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Structural Priming: A Critical Review

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Abstract

Repetition is a central phenomenon of behavior, and researchers make extensive use of it to illuminate psychological functioning. In the language sciences, a ubiquitous form of such repetition is *structural priming*, a tendency to repeat or better process a current sentence because of its structural similarity to a previously experienced ("prime") sentence (Bock, 1986). The recent explosion of research in structural priming has made it the dominant means of investigating the processes involved in the production (and increasingly, comprehension) of complex expressions such as sentences. This review considers its implications for the representation of syntax and the mechanisms of production, comprehension, and their relationship. It then addresses the potential functions of structural priming, before turning to its implications for first language acquisition, bilingualism, and aphasia We close with theoretical and empirical recommendations for future investigations.

Keywords

Syntax; Priming; Grammatical structure; Language production; Language comprehension

A central phenomenon in experimental psychology is repetition – when we perform an action that is the same in some respects as an action we have performed before, or that we have observed others perform before. Repetition is central because it can reflect the operation of many different underlying psychological mechanisms. It can reflect learning and development (as we acquire a capability, we begin to repeat the products of that capability), imitation (we can repeat others' behavior to accomplish social as well as learning and development goals), and (lack of) executive control (when repetitive behavior reflects a perseverative tendency and so an inability to inhibit a previous and now potent response). Repetition is also inversely related to creativity, in that when we repeat a previous behavior, we forgo the opportunity to create a novel behavior instead.

In the past couple of decades, research in the language sciences has revealed a new and striking form of repetition that we here call *structural priming*. When people talk or write, they tend to repeat the underlying basic structures that they recently produced or experienced others produce. This phenomenon has been the subject of heavy empirical scrutiny. Some of this scrutiny has been because, as in other domains in cognitive psychology (e.g., priming in the word-recognition literature; e.g., McNamara, 2005), the tendency to be affected by the repetition of aspects of knowledge can be used to diagnose the nature of that knowledge. So in this case, the tendency to repeat aspects of sentence structure helps researchers identify some of the representations that people construct when producing or comprehending language. As

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we shall see, much structural priming is unusually abstract, evidently reflecting the repetition of representations that are independent of meaning and sound. This is therefore informative about how people represent and use abstract structure that is not directly grounded in perceptual or conceptual knowledge. One possibility is that the representations that it identifies can be equated with the representations assumed in formal linguistics. In addition, the technique may inform us about the representations used by different populations, such as children, bilinguals, or aphasics.

Structural priming has also been heavily scrutinized because it helps us understand particular important types of repetitive phenomenon. Specifically, it may reflect processes of learning (Chang, Dell, & Bock, 2006) or it may reflect critical communicative, imitative, or social functions (Pickering & Garrod, 2004). It is important to note that such effects of priming attribute functional value to the repetition per se. Thus, the repetition that comes from structural priming has been used both 'epiphenomenally' (to tap into language representations and processes) and functionally (to better understand communication and language learning), to great scientific profit. In short, structural priming is an informative and heavily investigated phenomenon and therefore warrants an extensive and directed review. Below, we provide a historical introduction to structural priming, before turning to a detailed discussion of research findings and their theoretical implications.

Structural priming was discovered over 20 years ago, with the classic experimental demonstration being Bock (1986). There are now more than a hundred studies that use structural priming or closely related methods. Most are concerned with language production, but many recent studies address priming from comprehension to production, or priming within comprehension. In addition, there is good evidence of structural repetition outside the laboratory.

Some researchers use the term *syntactic priming* (e.g., Pickering & Branigan, 1999), but we shall use *structural priming* because it encompasses abstract linguistic priming that need not be syntactic (e.g., Bock, Loebell, & Morey, 1992), and indeed does not presuppose the existence of specifically syntactic representations. Moreover, *syntactic priming* is also used to refer to the facilitatory effects of a syntactically congruent context on lexical processing (e.g., Deutsch & Bentin, 1994; Wicha et al., 2005; Wright & Garrett, 1984). We also avoid the term *syntactic persistence* (Bock, 1986) because not all structural priming effects involve perseveration (e.g., Smith & Wheeldon, 2001). Note that the term *priming* can also refer to the experimental procedure (and the closely related data that are extracted from natural language corpora) rather than an explanation of the underlying cognitive processes.

In addition to reviewing and interpreting the literature, this article has a broader goal as well. The history of psychology is littered with thorough investigations of some empirical phenomenon for a number of years, which are then set aside and sometimes forgotten. One way to prevent this is to connect the data to theories of psychological functioning more generally, rather than narrowly investigating the phenomenon itself. Though it is important to understand structural priming itself, it is more critical to use syntactic priming to better understand how language is represented and processed.

The discovery of structural priming

Naturalistic investigation of structural repetition

Several researchers have noted that in everyday conversation, speakers tend to repeat their own or others' structural choices (e.g., Bühler, 1934; Kempen, 1977; Lashley, 1951). The first systematic investigation of this sort of repetition appears to be Schenkein (1980), who observed repetition of syntactic form in conversations between burglars over walkie-talkies. Next,

Weiner and Labov (1983) found that a strong predictor of passive use in interviews was the presence of another passive in the previous five utterances. This effect may have been due to the repetition of linguistic structure, though it could have other explanations such as a tendency to perseverate with a formal register. Estival (1985) then tried to confirm that Weiner and Labov's findings were due to linguistic rather than nonlinguistic structure on the basis of further analyses of their data. Another useful and extensive discussion of structural and other forms of repetition is provided by Tannen (1987, 1989, ch. 3), and some sociolinguists have appealed to repetition in explaining structural variation (e.g., Cameron & Flores-Ferran, 2004; Scherre & Naro, 1991; Travis, 2007). A very recent development has been the use of computational methods to precisely quantify structural repetition in fairly large corpora containing several thousand instances of specific linguistic forms (e.g., Gries, 2005; Szmrecsanyi, 2005, 2006). As we shall see, these studies reveal patterns that are typically consistent with experimental research and also demonstrate that repetition plays an important role in everyday language use.

Experimental investigations

Experimental work on structural repetition began with Levelt and Kelter (1982), who in one experiment asked Dutch shopkeepers *Om hoe laat gaat uw winkel dicht?* ("At what time does your shop close?") or *Hoe laat gaat uw winkel dicht?* ("What time does your shop close?"). In the former case, replies tended to include the preposition, for example *Om vijf uur* ("At five o'clock"); in the latter, replies tended to exclude the preposition, for example *Vijf uur* ("Five o'clock"). This was followed up by a highly influential demonstration from Bock (1986). Under the guise of a memory task, individual speakers repeated prime sentences and then described semantically unrelated target pictures. Primes consisted of transitive sentences in either an active (1a) or passive (1b) form and dative sentences in either a prepositional-object (2a) or double-object (2b) form:

(1a) One of the fans punched the referee.

(1b) The referee was punched by one of the fans.

(2a) A rock climber sold some cocaine to an undercover agent.

(2b) A rock climber sold an undercover agent some cocaine.

Speakers were more likely to use an active description of the target picture (e.g., *lightning is striking the church*) after (1a) than after (1b) and a passive description (e.g., *the church is being struck by lightning*) after (1b) than after (1a). Likewise, they tended to use a prepositional-object description of the target picture (e.g., *the man is reading a story to the boy*) after (2a) than after (2b) and a double-object description (e.g., *the man is reading the boy a story*) after (2b) than after (2a). In other words, speakers appeared to be structurally primed for both pairs of constructions. A strength of these demonstrations is that priming was observed in tasks presented to participants as memory paradigms, and which involved repeating and formulating sequences of unrelated sentences. This reveals that priming arises automatically, and does not depend on particular communicative intentions or prime-target relationships (e.g., question and answer; Levelt & Kelter, 1982) or discourse factors such as register (Weiner & Labov, 1983) in order to manifest itself.

After this initial investigation, Bock and colleagues produced three further papers on structural priming and its implications (Bock, 1989; Bock & Loebell, 1990; Bock et al., 1992; see Bock, 1990, and Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995, for discussion). Since the late 1990s, many other researchers have discovered the empirical and theoretical value of structural priming. Publications on the topic have appeared in large numbers, revealing the strength and ubiquity of the phenomenon. Bock's (1986) picture-description paradigm has been supplemented with sentence recall (Potter & Lombardi, 1998), written sentence completion (Pickering & Branigan, 1998), and spoken sentence completion (Branigan, Pickering, Stewart,

& McLean, 2000b; Hartsuiker & Westenberg, 2000). Not surprisingly, structural priming occurs in other languages, such as Dutch (Hartsuiker & Kolk, 1998b) and German (Scheepers, 2003). It occurs for a range of constructions, including the order of subject and locative (Hartsuiker, Kolk, & Huiskamp, 1999), the order of verb and auxiliary (Hartsuiker & Westenberg, 2000), and the form of complex noun phrases (Cleland & Pickering, 2003). It occurs from comprehension to production, both in isolation (Potter & Lombardi, 1998) and in dialogue (Branigan, Pickering, & Cleland, 2000a). In fact, some dialogue studies have shown considerably larger priming effects than in Bock's original demonstrations.

Recent studies have addressed the durability of priming, and indicate that it is sometimes relatively long lasting (Bock & Griffin, 2000), though there is also evidence for decay over time or intervening sentences (Branigan, Pickering, & Cleland, 1999). It is also enhanced by some forms of open-class repetition between prime and target, for example the head verb (Pickering & Branigan, 1998), suggesting that there is some lexical component to priming. Additionally, priming can affect timing as well as choice of form (Smith & Wheeldon, 2001). Finally, there is growing evidence for structural priming in comprehension, following very early demonstrations of effects of structural repetition (Mehler & Carey, 1967).

Thus far, almost all evidence for structural priming considers phenomena that are closely related to syntax. Yet, priming-like phenomena at other levels of representation are likely analogous and therefore relevant to the sentence-level structural priming under scrutiny here. For example, speakers may repeat abstract aspects of semantic structure (e.g., Garrod & Anderson, 1987; Meeuwissen, Roelofs, & Levelt, 2004). Additionally, Sevald and Dell (1994) found priming of words' consonant-vowel structure, and there is some evidence for priming of words' CV structure irrespective of the segmental content of that structure (Sevald, Dell, & Cole, 1995; see Roelofs & Meyer, 1998, for evidence that CV structure cannot be buffered or prepared in advance of actual production). This raises the intriguing possibility that all levels of processing that occur during production show priming, and therefore that the absence of priming suggests the absence of a corresponding level of representation.

One implication of priming is that it may be able to tell us about how different populations represent and process language. Thus, studies have shown priming in children (Savage, Lieven, Theakston, & Tomasello, 2003), Broca's aphasics (Hartsuiker & Kolk, 1998a), and amnesiacs (V. S. Ferreira, Bock, Wilson, & Cohen, 2005). It also occurs from one of a bilingual's languages to the other (Loebell & Bock, 2003), which suggests that structural knowledge is shared between languages.

In short, structural priming is relevant to a broad range of issues in the cognitive sciences. To demonstrate this, we argue that structural priming provides evidence for the mental representation of syntax. We then discuss its implications for the mechanisms of production, the relation between production and comprehension, and the mechanisms of comprehension. We then turn to address potential functions of structural priming, consider its implications for first language acquisition, bilingualism, and aphasia, and draw overall conclusions.

The mental representation of syntax

Since the beginning of the modern study of the psychology of language, a core concern has been the status of syntactic knowledge during language processing (e.g., Miller & Isard, 1963). One point of view (e.g., Bates & MacWhinney, 1982), sometimes termed *functionalist*, has been that syntactic knowledge is derivative upon other forms of knowledge, in particular, the specific features of meaning or the superficial properties of utterances (often termed *cues*). Another point of view (e.g., Bock, 1987; Frazier & Fodor, 1978), sometimes termed *autonomous*, has seen syntactic knowledge as independent of other forms of knowledge such as the specific features of meaning or the sensory or perceptual properties of utterances.

For example, consider the notion *subject of a sentence*. According to the functionalist viewpoint, the subject of a sentence is actually a set of features that accomplish communicative or cognitive functions, such as *topic*, *focus*, or *agent* (Bock & Kroch, 1989). According to the autonomous viewpoint, the subject of a sentence has an independent representational basis defined in terms of syntactic categories such as noun phrases; the other properties that are correlated with subjecthood (topic, agency) are seen as due to non-syntactic factors.

