28(8):1297–1302.
- Brooks PJ, Tomasello M. Young children learn to produce passives with nonce verbs. *Developmental Psychology* 1999;35(5):29–44. [PubMed: 9923462]

- Chang F. Symbolically speaking: A connectionist model of sentence production. *Cognitive Science* 2002;26:609–651.
- Chang F, Bock JK, Goldberg A. Can thematic roles leave traces of their places? *Cognition* 2003;90:29–49. [PubMed: 14597269]
- Chang F, Dell GS, Bock JK. Becoming syntactic. *Psychological Review* 2006;113:234–272. [PubMed: 16637761]
- Chang F, Dell GS, Bock JK, Griffin ZM. Structural priming as implicit learning: A comparison of models of sentence production. *Journal of Psycholinguistic Research* 2000;29(2):217–229. [PubMed: 10709186]
- Cleland AA, Pickering MJ. The use of lexical and syntactic information in language production: Evidence from the priming of noun-phrase structure. *Journal of Memory and Language* 2003;49(2):214–230.
- Cohen. NJ.; Eichenbaum, H. *Memory, amnesia, and the hippocampal system*. Cambridge, MA: MIT Press; 1993.
- Corley M, Scheepers C. Syntactic priming in English sentence production: Categorical and latency evidence from an internet-based study. *Psychonomic Bulletin and Review* 2002;9(1):126–131. [PubMed: 12026944]
- Dell GS, Burger LK, Svec WR. Language production and serial order: A functional analysis and a model. *Psychological Review* 1997;104(1):123–147. [PubMed: 9009882]
- Ferreira VS. The persistence of optional complementizer production: Why saying “that” is not saying “that” at all. *Journal of Memory and Language* 2003a;48(2):379–398.
- Ferreira, VS. The processing basis of syntactic persistence: We repeat what we learn; Paper presented at the 44th Annual Meeting of the Psychonomic Society; Vancouver, Canada. 2003b.
- Ferreira, VS.; Bock, JK.; Wilson, M.; Cohen, NJ. Structural persistence in anterograde amnesia: Evidence for implicit learning; Paper presented at the 46th Annual Meeting of the Psychonomic Society; Toronto, Canada. 2005.
- Fillmore, CJ. The case for case. In: Bach, E.; Harms, RT., editors. *Universals in linguistic theory*. New York: Holt, Rinehart and Winston; 1968. p. 1-88.
- Fox Tree JE, Meijer PJA. Building syntactic structure in speaking. *Journal of Psycholinguistic Research* 1999;28(1):71–92. [PubMed: 9949715]
- Garrod S, Anderson A. Saying what you mean in dialogue: A study in a conceptual and semantic coordination. *Cognition* 1987;27:181–218. [PubMed: 3691025]
- Garrod S, Pickering MJ. Why is conversation so easy? *Trends in Cognitive Sciences* 2004;8(1):8–11. [PubMed: 14697397]
- Gries S. Syntactic priming: A corpus-based approach. *Journal of Psycholinguistic Research* 2005;34:365–399. [PubMed: 16142588]
- Griffin ZM, Weinstein-Tull J. Conceptual structure modulates structural priming in the production of complex sentences. *Journal of Memory and Language* 2003;49(4):537–555.
- Hartsuiker RJ, Kolk HHJ. Syntactic persistence in Dutch. *Language and Speech* 1998;41(2):143–184. [PubMed: 10194875]
- Hartsuiker RJ, Kolk HHJ, Huiskamp P. Priming word order in sentence production. *Quarterly Journal of Experimental Psychology* 1999;52A:129–147.
- Hartsuiker RJ, Westenberg C. Word order priming in written and spoken sentence production. *Cognition* 2000;75(2):B27–B39. [PubMed: 10771278]
- Haywood, S.; Pickering, MJ.; Branigan, HP. Priming and audience design: Evidence for the effect of different processes on language production in dialogue; Paper presented at the 16th Annual CUNY Conference on Human Sentence Processing; Cambridge, MA. 2003 Mar.
- Huttenlocher J, Vasilyeva M, Cymerman E, Levine S. Language input and child syntax. *Cognitive Psychology* 2002;45(3):337–374. [PubMed: 12480478]
- Huttenlocher J, Vasilyeva M, Shimpi P. Syntactic priming in young children. *Journal of Memory and Language* 2004;50(2):182–195.
- Jackendoff, RS. *Semantic interpretation in generative grammar*. Cambridge, MA: MIT Press; 1972.
- Konopka, B.; Bock, JK. Helping syntax out: What do words do?; Paper presented at the 18th Annual CUNY Conference on Human Sentence Processing; Tucson, AZ. 2005 Apr.

- Kubovy M. Response availability and the apparent spontaneity of numerical choices. *Journal of Experimental Psychology: Human Perception and Performance* 1977;3:359–364.
- Kuiper, K. Smooth talkers: The linguistic performance of auctioneers and sportscasters. Mahwah, NJ: Lawrence Erlbaum Associates Inc; 1996.
- Landau, B.; Gleitman, LR. Language and experience: Evidence from the blind child. Cambridge, MA: Harvard University Press; 1985.
- Levelt WJM, Kelter S. Surface form and memory in question answering. *Cognitive Psychology* 1982;14:78–106.
- Loebell H, Bock K. Structural priming across languages. *Linguistics* 2003;41(5):791–824.
- Milner B, Corkin S, Teuber HL. Further analysis of the hippocampal amnesic syndrome: 14-year follow-up study of H. M. *Neuropsychologia* 1968;6(3):215–234.
- Pickering MJ, Branigan HP. The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language* 1998;39(4):633–651.
- Pickering MJ, Garrod S. Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences* 2004;27(2):169–226. [PubMed: 15595235]
- Pinker, S. Learnability and cognition: The acquisition of argument structure. Cambridge, MA: MIT Press; 1989.
- Roediger HL, Blaxton TA. Effects of varying modality, surface features, and retention interval on priming in word-fragment completion. *Memory and Cognition* 1987;15(5):379–388.
- Rumelhart, DE.; Hinton, GE.; Williams, RJ. Learning internal representations by error propagation. In: Rumelhart, DE.; McClelland, JL., editors. *Parallel distributed processing: Explorations in the microstructure of cognition*. Cambridge, MA: MIT Press; 1986.
- Scheepers C. Syntactic priming of relative clause attachments: Persistence of structural configuration in sentence production. *Cognition* 2003;89(3):179–205. [PubMed: 12963261]
- Smith M, Wheeldon L. Syntactic priming in spoken sentence production: An online study. *Cognition* 2001;78(2):123–164. [PubMed: 11074248]
- Squire LR. Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans. *Psychological Review* 1992;99(2):195–231. [PubMed: 1594723]
- Szmrecsanyi, B. Persistence phenomena in the grammar of spoken English. Albert-Ludwigs-Universität Freiburg; Freiburg, Germany: 2004. Unpublished Ph.D. dissertation
- Szmrecsanyi B. Language users as creatures of habit: A corpus-based analysis of persistence in spoken English. *Corpus Linguistics and Linguistic Theory* 2005;1:113–149.
- Tulving E, Schacter DL, Stark HA. Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1982;8:336–342.
- Weiner EJ, Labov W. Constraints on the agentless passive. *Journal of Linguistics* 1983;19:29–58.
- Wheeldon LR, Smith MC. Phrase structure priming: A short-lived effect. *Language and Cognitive Processes* 2003;18(4):431–442.