One reason that these two positions have existed alongside each other is that purely syntactic representations have been difficult to assess directly. Bock (1986) however noticed that structural priming might providing evidence for the existence of autonomous syntactic representations. This study and two that immediately followed (Bock, 1989; Bock & Loebell, 1990) provided support for an autonomous rather than functionalist view of syntactic structure. As noted above, Bock (1986) illustrated that structural priming can influence the choice of active versus passive forms and the choice of prepositional object versus double-object forms. Bock (1986) further suggested that this priming was not due to some form of priming of the construal of the pictures speakers described. Specifically, an explanation for priming that fits with a functionalist rather than autonomous viewpoint is that on hearing and repeating (say) a passive prime sentence, speakers construe the patient entity as prominent or important, presumably because it is mentioned first in the passive; this may cause speakers to focus on patient entities in target pictures following passive primes ("prominence priming"), which in turn could lead them to mention those patients first and hence produce passives. Critically, this explanation holds that the choice to mention the patient first that causes passive production rather vice versa. This is not compatible with the priming of syntactic structure, or even the autonomous representation of syntactic structure at all. If this explanation is correct, then speakers should describe target pictures with any sort of structure in which patients are prominent (e.g., an intransitive like "the church is burning"), and not just passive structures specifically ("the church was hit by lightning"). However, Bock (1986) found no such tendency: Prime sentences caused increased use of target descriptions with the same structure, rather than any structure in which patients were prominent.

We have noted that structural priming is observed even when the open-class, meaning-carrying words of a sentence are not repeated from prime to target sentences. However, given that particular syntactic structures are typically expressed with particular closed-class words (e.g., "The lightning was struck by the church"), another alternative explanation for structural priming that fits with a functionalist viewpoint is that when speakers produce particular closed-class words in prime sentences, they are primed to produce those same closed-class words again in their target descriptions, in turn causing the use of the prime's structure. Again, because the production of the primed function word led to the use of the prime's structure rather than the other way around, this would not be syntactic priming per se. Consistent with this possibility, Levelt and Kelter (1982, described above) showed that shopkeepers tended to repeat the form of callers utterances ("(At) what time do you close?" "(At) five o'clock."), but only when the question and answer included the same preposition.

Bock (1989) assessed this possibility. Speakers heard and repeated prepositional object or double-object prime sentences that included either the preposition *to* ("The girl is handing the paintbrush to the man on the ladder") or the preposition *for* ("The secretary was baking a cake for her boss"). They then described target pictures that could be described with prepositional object or double-object structures, but where the prepositional object form always included the preposition *to*. If function-word priming caused the appearance of structural priming, then only the prepositional datives with the preposition *to* should have caused prepositional dative target descriptions. Instead, Bock found that prepositional datives with *to* or with *for* caused equivalent production of prepositional dative targets with *to*. This finding was replicated by Fox Tree and Meijer (1999). These results suggest that what is primed is the production of an

abstract prepositional phrase structure (which fits with an autonomous viewpoint) rather than the production of particular function words (which would have fit with a functionalist viewpoint).

Further evidence supports the claim that priming is not entirely lexically based. V. S. Ferreira (2003) found priming of whether speakers produced *The mechanic mentioned the car could use a tune-up* or *The mechanic mentioned that the car could use a tune up*, and further showed that relative to a neutral baseline, the absence of the complementizer *that* primed more than the presence of *that*, arguing against a lexical locus for the effect. Pickering and Branigan (1998) found no effect of closed-class morphemes on priming, with *the doctor gave the medicine to the patient* being just as strongly primed following *the teacher gave the homework to the children* as when *the teacher gave* was replaced by *the teacher gives*, *the teacher was giving*, or *the teachers give*. Scheepers (2003) found that people were more likely to produce a German relative clause that modified a first noun phrase (*Der Rentner schimpfte über die Autorin der Flugblätter, die ziemlich unverschämt war*, "the pensioner railed about the author of the fliers that was quite outrageous") after producing another sentence including a relative clause modifying the first noun phrase, than they were after producing another sentence including a relative clause modifying the second noun phrase. This was so even though sentences with relative clauses modifying either noun phrase use the same words. (However, we point out below that Scheepers' study may involve priming of non-syntactic levels of representation or of comprehension processes.) Saffran and Martin (1997) showed that whereas aphasic patients are more likely to produce an abstract passive structure after a passive prime, they are no more likely to produce a passive with better-formed closed-class morphology after a passive prime than after an active. Finally, the existence of priming from one language to another (without cognate words in the two languages) makes a lexical explanation implausible (Hartsuiker, Pickering, & Veltkamp, 2004; Loebell & Bock, 2003). In sum, a wealth of evidence suggests that closed-class words or morphemes do not form the basis for structural priming in general.

Two other functionalist-style explanations for structural priming were assessed in Bock and Loebell (1990). One is whether priming is caused by a tendency to repeat the ordering of the thematic (or event[1]) roles that are played by the arguments in a sentence. For example, in a passive, the patient argument is described before the agent; perhaps what is primed is this ordering of thematic roles rather than the passive form per se. If so, then when thematic roles are not repeated from prime to target sentences, then priming should not be observed. Against this, Bock and Loebell found that sentences containing locative prepositional phrases (e.g., *The wealthy widow drove her Mercedes to the church*) primed prepositional-object descriptions when the prepositional phrase was not a locative (e.g., 2a), and that sentences containing a locative *by*-phrase (e.g., *The foreigner was loitering by the broken traffic light*) primed passive descriptions involving an agentive *by*-phrase (e.g., 1b). (Potter & Lombardi, 1998, observed that locative-to-passive priming was weaker than passive-to-passive priming, though it was still significant; but unlike Bock and Loebell, their passive and locative primes were unrelated sentences.) The second functionalist alternative is that speakers may repeat the overall sound or prosodic contour of sentences. That is, a particular sequence of words may cause the production of a sentence with a distinctive rhythm (relative to the unprimed alternative), compelling the repetition of structure. However, Bock and Loebell showed that whereas *Susan brought a book to Stella* did prime *The girl gave a brush to the man*, the prosodically similar but syntactically different *Susan brought a book to study* did not. This experiment therefore provides further evidence against a functionalist explanation of priming.

[1]For present purposes, *thematic role* and *event role*, as the terms have been used in the syntactic priming literature, are interchangeable. We use the term *thematic role* throughout.

More broadly, other correlates of syntactic structure are unlikely to fully explain structural priming. First, structural priming occurs in the absence of marked (unusual or stylistically special) forms. Most obviously, priming arises reliably with prepositional-object forms (e.g., 2a) and double-object forms (e.g., 2b), which are of similar frequency and style (with different studies showing either no preference or slight preferences for one form or the other). Furthermore, the Bock and Loebell (1990) results show not only that priming can occur in the absence of thematic repetition, but also that transitive priming cannot be due to a tendency to repeat unusual or marked forms, because the locative sentences (e.g., *the foreigner was loitering by the traffic light*) that primed passive targets are not unusual or marked. Indeed, an aphasic patient tested by Saffran and Martin (1997) showed the reverse effect: This patient was significantly more likely to produce a locative description after repeating a passive prime than after repeating an active prime. Additionally, the effect cannot be reduced to priming the order of thematic roles or the number of conceptual arguments in sentences, although there is evidence that both of these may be influential (discussed below; Chang, Bock, & Goldberg, 2003; Griffin & Weinstein-Tull, 2003). Finally, Bock et al. (1992) showed that semantic features of the roles assigned to particular sentence positions (e.g., whether an animate entity is produced as the subject of a sentence) appear to play some role in priming, but the same study found independent evidence of priming based on syntactic structure. Specifically, Bock et al. (1992) found transitive priming even when primes' and targets' corresponding arguments differed in animacy, suggesting that priming could not be explained in terms of the order of semantic properties of arguments. This study also revealed a separate priming effect related to animacy itself (also discussed below).

A more difficult-to-evaluate possibility comes from the claim that constructions tend to differ semantically as well as syntactically, either in terms of *information structure* (e.g., Lambrecht, 1994) or the inherent meaning of the construction, or both. Indeed, some approaches assume that differences in surface form always imply differences in meaning (E. Clark, 1987; Goldberg, 1995). If this is correct, how is it ever possible to prove that structural priming taps specifically into syntactic representations? One possibility is that these approaches may be incorrect, and that differences in form such as the choice between verb-auxiliary order (*gezien had*; "seen had") and auxiliary-verb order (*had gezien*; "had seen"), or between the presence and absence of complementizer *that*s at least sometimes do not correspond to semantic distinctions. Importantly, both are sensitive to priming (V. S. Ferreira, 2003; Hartsuiker & Westenberg, 2000). Another point is that priming appears to cut across meaning distinctions. For example, Bock and Loebell's (1990) finding of priming from locatives to passives is incompatible with the assumption that priming reflects the meaning of constructions in Goldberg's terms.

In conclusion, taken together, these results provide compelling evidence for autonomous syntax: The production of a sentence critically depends upon an abstract syntactic form that is defined in terms of part-of-speech forms (e.g., nouns, verbs, prepositions) and phrasal constituents organized from those (noun phrases, verb phrases, prepositional phrases), and this abstract syntactic form has a large influence upon structural priming. This runs against more functionalist approaches to syntactic structure (e.g., Bates & MacWhinney, 1982), as well as other views that eschew traditional representations of syntactic knowledge (e.g., McClelland, St. John, & Taraban, 1989). However, this conclusion should not be taken to mean that *only* abstract syntactic forms cause priming. We have already suggested that most or all levels of representation may prime. In short, abstract syntax is a central but apparently not exclusive type of knowledge that causes structural priming.

Structural priming and the nature of language production

Most approaches to language production follow Levelt's (1989) general outline of the process that takes speakers from intention to articulation. Production proper begins with a *message*: a nonlinguistic representation of the features of meaning that a speaker intends to express. This message undergoes *grammatical encoding*, whereby features of the message are mapped onto one or more syntactic representations. Speakers then construct sound-based representations (which may encode segmental, metrical, or prosodic information) via *phonological encoding*. Finally, speakers make use of articulatory mechanisms that ultimately move the muscles of the mouth and throat to present an expression to an audience (with different but presumably comparable mechanisms being used in the production of sign language or written language). However, many components of language production are subject to debate. In our view, structural priming has informed three of these components:

From message to syntax—Not much is known about the internal structures of nonlinguistic messages, perhaps in part because it has been difficult to devise methods to evaluate them. However, a lively debate concerns the issue of what properties of messages are *bound* or linked to corresponding syntactic properties. So, for example, if a speaker wishes to express the meaning that a dog is chasing a car, the message represents that a domestic canine is the acting entity (the *agent*) of a chasing event and a passenger vehicle is the acted-upon entity (the *patient*) of the same chasing event. If the speaker produces an active sentence, the canine is bound to the subject position; if the speaker produces a passive sentence, the vehicle is bound to the subject position. But what specific features of message-level representations are in fact used to perform this binding? This linking could be done on the basis of *thematic roles* such as agent or patient or on the basis of *primitive semantic features* such as animacy. The thematic role claim assumes that information about agents, patients, and other roles guide subsequent grammatical encoding. A domestic canine as an acting entity of a chasing event is encoded as an *agent* in the message, and the grammar of English encodes that active sentences involve linking agents to grammatical subject positions and that passive sentences involve linking patients to grammatical subject positions. In contrast, the primitive semantic features claim assumes that message-level representations include information about animacy, and that grammatical encoding looks to link an animate entity such as a canine to the subject (yielding an active in this case) or an inanimate entity such as a vehicle to the subject (yielding a passive).

Levels within grammatical encoding—Beginning with work in formal linguistics (Chomsky, 1965), and later with analyses of speech errors (Garrett, 1975), it is common to posit that syntactic processing proper involves a sequence of processing stages that convert a message into a grammatically encoded sequence. Formal linguistics has assumed that an underlying *deep* structure reflects a fundamental element of linguistic description. The deep structure is transformed into a surface structure (as described in more detail below) to reflect the actually observed sentence, the features of which of course can vary from language to language.

Theories of language production too have posited distinct stages within syntactic processing proper, at least partly based on different ways of interpreting seminal claims in the field (Garrett, 1975) of distinct *functional* and *positional* levels of processing. One interesting possibility is that the evidence from speech errors that suggested these distinct processing levels might be buttressed by evidence from structural priming. Furthermore, structural priming itself could provide evidence for even further stratification of syntactic processing.

The nature of syntactic knowledge—Given its abstract nature and intermediary status during language processing, it is not surprising that there are many debates about the precise

nature of syntactic knowledge. However, the central issue is the relationship between lexical knowledge (about individual words) and syntactic knowledge (about how words are structured into constituents). At one extreme is the possibility that syntactic knowledge is fully lexically independent. On this view, syntactic processing mechanisms construct syntactic structures without regard to grammatically irrelevant properties of individual lexical items. (Of course, certain lexical properties *are* grammatically critical, and so the processor would need to consult these properties at some stage, so that it could, for example, prevent ungrammatical utterances such as **The man donated the charity some money*).

At the other extreme is the possibility that syntactic knowledge is entirely lexically dependent. Here, syntactic knowledge is represented as part of lexical knowledge, so that, for example, the verb *give* can be used as a prepositional-object structure by deploying a form of *give* that brings with it the associated noun-phrase-plus-prepositional-phrase syntactic structure. Two corollaries of this viewpoint is that when a given word is used in different structures, it actually involves different lexical representations (e.g., the *give-prepositional-object* representation differs from the *give-double-object* representation), and that if the same syntactic construction appears with different verbs, different representations of that construction are actually involved (the particular structure associated with *give-prepositional-object* differs from the analogous structure associated with *show-prepositional-object*).

If syntactic knowledge shows some lexical dependence, a more radical possibility is that it might also show *modality* dependence – that aspects of syntactic knowledge might differ when people are speaking versus writing, for example. In general, theories of language production claim that syntactic knowledge, and in most cases some levels of lexical knowledge are modality *in*dependent, but there are reasons to believe (described below) that syntactic knowledge might deploy differently in different modalities. We now turn to structural priming evidence that has informed each of these issues.

Mapping from message to syntax

The first study to identify a meaning-level influence on syntactic priming was Bock et al. (1992), which found priming of the assignment of arguments with particular animacy features to particular grammatical relations. So, independent of syntactic structure, if speakers produced a prime sentence with an animate (or inanimate) entity assigned to the subject position, they then tended to produce a target sentence with an animate (or inanimate) entity assigned to the subject position. For example, subjects were more likely to produce "An alarm clock awakened a boy," which has an inanimate subject, after a prime such as "A boat carried five people," which also has an inanimate subject, than after a prime such as "Five people carried a boat," which has an animate subject. (Note that both of these primes have active structures, so syntactic differences cannot drive the effect.)

Bock et al. (1992) also observed standard priming of syntactic structure (discussed further below). Importantly, the syntactic-structure priming was fully independent of the animacy-to-structure priming – speakers showed no increased or reduced tendency to repeat actives or passives when also repeating the assignment of arguments with particular animacy values to particular syntactic roles. Together, these observations suggest two critical properties of production: First, because syntactic and animacy priming were independent, this implies that the animacy priming was equal when the effective animacy features were in arguments with the same or different thematic roles. So, a prime with an agent grammatical subject that was inanimate (an active prime) caused just as much animacy priming as a prime with a patient grammatical subject that was inanimate (a passive prime). Furthermore, consistent with Bock and Loebell (1990), thematic roles per se did not cause priming. Together, these observations support the above-described primitive-semantic-features approach to binding, in which grammatical relations such as *sentence subject* look to the primitive semantic features of

message level entities, rather than to any possible thematic role features of those message-level entities.

A second suggestion follows from the additivity of animacy priming and syntactic priming. This additivity means that the tendency to assign (say) an inanimate argument to the grammatical subject in a target sentence because the prime sentence assigned an inanimate argument to the grammatical subject is just as strong when the prime and target sentences have the same or different structures. Thus, the influence of priming upon the choice of syntactic structure is independent of the previous influence of priming upon the choice of grammatical subject. In turn, this implies the semantic-level processing that underlies the animacy effect is encapsulated from the syntactic-level processing that underlies the syntactic effect. The alternative – that the animacy priming 'boosts' the syntactic priming, thereby suggesting interactivity between the levels – is disconfirmed.

It is worth noting that it is possible that semantic features are bound to linear positions in sentences (see Branigan, Pickering, & Tanaka, 2008, for discussion), rather than to grammatical relations. For example, speakers might be primed to bind the animate entity to first position rather than to the grammatical relation of subject, because linear order and grammatical relations are confounded for English transitives. This interpretation is less straightforwardly compatible with traditional views of sentence production (e.g., Garrett, 1975).

Although data from Bock et al. (1992) suggest that primitive semantic features rather than thematic roles underlie the binding of message-level elements to grammatical relations, two other studies have used structural priming to reveal potential influences of thematic roles on sentence production, most likely at different loci within the flow of production. One, by Griffin and Weinstein-Tull (2003), illustrated that in a sentence-recall task, speakers were more likely to paraphrase a finite complement clause (*John believed that Mary was nice*) as a noun phrase plus infinitive clause (*John believed Mary to be nice*) after producing (from memory) another infinitive with an *object-raising* verb (*A teaching assistant reported the exam to be too difficult*) than after an infinitive with an *object-control* verb (*Allen encouraged his roommate to be more studious.*). Other patterns of persistence revealed that the difference was likely due to the fact that infinitives with object-control verbs have an extra thematic role (e.g., Allen is encouraging his roommate, as well as wanting his roommate to be more studious) relative to object-raising verbs (the teaching assistant isn't reporting an exam, only that it is too difficult). Griffin and Weinstein-Tull propose that structures are planned in roughly proposition-sized units (e.g., Ford, 1982; Ford & Holmes, 1978), and that the extra thematic role in object-control verbs allows a referent to be available during syntactic formulation of the first proposition, whereas the absence of that thematic role in object-raising verbs implies that production must dip into the second proposition before producing the identical constituent sequence. This study therefore found an effect of meaning-structure on syntactic formulation that can be characterized in terms of thematic roles, and the explanation provides an account of its time-course as well, such that the relationship between unfolding syntactic structure and the representation of propositional structure affected priming.

Another demonstration of an effect of thematic roles on sentence production comes from Chang et al. (2003). Recall that Bock and Loebell (1990) revealed that structural priming was insensitive to thematic-role differences (e.g., locatives primed passives as much as passives did, relative to active priming). Chang et al. explored a sentence choice where thematic-role assignments differ but where the order of phrasal constituents is the same. In this *spray-load* alternation, both *The maid rubbed [polish] [onto the table]* and *The maid rubbed [the table] [with polish]* involve noun-phrase-verb-noun-phrase-prepositional-phrase sequences. However, the post-verbal noun phrase is the theme in the former example and the location in

the latter example, whereas the prepositional phrase is the location in the former example and the theme[2] in the latter example. Using a sentence-recall procedure, they found that speakers were primed to produce the same event-role sequences from primes to targets (e.g., *The maid rubbed [polish] [onto the table]* primed the production of *The farmer heaped [straw] [onto the wagon]* over …*[the wagon] [with straw]*). How can this result be squared with the observations of Bock and Loebell (1990) that syntax primes irrespective of thematic role differences, and Bock et al.'s (1992) result that thematic roles don't prime at all? Chang et al. argue that the key difference is that in demonstrations of the insensitivity of thematic-role effects, syntactic distinctions trump thematic distinctions; put another way, thematic influences on structural persistence, though observable, are too weak to compel the production of one syntactic structure rather than another. In contrast, with *spray-load* alternations, the lack of syntactic difference between the alternatives permits the thematic effect to be observed. Chang et al. (2006) take this logic one step further, arguing that because there is no syntactic distinction between *spray-load* alternatives, the thematic distinctions are necessary for production mechanisms to produce the sentences correctly.

Some other evidence is compatible with a stronger effect of thematic role order. Hare and Goldberg (1999) had participants repeat prepositional-object sentences (e.g., 2a), double-object sentences (e.g., 2b), or sentences such as *The officers provided the soldiers with guns*, and then describe pictures using a prepositional-object sentence or a double-object sentence. *Provide-with* sentences have the same order of thematic roles (agent, recipient, theme) as double-object sentences. Indeed, they found that *provide-with* primes behaved like double-object primes, even though their post-verbal arguments (a noun phrase followed by a prepositional phrase) appear to be syntactically equivalent to prepositional-object primes. Although participants in this study did encounter only one prime condition (and therefore may conceivably have responded strategically), a recent cross-linguistic study from Greek to English (Salamoura & Williams, 2007) found similar results in a within-participants design. These results may reflect priming of the order of thematic roles, or priming of the binding of animate arguments to direct objects (and so on), as in Bock et al. (1992). However, both explanations would require priming of syntactic structure to be entirely overridden. In sum, the effects of thematic roles on priming are mixed, and more work is needed to determine how they fit into the mapping from message to syntax.

Levels of syntactic representation

A very prominent account of language structure, transformational grammar, assumes the existence of two levels of syntactic structure (Chomsky, 1965). Roughly speaking, transformational grammar generates deep structure representations, which are then transformed to surface structure representations, which correspond to actually observable forms. For example, the passive sentence *The boy was awakened by the alarm clock* results from a transformation of a deep structure like "___ was awakened the boy by the alarm clock." Note that in the passive surface structure, *the boy* is the grammatical subject (the surface subject), but in the deep structure, the same *the boy* is the grammatical object (the deep object). Hence, *the boy* "moves" to the subject position, yielding the surface structure. More recent versions of the theory assume further levels such as Logical Form, which is a syntactic level that encodes certain meaning related information, and the existence of traces, which are records in surface structure of the deep structure location of phrases that have subsequently been moved (e.g., Chomsky, 1981). Note however that other theories do not assume multiple levels of constituent structure or the existence of some or all traces (e.g., Bresnan & Kaplan, 1982; Gazdar, Klein, Pullum, & Sag, 1985; Pollard & Sag, 1994; Steedman, 2000.)

[2]The distinction between themes and patients is not always clear, but in many accounts that distinguish the two, patients involve a change-of-state but themes do not.

The viability of this transformational view of syntactic knowledge was directly assessed by Bock et al. (1992). As well as addressing the mapping from message to syntax, this study suggests that speakers do not in fact construct a representation akin to deep structure in the production of passives. Participants produced primes such as (3a-d):

(3a) Five people carried the boat. (active, animate surface subject, inanimate deep object)

(3b) The boat was carried by five people. (passive, inanimate surface subject, inanimate deep object)

(3c) The boat carried five people. (active, inanimate surface subject, animate deep object)

(3d) Five people were carried by the boat. (passive, animate surface subject, animate deep object)

(Recall that according to transformational approaches, in passives such as (3b) and (3d), the surface subject *is* the [moved] deep object, and so must have the same animacy.) Participants then described pictures of (say) an alarm clock waking a boy, for which they could use either an active or a passive form. In the active form, the targets therefore had inanimate surface subjects and animate deep objects:

(4) The alarm clock awakened the boy (active, inanimate surface subject, animate deep object)

We have already noted that the experiment revealed (a) a tendency for speakers to produce more actives like (4) following active primes (3a, 3c) than passive primes (3b, 3d), thereby revealing standard structural priming, and (b) that speakers were more likely to produce actives like (4) following primes with inanimate surface subjects (3b, 3c) than animate surface subjects (3a, 3d). In fact, this animacy effect disconfirms a transformational account of syntactic production. Critical is the differential influence of (3b) versus (3d). Note that (3b) and (3d) are both passive structures, and so syntactically mismatch active targets like (4); thus, syntactic features by themselves cannot explain why (3b) primes (4) more than (3d) does. Instead, note that (3b) matches (4) only in that both have inanimate *surface subjects*, whereas (3d) matches (4) only in that both have inanimate *deep objects*. Thus, a match in animacy between surface subjects and not deep objects promotes the production of more primed (active) structures like (4). Put another way, when speakers produced primes with inanimate entities as surface subjects, they tended to produce targets with inanimate entities as surface subjects; in contrast, when speakers produced primes with animate entities as deep objects, they did not tend to produce targets with animate entities as deep objects. This reveals that semantic representations – representations with particular animacy values – are mapped onto surface structure positions, not deep structure positions, contradicting an approach to production that is directly translated from transformational accounts of syntactic representation in formal linguistics.

Bock et al.'s (1992) results suggest that the surface constituent structure may be constructed in a single stage (presumably from a functional representation input). But there is another two-stage account, in which speakers construct an unordered representation first, then linearize it. Hartsuiker et al. (1999) found that Dutch participants tended to perseverate in the production of "locative-inverted" sentences such as *Op de tafel ligt een bal* ("On the table is a ball") or their normally ordered counterparts (*Een bal ligt op de tafel*; "A ball is on the table"). Similarly, Hartsuiker and Westenberg (2000) found priming of the order of main verb and auxiliary. Such alternatives involve the same grammatical relations (subject and oblique argument). Hartsuiker and colleagues' explanation is that speakers first construct from the functional representation an unordered constituent-structure representation (which is compatible with either order) and then linearize that representation. The process of constructing the unordered representation causes priming for structural alternatives that assign different arguments to different grammatical relations (e.g., actives vs. passives), whereas the separate linearization process

causes priming for structural alternatives that have identical argument-to-grammatical-relation structure but different surface orderings (e.g., verb-auxiliary ordering). This view is consistent with a linguistic account in which dominance relations (which nodes are superior to others) are computed separately from precedence relations (which nodes come first), such as Generalized Phrase Structure Grammar (Gazdar et al., 1985).

However, it is equally possible that speakers construct linearized representations directly from functional representations. To distinguish these accounts, Pickering, Branigan, and McLean (2002) had participants produce written and spoken completions to (5a-d):

(5a) The racing driver showed the torn overall… (prepositional-object-inducing prime)

(5b) The racing driver showed the helpful mechanic… (double-object-inducing prime)

(5c) The racing driver sneezed very… (baseline-inducing prime)

(5d) The racing driver showed to the helpful mechanic… (shifted-inducing prime)

Participants tended to complete the primes in the predicted way (e.g., with *to his colleague* in 5a). The shifted-prime (5d) was completed with a noun phrase (e.g., *the damaged wheel*), so that its constituents were the same as (5a) but in a different order. They then completed target fragments such as *The patient showed*. Participants were most likely to produce a prepositional-object target completion following (5a), somewhat less likely following (5c), and least likely following (5b). This demonstrates that both prepositional- and double-object forms served as primes (i.e., priming was two-way). More important, target completions following (5d) were just like those following (5c), not like (5a). This suggested that the shifted form was represented differently than the prepositional-object form, and therefore that they did not share an unordered constituent-structure representation. Note that Salamoura and Williams (2007) replicated this pattern of results in a study of cross-linguistic priming from Greek to English; in Greek (unlike English), the “shifted” word order is common. Thus, no evidence supports the possibility that any hypothetical representation that underlies alternatives that are distinct only in terms of word order, such as a dominance-only representation, can cause priming. Additionally, the results suggest that priming is not caused by the repetition of an unordered set of phrasal categories alone, such as prepositional phrases (because the shifted sentences do not behave like prepositional-object sentences).

With all of this evidence in mind, an interesting possibility is that the inventory of grammatical relations in a sentence by itself constitutes an important locus of priming. For example, active sentences involve a subject and a direct object, whereas passive sentences involve a subject and an oblique argument (or characterized somewhat differently, actives involve assigning one kind of thematic role to the subject grammatical relation, and passives involve assigning a different kind of thematic role to the subject grammatical relation). In English at least, word order follows automatically from these choices regarding grammatical function (e.g., only one constituent structure is compatible with being an active transitive or a passive transitive). Therefore, it is possible that the tendency to perseverate in transitive sentences really involves priming the tendency to perseverate grammatical relation assignment (see Hartsuiker et al., 1999, for discussion). However, many other observed priming effects (e.g., Hartsuiker et al., 1999; Hartsuiker & Westenberg, 2000) occur in the absence of differences among grammatical relations between the alternative forms. This suggests that structural priming cannot be entirely based on repetition of grammatical relations.

The nature of syntactic knowledge

Evidence for a lexically independent component—As noted, a primary debate in psycholinguistics concerning the nature of syntactic knowledge is its lexical dependence: whether syntactic knowledge is fully independent of lexical knowledge (setting aside

subcategorization restrictions), fully dependent, or somewhere in between. To the extent that there is a lexically independent component to syntactic knowledge, it can be characterized in terms of the notion of *phrase-structure rules* (e.g., Gazdar et al., 1985; Jackendoff, 1972) – rewrite rules that describe the structure of a sentence in terms *constituents* that group together words in terms of basic parts of speech such as noun (N), verb (V), or preposition (P), and phrasal categories headed by those parts such as noun phrase (NP), verb phrase (VP), and prepositional phrase (PP) For example, a verb phrase could be described as VP → V NP. Although more sophisticated formalisms for representing syntactic knowledge have been developed in recent years, phrase structure rules are adequate for effectively describing many aspects of syntax and require a minimum of theoretical commitments.[3] What is critical about this notion of phrase structure rules for present purposes is that at least as construed here, they are lexically independent: *VP → V NP PP*, not *VP → give NP PP*.

Structural priming can be viewed as providing evidence for the psychological reality of something like phrase-structure rules, at least ones that refer to "overt" constituents alone, thereby suggesting the lexical independence of syntactic structure. For example, a prepositional object structure such as *gave the book to the girl* can be generated by the rule VP → V NP PP, which means that a verb phrase can consist of a verb (here, *gave*) followed by a noun phrase (here, *the book*), followed by a prepositional phrase (here, *to the girl*). In contrast, the associated double-object structure *gave the girl the book* can be generated by the rule VP → V NP NP, which means that a verb phrase can consist of a verb followed by two noun phrases. The same rule applies whatever the lexical content, so priming should occur even without lexical repetition between prime and target in terms of either closed-class items (Bock, 1989) or open-class items (Bock, 1986; note that a "boost" from open-class lexical repetition is not excluded by this account – see below). Priming should also occur irrespective of thematic differences between prime and target (Bock & Loebell, 1990), because traditional phrase-structure rules do not make reference to such thematic differences. The rules critically pay attention to the order of constituents (e.g., the shifted construction *gave to the girl the book* would use VP → V PP NP), so priming should not occur if the same constituents occur in different orders, as described above (Pickering et al., 2002). Additionally, traditional phrase structure rules do not make reference to empty categories, so therefore are consistent with priming from locatives to passives (Bock & Loebell, 1990), and do not involve transformations, thus supporting the direct mapping from semantics to surface structure positions (Bock et al., 1992).

The most straightforward application of a phrase-structure rule account to sentence production would hold that speakers construct representations for their utterances by making choices among different phrase-structure rules, in consultation with lexically specific information. For example, speakers might choose between *gave the book to the girl* and *gave the girl the book* by selecting one or the other phrase structure rule. Priming would therefore serve to influence that choice, with (for example) recent application of VP → V NP PP increasing the likelihood of reusing VP → V NP PP. On this account, it would not matter whether the prime and target sentences differed in other *structural* respects. For example, (6a-c) below all use the same rule:

(6a) The boy gave the book to the girl.

(6b) The boy gave the book that I liked to the girl.

(6c) I think that the boy gave the book to the girl.

[3]One reason to adopt phrase structure rules is that they are a particularly simple way to describe the operations that lead to the formation of local constituent-structure trees (i.e., trees with a single mother node and a number of daughters nodes). Hence they can be seen as corresponding to any linguistic formalism that leads to the construction of the same local trees. As should be apparent from this review, the evidence from priming is consistent with simple phrase structure trees (such as those in Fig. 1).

Tree diagrams for (6a-c) are shown in Figure 1, with the product of the critical phrase structure fragment (VP → V NP PP) emphasized with boldface. In (6a), the verb phrase forms part of the main clause and contains arguments consisting of simple phrases. In (6b), the theme *the book that I liked* is a complex noun phrase, containing a relative clause as well as the head noun. This requires additional phrase structure rules for the relative clause, but critically, still involves the key VP → V NP PP rule. In (6c), the verb phrase *gave the book to the girl* is part of a subordinate clause, and therefore analysis of the sentence requires phrase structure rules to explain the relationship between the main verb (*think*) and the subordinate clause. Even so, in the subordinate clause, the same rule VP → V NP PP constructs the same "local" component of the grammatical structure of the sentence (the same "local tree"). (It should be noted that this discussion could be cast in terms of other formal-linguistic accounts, such as head-driven phrase structure grammar [Pollard & Sag, 1994], lexical-functional grammar [Bresnan & Kaplan, 1982] or combinatory categorial grammar [Steedman, 2000]. We focus here on phrase-structure rules because they are an accessible way to express the idea that priming may involve contentless structures that are common to sentences such as [6a] through [6c] above.)

If priming involves the activation of individual grammatical rules that determine local components of the grammatical structure of the sentence, then it should not matter whether the prime and target differ in terms of other aspects of their grammatical structure. This means that any of (6a-c) should serve equally well as a prime of a PO sentence such as *The woman sent the parcel to the man*. Current evidence suggests that this is indeed the case. Fox Tree and Meijer (1999) had speakers produce prime and target sentences that were prepositional objects or double objects, but where one postverbal argument was sometimes modified by a relative clause (*The professor offered his students the theories [that had insulted many people]*). Results showed identical priming effects regardless of whether prime and target sentences' postverbal arguments matched in terms of modification (i.e., the presence or absence of *that had insulted many people* had no effect on priming). This suggests that priming is specifically sensitive to something akin to using a particular phrase-structure rule from one sentence to the next. In this case, irrespective of whether an argument was modified by a relative clause, target production allowed speakers to repeat the critical VP → V NP PP rule or VP → V NP NP rule, and so priming was observed. Additionally, Pickering and Branigan (1998) found reliable priming when the prime and target verb phrases differed with respect to the internal structure of the complement noun phrases.

Branigan, Pickering, McLean, and Stewart (2006) addressed the complementary question of whether differences in global structure affect priming. They found priming of the dative alternation occurred irrespective of whether the prime and target both involved simple main clauses (e.g., *the girl gave the puppy to the boy*), or whether one involved a simple main clause and other involved a complex sentence in which the critical construction was embedded. In fact, priming occurred when the prime involved a subordinate clause (e.g., *John said that the girl gave the puppy to the boy*) and the target involved a main clause, when both involved subordinate clauses, and when the prime involved a main clause and the target involved a subordinate clause. Although there was a numerical trend for greater priming when both sentences involved the same sentence type, this trend was not significant. Again, this suggests that when the application of a particular phrase structure rule can be repeated, priming is observed, regardless of other phrase-structure rules that may also be applied.[4]

[4]Note that Branigan et al. (2006) repeated verbs from prime to target sentences which, as described in the next section, is used as a signature of lexical dependence. However, the primary reason Branigan et al. repeated verbs was not to diagnose lexical dependence, but rather, to increase the size of the effect (e.g., Pickering & Branigan, 1998) and thereby increase power to detect differences among conditions. Presumably, comparable but smaller effects would occur if the verb were not repeated.

The evidence cited thus far suggests that the choice of something like a phrase-structure rule can be primed. Recent evidence further suggests that the order of the choice of phrase-structure rules can also be primed. Scheepers (2003) explored the production of German relative-clause sentences such as (the German translation of) *Someone shot the servant of the actress who was on the balcony*. Such sentences are ambiguous in English, because either the servant or the actress might be on the balcony (Cuetos & Mitchell, 1988). But their German equivalents are not always ambiguous, because the relative pronoun (*who* in the English examples) sometimes agrees in gender with the noun phrase it modifies. Scheepers had speakers produce primes by completing unambiguous fragments (e.g., *The assistant announced the score of the candidate that*…, where the "that" can only refer to *score* or *candidate*). They then produced targets when given an ambiguous fragment (*The pensioner railed about the author of the fliers that*…, where *that* could refer to either the author or the fliers). He found priming: When the unambiguous prime required "high" versus "low" attachment (e.g., *score* vs. *candidate* is modified by the relative clause), speakers completed ambiguous fragments also with high or low attachment (producing a relative clause that modified *author* or *fliers* respectively). As Scheepers (2003) points out, these results cannot reflect priming of which phrase-structure rule is selected, because high and low attachment involve the same set of rules (just applied in different orders). This study therefore implies that the order in which rules are applied can be primed. Desmet and Declercq (2006) replicated Scheepers' findings cross-linguistically.

It is important to note, however, that the effect revealed by Scheepers (2003) must involve meaning-level representations. Unlike other demonstrations of structural priming, the high and low attached targets differ *propositionally* in meaning – whether a speaker chooses to modify *author* or *fliers* with a relative clause must be determined by the meaning that they wish to convey. In other studies, the two target alternatives are always similar in meaning in terms of who did what to whom (e.g., they may both be compatible with the same picture in a picture-description study). Thus, the same propositional meaning might lead to the production of a prepositional object or double-object target, with the choice depending on syntactic-processing proper (and as noted above, Bock [1986] argued that differences in the construal of the target event could not have produced the priming effects she reported). Note that Scheepers demonstrated that the entire priming effect could not be located at the level of meaning. Specifically, in a control experiment, subjects produced primes that had the same types of noun phrases, but that were modified by adverbial clauses rather than relative clauses ("the servant of the actress when she…" instead of "the servant of the actress who…"). Then, subjects produced targets with relative-clause modifiers. Subjects did not tend to use a high- or low-attached relative clause when the prime included adverbials that referred back to the corresponding (high or low) noun phrase, suggesting that without a syntactic match between prime and target, priming is not observed. It is possible that the manipulation of syntactic structure was able to affect speakers' choice of propositional meaning because they have little commitment to expressing a particular meaning in a sentence-completion task. It may also be that speakers were primed to comprehend the target fragment using high versus low attachment. However, neither of these possibilities explains what mechanism leads to such effects of meaning on syntax.

In sum, structural priming provides good evidence that sentence production operates with mechanisms that have many of the essential properties of phrase-structure rules. An obvious direction for future work would be to explore detailed features of different linguistic approaches to discriminate among them. In any case, for current purposes, the operation of phrase-structure-rule-like representations in production suggests that syntactic knowledge is independent of lexical knowledge. However, this does not necessarily mean that syntactic knowledge is *fully* independent of lexical knowledge. It is possible that the use of representationally independent syntactic knowledge (as embodied by, say, phrase structure

rules) could be influenced by grammatically irrelevant lexical factors. Indeed this seems to be the case, the evidence for which we turn to next.

Evidence for a lexically dependent component—Although (as has been noted) structural priming is observed in the absence of lexical overlap between prime and target sentences, a key finding is that priming is enhanced by open-class lexical overlap. In the first demonstration of this effect, Pickering and Branigan (1998) had participants complete prime fragments similar to (7a-b) and target fragments, so that prime and target either did or did not use the same verb:

(7a) The racing driver showed the torn overall… (prepositional-object-inducing prime)

(7b) The racing driver showed the helpful mechanic… (double-object-inducing prime)

Priming was significantly enhanced by verb repetition. Other studies have replicated these results using sentence completion (Cleland & Pickering, 2006; Corley & Scheepers, 2002) or dialogue (Branigan et al., 2000a; Schoonbaert, Hartsuiker, & Pickering, 2007), and there are similar effects of noun repetition in the production of complex noun phrases (*the red sheep* vs. *the sheep that is red*; Cleland & Pickering, 2003). We refer to this as the *lexical boost* to structural priming.

Corpus studies have also provided evidence of a lexical boost. Gries (2005) identified 3003 pairs of prepositional-object and double-object constructions (which were not necessarily adjacent) in a corpus of British English. The constructions were of similar frequency. In nearly two-thirds of instances, the first and second member of the pair involved the same construction – that is, priming was observed. Interestingly, this tendency to repeat structure was significantly stronger when the prime and target used the same verb than when they did not.

However, though it is clear that this is a lexical boost to structural priming, there is a clear contrast between content-word and function-word repetition: As already noted, structural priming does not depend on repetition of function words such as prepositions (*to*;Bock, 1989; Fox Tree & Meijer, 1999) or complementizers (*that*; V. S. Ferreira, 2003). Similarly, Pickering and Branigan (1998) found no effect of whether prime and target verb used the same form of the verb or different forms. In one experiment, the target verb was simple past tense (e.g., *showed*) and the prime verb was either past or present tense (*shows*). Priming was unaffected by this manipulation. Two other experiments manipulated whether prime and target varied in aspect (*showed* vs. *was showing*), number (*shows* vs. *show*), or not, and again found no effects. Thus, closed-class words (e.g., *to*) and closed-class morphemes (e.g., *-ed*) behave similarly.

The fact that structural priming occurs in the absence of content-word repetition but yet is enhanced by such repetition appears to indicate that syntactic information is partly abstract and partly associated with particular lexical entries. There appear to be two possibilities for how such a state-of-affairs can be represented. One is a two-locus account, which assumes that separate mechanisms or cognitive systems lead to abstract (lexically independent) priming and lexicalized (lexically boosted) priming. The other is a one-locus account, which assumes that a single mechanism can explain both abstract priming and the lexical boost. The two-locus account suggests that a dissociation of the two priming effects should occur under some circumstances but the one-locus account does not. In this section, we outline the main one-locus account of priming, and return to the two-locus account when considering implicit learning below.

Pickering and Branigan (1998) provided a one-locus explanation of structural priming and the lexical boost, based on the model of lexical access developed by Levelt, Roelofs, and Meyer (1999; Roelofs, 1992, 1993). Levelt et al. assumed that syntactic information is encoded at the

lemma stratum, and that lemmas (roughly corresponding to the base forms of words) are associated with syntactic information, such as number or gender. Pickering and Branigan (1998) extended this account so that lemmas (e.g., *show*, *give*) are linked to *combinatorial nodes* that are activated whenever the speaker uses a particular construction. For example, an *NP,PP* node is activated whenever the speaker uses the prepositional-object construction; and an *NP,NP* node is activated whenever the speaker uses the double-object construction. Lemmas are linked to the nodes that express the structures they are compatible with, so that both *give* and *show* are linked to both *NP,PP* and *NP,NP* combinatorial nodes. So when uttering *John gave a book to the boy*, the speaker activates the lemma *give* and the *NP,PP* node (as well as nodes corresponding to past tense, singular, etc.), as shown in Figure 2. It may be appropriate to associate combinatorial nodes with phrase-structure rules, with activation of the *NP,PP* node corresponding to use of the VP → V NP PP rule, activation of the *NP,NP* node corresponding to use of the VP → V NP NP rule, and so on.

On this account, priming is due to residual activation of combinatorial and lemma nodes, as well as the links between the two (as illustrated in Panel C of Figure 2). More specifically, lexically independent priming occurs as a result of the residual activation of the relevant combinatorial node (e.g., the *NP,NP* node). But when a sentence contains the same verb as a previous sentence (e.g., *give*), syntactic priming results from residual activation of the pre-activated lemma node (*give*), of the strengthened link between this lemma node and the *NP,NP* combinatorial node, and (as in lexically independent priming) of the combinatorial node itself. When subsequent sentences contain a different verb, the priming effect should be smaller, because it results only from residual activation of the combinatorial node. But it does not matter whether subsequent sentences contain the same or different forms of the same verb (e.g., *give* vs. *giving*), because the same lemma node is activated in both cases. In this account, there is only one locus to priming, because one set of processing principles with the same network of representations is what underlies both lexically independent structural priming and the lexical boost to structural priming. It therefore contrasts with an account that places the lexically independent effect and the lexical boost in different cognitive (memory) systems; see *Priming and language learning* below.

Cleland and Pickering (2003) used this account to interpret their data on the priming of complex noun phrases in dialogue. A confederate described a picture of a colored object using an adjective-noun order (e.g., *the red sheep*) or an alternative noun-relative clause order (*the sheep that's red*). Participants tended to repeat the order just used by the confederate, demonstrating a structural priming effect for noun phrases. There was also a lexical boost, with the tendency to repeat structure being stronger when the prime and target used the same noun (*sheep-sheep*) than when they did not (*knife-sheep*). In addition, semantic relatedness between the prime and target enhanced priming, with *the sheep that is red* being more likely after *the goat that is red* than after *the knife that is red*. However, this *semantic boost* was smaller than the lexical boost. Finally, there was no sign of a boost from phonological relatedness (*ship-sheep*). Cleland and Pickering assumed that lemma nodes were linked to conceptual nodes, and that semantically related conceptual nodes, such as SHEEP and GOAT, thus become activated at the same time. One account of the semantic boost is that it arises during prime processing. By this account, the prime sentence *the goat that is red* strongly activates the conceptual node GOAT, but some activation spread to related nodes such as SHEEP. This leads to strong activation of the lemma *goat*, and weaker activation of the lemma *sheep*. Additionally, the combinatorial node *N,RC* (associated with the noun-relative clause construction) is activated. The activation of *goat* and the *N,RC* node leads to the activation of the link between them, and hence the strong lexical boost; the weaker activation of *sheep* and the *N,RC* node leads to the weaker activation of the link between them, and hence the weaker semantic boost. However, Schoonbaert et al. (2007) pointed out that these data are equally compatible with an account whereby the semantic boost arises during target processing, in

which production of the target *the sheep that is red* leads to activation of the lemma *goat*. Because the link between the lemma *goat* and the *N,RC* node retains some activation from processing of the prime, the activation of the *N,RC* node is strengthened.

Further insights about the nature of the relationship between lexical and syntactic processing comes from the already-noted finding that repetition of content words from prime to target boosts priming, but repetition of function words does not. Within current accounts of sentence production, this dissociation might be explained in three different ways. First, the relationship between closed-class forms and syntactic structure may be different from the relationship between open-class forms and syntactic structure. One possibility is that closed-class forms such as prepositions are integrated into syntactic representations (e.g., prepositional phrases may be represented by structures like "to $\_\_\_\_\__{NP}$" or "for $\_\_\_\_\__{NP}$"). However, such "closed-class immanence" accounts fail to explain why structures with different prepositions prime just as much as structures with the same prepositions (Bock, 1989). Alternatively within this explanation, closed-class forms may be inserted later into structures than open-class forms, perhaps because their use depends more on syntactic conditions than semantic conditions (Levelt, 1989). This accords with the notion of *indirect election*, whereby the activation of closed-class lemmas can depend on the activation of other lemmas rather than conceptual nodes (Levelt, 1989). They may therefore be inserted into structures after the overall structure of the sentence (e.g., passive vs. active) has been specified, so that any priming of such representations will have arrived too late to influence that choice of overall structure.

Second, closed- and open-class repetition may have qualitatively similar influences on structural priming but quantitatively different influences. Specifically, closed-class forms are typically short, very common, and semantically impoverished. In effect, they may be produced too quickly or efficiently to cause observable priming effects. This explanation predicts, for example, that the lexical boost should be smaller for repeated open-class words that are high frequency, compared to repeated open-class words that are low frequency.

A third explanation hinges on the semantic difference between closed- and open-class forms. It may be that the open-class lexical boost is due to the *semantic* similarity between prime and target forms irrespective of lexical repetition per se (Griffin & Weinstein-Tull, 2003). So, if the prime and target both involve *giving*, then the prime and target involve semantically similar events, compared to if the prime involves *giving* and the target involves *tossing*. In contrast, if the prime involves *giving to* and the target involves *tossing to*, versus the prime involving *baking for* and the target involving *tossing to*, the semantic difference between *giving to* and *baking for* may be sufficiently minor that it does not influence degree of priming. However, Schoonbaert et al. (2007) showed that in bilingual speakers, the lexical boost when priming *within* a language (e.g., from an English prime with the verb *give* to an English target with the verb *give*) was much larger than when priming *between* languages (e.g., from a Dutch prime with the Dutch translation of *give* to an English target with the verb *give*). But when the verbs were unrelated, within- and between-language priming were similar. Because translation equivalents are highly similar in meaning, if the lexical boost had been largely due to semantic similarity between prime and target, the lexical boost and the translation-equivalent boost should have been similar. (Priming in bilinguals is discussed further below.)

It is further worth noting that the second and third explanations just posited predict that closed-class forms should cause *less* of a boost to priming than open-class forms, whereas to date, closed-class repetition has yielded *no* boost to priming. Thus, current evidence provides some support for the first explanation. The differential influence of closed- and open-class forms therefore appears to be well established but not well understood.

Melinger and Dobel (2005) presented some further evidence that appears compatible with a lexicalist account of priming. In two experiments, they showed that when participants read *only* a prime verb (rather than a whole sentence) that could only be used with one type of structure, they tended to describe target pictures with that same type of structure. These results can be explained in terms of Pickering and Branigan's (1998) model, on the assumption that combinatorial nodes can be activated by a verb on its own and do not require the verb to be used in combination with its arguments.

Evidence for modality independence—According to most accounts that assume phrase-structure rules or lemma-like representations (e.g., Levelt, 1989), syntactic knowledge is modality independent – the same representations are involved regardless of whether someone is speaking or writing. That said, there are reasons to believe that syntactic knowledge is deployed differently when speaking versus writing. Though writing and speaking are both forms of production, different specific processes must be responsible for the very distinct output each skill creates. Obviously, the articulators are very different between writing and speaking. However, more cognitively relevant differences also exist between the modalities, for example, relating to the timing of output. Furthermore, analyses of the performance of brain-damaged subjects suggests that at least under some circumstances, the syntactic knowledge of individual words dissociates between written and spoken production (e.g., Caramazza & Hillis, 1991). Moreover, writing versus speaking have distinct 'styles,' with different sorts of sentences being appropriate for each (e.g., Biber, 1988). Together, these observations suggest that some form of knowledge use differs between speaking and writing; a question of interest is whether priming reveals the modality independence or the modality dependence of the syntactic knowledge priming is largely sensitive to.

To the extent that different syntactic knowledge is deployed in the two modalities, we should see that structural priming is weaker between modalities – when a speaker writes a prime and speaks a target or vice versa – compared to within modalities – when a speaker writes or speaks both primes and targets. However, Cleland and Pickering (2006) revealed approximately equal priming between as within modality, regardless of whether targets were spoken or written. Cleland and Pickering also found a lexical boost that was about equal between as within modalities. These observations provide strong evidence that at least those aspects of structural knowledge that underlie structural priming are modality independent – they are used in the same way both when speaking and when writing. In turn, this suggests that such structural knowledge has an abstract character. This fits both with the combinatorial node approach described above (Pickering & Branigan, 1998) as well as the implicit-learning approach described below.

Conclusions

We opened this section of this review by noting that structural priming has been used to inform three general issues within the production literature. Here, we summarize the evidence.

From message to syntax—The evidence here is decidedly mixed. Bock and Loebell (1990) and Bock et al. (1992) provide strong evidence that thematic role distinctions are irrelevant as far as structural priming is concerned. But Griffin and Weinstein-Tull (2003), Chang et al. (2003), Hare and Goldberg (1999), and Salamoura and Williams (2007) all suggest that thematic role distinctions can influence priming. A useful avenue of future study would be not simply to investigate whether thematic roles are effective during priming, but to investigate why these different studies have come to different conclusions. To do so, it may be important to consider properties of the specific structures that have and have not revealed influences of thematic role features.

Levels within grammatical encoding—No evidence thus far has revealed that a representation akin to deep structure in traditional theories of transformational grammar operates during production; indeed, evidence suggests that such a level is not influential (Bock et al., 1992). Current evidence is consistent with the possibility, first posed by Garrett (1975), that linguistic expressions include a functional level of representation, characterized in terms of subject, direct object, and so forth; whether those representations are represented order-independently has not been informed by evidence from structural priming. Beyond these, there is no convincing evidence from structural priming concerning any further stratification of the production process. Though initial indications were consistent with the representation of dominance-only relations (Hartsuiker et al., 1999; Hartsuiker & Westenberg, 2000), other investigations specifically failed to find evidence for such a representation (Pickering et al., 2002). In short, the most likely state of affairs, as suggested by priming, is that speakers begin with a functional level of representation (Garrett, 1975) that is mapped directly to an order-specified level of constituent structure (Pickering et al., 2002).

The nature of syntactic knowledge—Syntactic knowledge is not fully abstract, as revealed by the lexical boost (Pickering & Branigan, 1998), and the semantic boost (Cleland & Pickering, 2003). Syntactic knowledge is also not fully lexicalized, as revealed by the fact that priming is observed regardless of lexical content (Bock, 1986, and many demonstrations since). Indeed, the bulk of evidence is consistent with the possibility that structural priming influences the choice among (Fox Tree & Meijer, 1999; Branigan et al., 2006) and ordering of (Scheepers, 2003; Desmet & Declercq, 2006) phrase-structure rules or similar representations, which are clear implementations of lexically independent syntactic knowledge. Priming appears to be entirely insensitive to the function words in an utterance (Bock, 1989; Pickering & Branigan, 1998; V. S. Ferreira, 2003), and appears to be equivalent in the spoken and written modalities (Cleland & Pickering, 2006). The overwhelming evidence that structural priming at least in part occurs at a syntactic level suggests that such representations cannot be phonological, so there is good evidence that any phonological representation constitutes a separate level. Overall, the evidence is consistent with lexical-syntactic interactionism (which can be represented through combinatorial nodes – Pickering & Branigan, 1998): Syntactic knowledge is representationally independent of lexical knowledge, yet can be influenced by ongoing lexical processing.

Priming from comprehension to production

Above, we described a general model of production, beginning with a message feeding a grammatical encoding process, continuing on to phonological encoding and finally articulation. We briefly considered the relationship between these mechanisms and modality with respect to written versus spoken production. But modality is also about producing versus comprehending. If syntactic knowledge is modality independent, priming should arise from comprehension to production.

Early research on structural priming purely addressed priming within production, and argued that priming affected syntactic *procedures* specific to production (Bock & Loebell, 1990). However, more recent evidence suggests that priming in fact does arise from comprehension to production, and therefore suggests that priming influences mechanisms that are common to comprehension and production. This is an exciting discovery: Theoretically, it suggests that language use involves very general, abstract mechanisms that may bear a close relationship to linguistic knowledge. Practically, it opens a new way to investigate language comprehension: By assessing the effects of comprehending different types of sentences upon production. Comprehension-to-production evidence is described next, followed by a review of the evidence of priming during interactive dialogue.

In most experiments on structural priming, the participant produces both the prime and target utterance. But there have been several demonstrations that merely comprehending the prime can affect target production. Potter and Lombardi (1998) found that recall of a target sentence was affected by recall of a prime sentence, but also showed that it was affected when the prime sentence was simply read (one individually presented word at a time). Bock, Chang, Dell, and Onishi (2007) found priming of picture description when participants heard a prime sentence. The size and pattern of effects were very similar to priming effects when participants produced the prime sentences (Bock & Griffin, 2000). Additionally, strong priming occurs between comprehension and production in dialogue tasks (e.g., Branigan et al., 2000a; Cleland & Pickering, 2003), as discussed below.

The possibility of using priming to inform issues within language-comprehension research is suggested by work by Van Gompel, Pickering, Pearson, and Jacob (2006). They revealed comprehension-to-production priming, but on the basis of comprehended analyses that proved incorrect and so were eventually abandoned (so called *garden-path analyses*). For example, people tend to initially assume that the man visited the children in (8a) and hence that *visiting* is transitive. This analysis is ruled out by the comma in (8b) and the correct intransitive analysis of *visiting* is adopted immediately (e.g., Frazier & Rayner, 1982):

(8a) While the man was visiting the children who were surprisingly pleasant and funny played outside.

(8b) While the man was visiting, the children who were surprisingly pleasant and funny played outside.

Van Gompel et al. found that people were more likely to produce a transitive (rather than an intransitive) utterance after reading (8a) than (8b), thus indicating that they were primed by comprehension of the abandoned analysis (cf. Christianson, Hollingworth, Halliwell, & Ferreira, 2001). This priming might be syntactic (repetition of construction) or semantic (repetition of transitive event); however, the syntactic explanation would require it to affect choice of meaning (cf. Scheepers, 2003, as discussed above). In any case, given the prominence of research within language comprehension on garden-path structures, the influence of such structures on priming suggests that traditional evidence about comprehension (e.g., from self-paced reading or from eye-movement monitoring during reading or scene perception) can be supplemented with production data.

These results demonstrate that the mechanisms of language comprehension and language production exhibit significant overlap, inasmuch as the quality and quantity of priming effects are highly comparable regardless of whether primes are produced or are only comprehended, and when signature comprehension effects (such as garden pathing) can be seen to influence production. Indeed, priming between production and comprehension, just like priming between writing and speaking, supports the claim that both processes draw on common representations of linguistic information, particularly ones associated with syntax.

However, there are at least two reasons for caution. First, we cannot conclusively rule out an alternative account in which production and comprehension processes draw on separate but linked representations. For example, comprehending a passive might activate a passive-in-comprehension representation, and this might in turn activate a passive-in-production representation. Such an account would naturally predict less priming from comprehension to production than from production to production, and there is no evidence that this is the case, but the relevant evidence is limited.

Second, participants may generate production-based representations as a result of comprehending a prime sentence. They might do this by rehearsing what they have heard. It may be possible to test this account by interfering with rehearsal or by greatly reducing the

time between comprehension and production. Another possibility is that participants use production mechanisms naturally as part of the process of comprehension, specifically to make predictions about upcoming information (Pickering & Garrod, 2007). However, any explanation of comprehension-to-production priming requires comprehension and production to be closely entwined, so that people find it very easy to switch between mechanisms.

Structural alignment in dialogue

In dialogue, interlocutors constantly switch between comprehension and production, and are clearly able to use what they have just comprehended to guide what they produce. Thus it is not surprising that dialogue is extremely repetitive (e.g., Schenkein, 1980; Tannen, 1989). This repetition takes place at many different linguistic levels. For example, Brennan and Clark (1996) had interlocutors describe pictures to each other, and found that they tended to imitate each other's choice of referring expressions. Garrod and Anderson (1987) had pairs of participants play a cooperative maze game, in which they took turns to describe their positions to each other. If one player said *I'm two along, four up*, her partner tended to say *I'm one along, five up*; whereas if she said *I'm at B4*, her partner tended to say *I'm at A5*. These players repeated each other's choice of a "path" or a "coordinate" description scheme, rather than specific words. They also aligned on the interpretation of these descriptions, for example treating the origin as the bottom left corner of the maze. There is also evidence that interlocutors tend to interpret spatial expressions such as *left* and *right* in the same way (Schober, 1993; Watson, Pickering, & Branigan, 2004). In addition, they align on accent and speech rate (Giles, Coupland, & Coupland, 1991) and on phonetic realizations of repeated words (Pardo, 2006). In addition, Levelt and Kelter's (1982) demonstration of priming in question-answering constitutes a form of alignment in dialogue.

It is therefore not surprising that structural priming also occurs in dialogue. Branigan et al. (2000a) had two interlocutors take turns describing cards to each other and finding those cards in an array. One of the participants was a confederate of the experimenter who produced scripted responses (depending on experimental condition). For example, the confederate might describe a card as either *the cricketer giving the plate to the diver* (the *prepositional object* form) or as *the cricketer giving the diver the plate* (the *double object* form). The experimental participant tended to mirror the syntactic form used by the confederate, with a prepositional-object form being considerably more likely after the prepositional-object prime and a double-object form being more likely after a double-object prime. Branigan et al. (2000a) also demonstrated a lexical boost in dialogue, in that priming was enhanced when the prime and target used the same verb than when they used different verbs. In fact, all effects were extremely large, with participants being 55% more likely to use the same form than the opposite form when the verb was repeated, and 26% more likely when the verb was not repeated.

Other investigations have revealed priming in dialogue as well. As discussed above, Cleland and Pickering (2003) found priming of noun-phrase structure in dialogue (*the sheep that's red* vs. *the red sheep*), with this tendency being enhanced by lexical repetition and indeed by semantic relatedness between the prime and target nouns. Haywood, Pickering, and Branigan (2005) found that participants were more likely to use a locally disambiguated instruction such as *Put the penguin that's in the cup on the star* when they had just been instructed to perform a similar act with a prime containing *that's* than when the prime did not contain *that's* (a lexical explanation of these results is unlikely because of the evidence against closed-class priming; e.g., Bock, 1989). There was also a tendency to avoid instructions that might "garden-path" addressees (e.g., erroneously moving a penguin into a cup), but the tendency toward priming was much stronger.

Finally, priming has been used to investigate the role of dialogue-specific factors, such as whether a conversational participant is a speaker, addressee, or side participant (Clark, 1996).

Branigan, Pickering, McLean, and Cleland (2007) found that interlocutors were more likely to repeat grammatical forms when they had just been addressed than when they were part of the conversation but had not been addressed (a side-participant). This effect occurred whether they responded to the previous speaker or the previous addressee. However, it did not matter whether an addressee responded to the previous speaker or a previous side-participant. In other words, priming is stronger if you were addressed than if you were not, but is not enhanced by reciprocity. A likely explanation is that participants encode more deeply when they are directly addressed, perhaps as a result of acting on the prime (or preparing potential responses). This experiment also demonstrated that the strength of priming can vary for reasons unconnected to linguistic structure or the proximity of the prime and target.

In conclusion, priming from comprehension to production in both dialogue and monologue indicates that the structural representations constructed by the production and comprehension mechanisms are very closely linked and may be identical. But we have not so far considered the nature of language comprehension in any detail. To address this, the next section reviews the small but rapidly growing literature concerned with the priming *of* comprehension. After this, we consider explanations of structural priming, one of which assumes that priming in dialogue serves to promote alignment between interlocutors.

Priming of comprehension

Investigations into the priming of production have been informative about the nature of production; we might therefore expect that investigations into the priming of comprehension would be similarly informative about the nature of comprehension. But so far, they have had relatively little effect, as is apparent in reviews of sentence comprehension or parsing (e.g., Pickering & Van Gompel, 2006). The main reason is that very few researchers have directly addressed priming of comprehension until extremely recently, though (as we shall see) many studies provide indirect evidence of priming. In addition, theories of language comprehension focus much less on levels of representation than do theories of language production, and instead emphasize the resolution of ambiguity, the time-course of language comprehension, whether people can consider more than one analysis at a time, and the way in which syntactic processing is affected by semantic processing (and other factors such as frequency). This section therefore considers the extent to which priming of comprehension can be informative about comprehension.

Theories of comprehension tend to assume that syntax is represented autonomously, though they do not use structural priming data (such as Bock, 1986) to justify this assumption. Some studies have attempted to justify deep-structure representations (Bever & McElree, 1988; see also Fodor, Bever, & Garrett, 1974), but there is no consensus on their existence (e.g., Pickering & Barry, 1991), and most current researchers simply assume one level of syntactic representation concerned with constituent structure (as in Fig. 1). Instead, researchers have noticed that sentence fragments tend to be syntactically ambiguous, and ask whether the processor chooses analyses on the basis of syntactic preferences alone (e.g., selecting the one requiring fewest nodes; Frazier, 1987), or whether semantics (and other factors) can affect choice of analysis (e.g., favoring more plausible analyses; MacDonald, Pearlmutter, & Seidenberg, 1994). Important studies tend to focus on the time-course of comprehension, using sensitive methods such as eye-tracking (e.g., Trueswell, Tanenhaus, & Garnsey, 1994).

If priming impacts language-comprehension research, we might expect it to address the nature of the structural representations that people construct. For example, do they construct one or more than one level of syntactic representation? Do they construct representations in terms of grammatical relations, thematic roles, or both? And are syntactic representations inextricably bound up with lexical information, or does comprehension involve partly separable

representations of abstract syntax and lexical items? In particular, priming might show how such representations evolve over time, in a way that has not proved possible in studies of language production. As we shall see, we have few answers at the moment, but there are signs of a buildup of relevant research. We first review early work relating to priming in comprehension (and ask why there was so little), and then consider a range of findings that suggest some kind of priming in comprehension. After this, we consider very recent research (starting in 2004) that directly addresses priming in comprehension and considers how it might inform theories of language comprehension.

Early evidence for priming of comprehension

Given that there are very many more studies of comprehension than production, it may be quite surprising that there have been so few studies of priming of comprehension. In particular, very few studies have investigated whether comprehension of a sentence with a particular structure is facilitated by the immediately prior comprehension of a single exemplar of a structurally similar sentence. This is remarkable because such studies would closely mirror studies of structural priming of production (e.g., Bock, 1986) and other types of priming of comprehension (e.g., Meyer & Schvaneveldt, 1971). Moreover, the evidence for priming from comprehension to production (Branigan et al., 2000a; Levelt & Kelter, 1982; Potter & Lombardi, 1998) antedates the direct evidence for priming of comprehension, and surely gives good reason to assume that priming of comprehension might occur.

So why has there been so little evidence for priming of comprehension? The most obvious reason is that all acts of production involve critical structural choices – should the speaker produce an active or a passive, an adjective or a relative clause, and so on – just as they involve choices about which words to use, and that the main effect of priming is to direct such choices. In contrast, important choices may be comparatively rare in comprehension. Unusual exceptions may be when comprehenders must understand “difficult” structural ambiguities. For example, a sentence has to mislead a comprehender quite seriously for a robust “garden-path” effect to occur (e.g., Frazier & Rayner, 1982). It may be that structural priming in comprehension is largely limited to cases where there is considerable ambiguity and where it is difficult to recover from misanalysis. If so, researchers may have sought priming using the wrong types of sentences (i.e., ones that show little ambiguity). However, it is also possible that such effects have proved elusive because comprehension research usually measures reaction times, and structural priming in production has only shown fairly small effects on reaction time in three published studies (Corley & Scheepers, 2002; Smith & Wheeldon, 2001; Wheeldon & Smith, 2003).

Even so, at least some evidence that syntactic repetition can facilitate comprehension considerably pre-dates experimental evidence for structural priming in production. Mehler and Carey (1967) found that auditory presentation of many sentences of a particular syntactic form (e.g., *They are forecasting cyclones* vs. *They are recurring mistakes*) facilitated processing of sentences with the same form. Subsequent studies showed comparable effects on sentence-picture matching (Mehler & Carey, 1968) and interpreting 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). After this early burst of research, there was little interest in the effects of structural priming in comprehension.

Effects of structural repetition

Many more recent studies find evidence of structural repetition, though their results are rarely interpreted in relation to studies such as Bock (1986) or Mehler and Carey (1967). First, several studies address aspects of structural parallelism, a phenomenon that may be related to structural

priming. One study found effects of parallelism on the comprehension of sentences involving coordination (Frazier, Taft, Clifton, Roeper, & Ehrlich, 1984). For example, participants read *and the short thug hit Sam* more quickly after *The tall gangster hit John* than after *John was hit by the tall gangster*. This study used many sentence types (actives/passives, shifted/non-shifted noun phrases, etc.), and the authors did not demonstrate that parallelism effects occurred for each sentence type considered individually. Frazier, Munn, and Clifton (2000) also found parallelism effects, but interestingly not outside coordination (e.g., *a tall woman* was no easier after *A strange man noticed* than after *A man noticed*), so these effects may not relate closely to structural priming between utterances. In these two studies, the conjuncts were clearly related in meaning. Indeed, Frazier et al. (2000) did not interpret their results in terms of structural priming.

Most other studies of parallelism have addressed the question of how people interpret ambiguous pronouns. Specifically, the *parallel function hypothesis* holds that such pronouns are likely to be interpreted as coreferential with a potential antecedent that has the same grammatical relation (Grober, Beardsley, & Caramazza, 1978; Sheldon, 1974; Smyth, 1994). For example, *he* preferentially refers to *William* in (13a) but *him* preferentially refers to *Oliver* in (13b), so long as the pronouns are not stressed:

(13a) William hit Oliver and he slapped Rod.

(13b) William hit Oliver and Rod slapped him.

There is a tendency for all pronouns to refer to subjects, at least in part because subjects are likely to refer to the topic. But there is also some evidence for parallelism, with object interpretations of non-subject pronouns being more likely and more rapid than subject interpretations of non-subject pronouns (Chambers & Smyth, 1998; cf. Frisch, beim Graben, & Schlesewsky, 2004). Such parallelism effects appear strongest when the two clauses are syntactically and semantically similar, for example having the same constituent structure or thematic roles (Smyth, 1994; Stevenson, Nelson, & Stenning, 1995). This observation is particularly interesting, because it may be analogous to the finding that structural priming is enhanced by lexical repetition (Pickering & Branigan, 1998) or semantic similarity (Cleland & Pickering, 2003). In other words, similarity at one level of representation increases the tendency to similarity at other levels (see Pickering & Garrod, 2004). It seems that the referent-to-structural-position assignment made in the first clause primes the same referent-to-structural position assignment in the second clause.

There is also some evidence that noun phrases are preferentially interpreted as having the same grammatical relation or playing the same thematic role in the construction known as *gapping*. Carlson (2001) had participants interpret sentences such as *Josh visited the office during the vacation and Sarah during the week*, which is ambiguous between a gapping analysis in which Sarah visited the office during the week and a non-gapping analysis in which Josh visited Sarah during the week. In a written questionnaire, participants were more likely to adopt the gapping analysis for this sentence than for *Josh visited Marjorie during the vacation and Sarah during the week*. The gapping analysis appears to be difficult when it requires *Sarah* to play a parallel role to *the office* but more straightforward when it requires *Sarah* to play a parallel role to *Marjorie*. This parallelism effect may of course be a result of the coordinate structure, as in Frazier et al. (1984, 2000). In addition, Traxler, McElree, Williams, and Pickering (2005) found that the interpretation of coerced expressions such as *started the book* was facilitated by repetition of the expression or its contextually appropriate interpretation (e.g., *started reading the book*). Thus, the locus of this effect is presumably semantic.

It also appears that the interpretation of noun-noun compounds is subject to priming. Wisniewski and Love (1998) found that people tended to interpret novel combinations such as *spear chisel* in terms of a thematic relation[5] between the modifier and head concepts (e.g., a

chisel used to make spears) following a relational prime (*clothing truck*) but as mapping (attributing) a property of the modifier to the head (e.g., a long chisel, where length is a property of spears) following a property-mapping prime (*bus truck*). Gagné (2001) found that people comprehended *murder film* (meaning a film about murder) more quickly and accurately after comprehending a combination that involved the same thematic relation and modifier (*murder investigation*, i.e., investigation about murder) versus a different relation and same modifier (*murder attempt*, i.e., attempt to commit murder). She did not find relational priming when the head was repeated rather than the modifier, with the same-relation prime *poverty film* and different-relation prime *foreign film* having equivalent effects on *murder film*. These and other studies demonstrate priming of the abstract semantic properties of conceptual combinations using both judgment and reaction-time data (see also Gagné, 2002; Gagné & Shoben, 2002; Gagné, Spalding, & Ji, 2005). Importantly, Gagné (2001) argued that information about relations is stored with the modifier. But recent studies have shown priming when the head is repeated and when neither word is repeated (Estes, 2003; Estes & Jones, 2006; Raffray, Pickering, & Branigan, 2007). Interestingly, priming with repetition of either the head or the modifier is stronger than priming without any repetition (Raffray et al., 2007). Priming of conceptual combination can therefore display a lexical boost, which provides a reason to equate it with other forms of structural priming (e.g., Pickering & Branigan, 1998; see Branigan, Pickering, & McLean, 2005, discussed below). Note that it is not always clear whether participants select among established interpretations or construct novel interpretations on the fly. A comparable issue arises in production studies using young children (Brooks & Tomasello, 1999; Huttenlocher,Vasilyeva, & Shimpi, 2004; Savage et al., 2003).

Other findings relate more closely to syntax. Trueswell and Kim (1998) found that comprehending an ambiguous sentence was facilitated or inhibited by the preferred analysis of a subliminally presented verb (or noun; see Novick, Kim, & Trueswell, 2003). They argued that this verb activated a set of syntactic and semantic features that facilitated the selection of the same features for the real verb. This *fast priming* therefore takes place between verbs, and also occurs on the basis of a single-word prime (cf. Melinger & Dobel, 2005). However, its relationship to structural priming from complete sentences is not clear.

Noppeney and Price (2004) conducted an fMRI study in which they compared BOLD (blood-oxygen-level dependent) responses to blocks of syntactically similar versus dissimilar sentences. Participants showed more activation in the left temporal pole for syntactically dissimilar versus similar sentences. The authors also demonstrated shorter sentence reading time for the syntactically similar versus dissimilar sentences. These effects may of course reflect strategic processes that occur when participants realized each block contained many syntactically similar sentences (as in Mehler & Carey, 1967).

Priming in comprehension appears with novel constructions as well. Kaschak and Glenberg (2004) had participants read sentences such as (14a), which use a novel construction for their participants, or a familiar control sentence such as (14b):

(14a) The wood floor needs cleaned before our parents get here.

(14b) The wood floor needs to be cleaned before our parents get here.

Repeated exposure to sentences such as (14a) facilitated comprehension of similar structures to a greater extent than repeated exposure to sentences such as (14b). Additionally, (14a) temporarily has an analysis in which *cleaned* serves as a modifier, as in *The wood floor needs cleaned corners.* In one experiment, participants that were exposed to sentences such as (14a)

[5]As in *thematic role*, this use of *thematic* refers to a category of semantic relation, but the specific categories do not tend to be the same.

subsequently found (15) easier to process than participants that were exposed to sentences such as (14b):

(15) The meal needs cooked vegetables so the guests will be happy.

No comparable difference occurred for sentences that did not involve this modifier construction. These results suggest that participants construct the (inappropriate) modifier analysis when reading sentences such as (14a), and that this inappropriate analysis facilitated subsequent processing of modifier sentences. These effects are probably less likely to be strategic than Mehler and Carey (1967), because the effect is based on an abandoned analysis. (We have already noted that the comprehension of abandoned analyses can be primed in production; Van Gompel et al., 2006.)

Kaschak (2006) also found that repeated exposure to sentences such as (14a) facilitated comprehension of *pseudocleft* sentences such as (16):

(16a) John thinks that what the meal needs is cooked given that dinner is in an hour.

(16b) John thinks that what the dog wants is walked before it gets too late.

Hence the effect generalized to a different construction (though regularly related to the original construction) and to a different verb *wants* (though the effects may be somewhat reduced in this case).

There have been some other isolated observations that suggest structural priming in comprehension. Rawson (2004) repeatedly exposed participants to ambiguous or unambiguous sentences in short texts and found largely item-specific speed-up effects, with more speed-up for ambiguous than unambiguous sentences. There were also some smaller effects that carried over to structurally similar sentences. Perhaps similarly, participants judge some types of sentences as more acceptable following exposure to structurally similar sentences (Luka & Barsalou, 2005; Snyder, 2000). Linguistic judgments may therefore be more malleable than often assumed (see Schütze, 1996). Finally, people prefer answers that are grammatically congruent with their questions (Levelt & Kelter, 1982). Evidence for priming of comprehension in children is discussed below.

To summarize, many studies find effects of repeated presentation of locally or globally ambiguous sentences of one syntactic form facilitating comprehension of sentences with that structure (e.g., Mehler & Carey, 1967; Noppeney & Price, 2004), affecting the degree of preference for that structure (e.g., Luka & Barsalou, 2005), or facilitating the learning of novel structures (e.g., Kaschak & Glenberg, 2004). As noted, participants may become aware of the extensive repetition and tune into particular characteristics of the critical sentences over time. Moreover, the effects of extensive repetition may be very different from the effects of a single prime trial. In addition, they do not indicate how repetition affects the time-course of comprehension. While they suggest that syntactic repetition can affect comprehension in some way, they do not directly inform theories of online sentence comprehension. The studies of parallelism in coordination (e.g., Frazier et al., 1984), pronoun resolution (e.g., Grober et al., 1978), and gapping (Carlson, 2001) use a single prime, but their effects are less clearly related to structural priming as discussed in this paper. The same is true of studies concerned with the interpretation of noun-noun compounds (e.g., Estes & Jones, 2006; Gagné, 2001).

Direct assessment of structural priming in comprehension

We now turn to recent studies that appear to support structural priming in comprehension, and which are explicitly modelled on studies of structural priming in production (e.g., Bock, 1986). Branigan et al. (2005) presented participants with expressions such as (17), which can

mean that the policeman used the gun to prod the doctor (verb attachment analysis) or that the policeman prodded the doctor who had the gun (noun attachment analysis):

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

Participants then saw two pictures, one which matched one or other interpretation, and one which matched neither interpretation. Next, they were presented with a structurally similar target expression and then two pictures, but this time each picture matched one interpretation of the target sentence. When the verb was repeated between prime and target, participants tended to choose the picture that matched the analysis assigned to the prime sentence. When the verb was not repeated, this tendency was not significant, and priming was significantly stronger when the verb was repeated than when it was not. In fact, the magnitude of priming was very similar in both same- and different-verb experiments to Pickering and Branigan (1998, Experiment 1), in which different-verb priming was not fully significant either. Another experiment with repeated verbs showed priming from production to comprehension, of very similar magnitude to priming from comprehension to comprehension. This reinforces the argument for parity between production and comprehension that we made on the basis of comprehension-to-production priming. Finally, priming also sped up picture-matching decisions in a repeated-verb experiment in which only one target picture was compatible with the target sentence.

These experiments show that priming can affect final choice of analysis, but are less informative about the process by which people develop an interpretation (see Traxler & Tooley, 2007). In six eye-tracking experiments, Pickering and Traxler (2008) investigated the comprehension of reduced-relative sentences such as (18):

(18) The speaker proposed by the group would work perfectly for the program.

Readers initially tend to assume that *the speaker* is the agent of *proposed*, and that *proposed* is a past-tense verb. On reading *by the group*, they realize that this analysis is unlikely, and experience processing difficulty (F. Ferreira & Clifton, 1986; Trueswell et al., 1994). Around this point, they reinterpret the sentence as a reduced relative. Pickering and Traxler found that this difficulty was reduced following a reduced-relative prime, but only when the verb was repeated. Further experiments showed that the prime could also be an unreduced relative (*the speaker that was proposed by the group*), a short relative (without *by the group*) or even a passive. These experiments therefore suggest that all these constructions share a level of representation during comprehension. For example, all the constructions that prime the reduced relative involve an initial patient, so one possibility is that a locus of priming is the binding of the first noun phrase (*the speaker*) as the patient of the verb (*proposed*), and therefore that such a representation is constructed during the earliest stages of comprehension. Thus, priming appears to transfer between certain related constructions in on-line comprehension, perhaps as it does in learning (Kaschak, 2006). In language production, priming sometimes transfers across constructions (Bock & Loebell, 1990), but there are also instances where priming does not (e.g., Pickering et al., 2002).

Traxler (in press) extended this work by considering whether priming occurred between agentive prepositional phrases (e.g., *watched by the cop*, similar to [18]) and instrumental prepositional phrases (e.g., *watched with the binoculars*) in reduced-relative constructions. Interestingly, comprehension of instrument phrases was facilitated more by prior comprehension of instrumental prepositional phrases than agentive prepositional phrases. This suggests that priming may be sensitive to a level of representation at which different types of adjuncts are distinguished, or that semantic relatedness enhances structural priming (cf. Cleland & Pickering, 2003).

Ledoux, Traxler, and Swaab (2007) conducted a comparable study using event-related potentials and found a smaller positivity (associated with syntactic ambiguity resolution) at *group* following a reduced-relative prime in comparison to a main-clause prime. This therefore provides evidence that priming is syntactic (though note that the effect occurs fairly late). In addition, Traxler and Tooley (in press) provided evidence against a strategic interpretation of priming in comprehension, and also found that verb repetition was necessary for priming. However, Traxler (2008) did find priming without verb repetition in a study concerned with the resolution of prepositional-phrase attachment ambiguities (cf. Branigan et al., 2005).

Finally, three studies have shown structural priming in comprehension using the "visual world" paradigm (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). In German sentences, the subject typically precedes the object, but it is also possible for the object to precede the subject. Scheepers and Crocker (2004) had participants read aloud a subject-first, object-first, or neutral (intransitive passive) prime sentence. They then heard a sentence whose initial noun phrase could be the subject or the object, such as *Die Krankenschwester* (the nurse), and simultaneously viewed a picture containing three entities: a nurse, a priest that the nurse is blow-drying, and a sportsman that is pushing the nurse. Prime and target sentences were unrelated and used different verbs. Previous research has shown that participants tend to move their eyes to the entity that they predict will be referred to next (Altmann & Kamide, 1999). If they interpret *Die Krankenschwester* as the object (and assuming that the object will be the patient), they should look at the sportsman (because the nurse is the patient of the pushing action). They were more likely to do this following the object-first prime than the other conditions. This result demonstrated very rapid and verb-independent priming, because it affected the interpretation of the first noun phrase even before the verb was encountered.

Arai, Van Gompel, and Scheepers (2007) conducted two experiments using dative sentences. For example, participants saw a picture of a pirate, a princess, and a necklace, and heard either *the pirate will send the necklace to the princess* or *the pirate will send the princess the necklace*. While hearing the verb, participants were more likely to gaze (anticipatorily) at the princess after having read a double object prime aloud but more likely to gaze at the necklace after having read a prepositional object prime, in an experiment when the verb was repeated. In a second experiment, using different verbs, no priming was found; and a combined analysis showed that repeating verbs enhanced priming. Other analyses confirmed this pattern and suggested that priming began 600-900 ms after the onset of the verb *send*. These studies have the potential advantage that the two interpretations have very similar meanings, so syntactic explanations of priming are particularly convincing.

However, Thothathiri and Snedeker (in press-a) reported comprehension priming between verbs in three experiments in which participants acted out target instructions using dative sentences (e.g., *Show the horn to the dog.*) Participants first acted out two prime instructions (Experiment 1) or listened to a passage containing two prime utterances (Experiments 2 and 3). The reason Thothathiri and Snedeker found different results from Arai et al. (in press) is not clear, but may relate to the use of the act-out task or to the fact that Thothathiri and Snedeker had instructions intervening between prime and target in at least some experiments. Separating prime and target might eliminate the lexical boost (cf. Hartsuiker et al., in press, for production), and the use of two primes might enhance between-verb priming (cf. Pickering & Branigan, 1998). Finally, Thothathiri and Snedeker found that priming occurred across a change of speaker, which provides further evidence for the abstract nature of priming (cf. Branigan et al., 2007, for comprehension-to-production priming across speakers).

Given the disparate nature of research into priming of comprehension, what can we deduce about its characteristics or about the nature of comprehension itself? Priming clearly occurs for different constructions and different languages. We have already noted that priming occurs

between constructions, but that little is known about the nature of the representations that are primed (Pickering & Traxler, 2008; Traxler, in press). More generally, the clearest effects of priming during comprehension appear to occur when prime and target are most closely related, just as they do in production. Five studies (using a range of methods) have found priming with verb repetition but no significant priming without verb repetition (Arai et al., 2007; Branigan et al., 2005; Ledoux et al., 2007; Pickering & Traxler, 2008; Traxler & Tooley, in press). However, Scheepers and Crocker (2004), Thothathiri and Snedeker (in press-a), and Traxler (2008) did find priming in the absence of verb repetition (and Kaschak, 2006, found effects between verbs in his learning-based paradigm). Verb repetition clearly enhances priming of comprehension but it is unclear when priming occurs without verb repetition.

At this point, it appears to be the case that priming in comprehension versus production are at least quantitatively different – priming is weaker in comprehension than it is in production. This follows from the fact that in nearly every case, to observe priming within comprehension, some "boost" is needed. For example, priming in comprehension can be observed when the prime structure is frequently repeated (e.g., Mehler & Carey, 1967), when prime and target sentences are semantically related or coherent in some way (e.g., the studies of parallelism), when the verb is repeated between prime and target sentences, or if the prime is presented essentially at the same time that the target is processed (fast priming; Trueswell & Kim, 1998). Two of the visual world studies (Scheepers & Crocker, 2004; Thothathiri & Snedeker, in press) are exceptions to this, but a possible explanation is that viewing the objects in the array leads to activation of production mechanisms which drive predictions about the structure of the upcoming utterance (Pickering & Garrod, 2007). Also, the literature on conceptual combination also does not involve any obvious "boosting" factor; it may be that comprehending a novel compound involves a choice in a way that is analogous to making structural choices in production, and so priming is observed. Overall, it is unclear whether priming in comprehension generally requires a boost because priming of comprehension involve different cognitive bases than priming of production, or because priming of comprehension is typically assessed with less sensitive reaction-time measures.

Explanations for structural priming

The previous sections have used evidence from structural priming to investigate the mechanisms of production and comprehension and their relationship. But the review also indicates that priming is extremely widespread, and therefore suggests that it may have particular communicative or cognitive functions. We identify three potential functions as promoting alignment in dialogue, fluency, and learning, and use this to interpret further data about priming such as its effects on timing of responses and its longevity. Not surprisingly, our emphasis is on production to a greater extent than comprehension.

Alignment in dialogue

We have noted that interlocutors tend to repeat various aspects of each other's utterances (e.g., Garrod & Anderson, 1987) and that they specifically repeat each other's syntactic choices (e.g., Branigan et al., 2000a). Moreover, many of these effects are extremely strong. This reinforces the suggestion that priming should occur at any level represented in people's cognitive systems. But it also supports the suggestion that all kinds of priming may have major effects on dialogue, with interlocutors being "pulled together" at different levels at the same time.

Pickering and Garrod (2004) argued that all forms of priming in dialogue, including structural and lexical priming, serve the function of promoting *alignment* between interlocutors. They argued that dialogue is successful when interlocutors end up with aligned mental states (they come to see relevant aspects of the world in similar ways), and that the principal mechanism underlying such alignment is priming. Informally, people are more likely to share

understanding if they share linguistic forms as well. Pickering and Garrod argued that alignment at one level tends to lead to more alignment at other levels. For example, structural priming is enhanced by alignment at the lexical level (the lexical boost; Branigan et al., 2000a; Cleland & Pickering, 2003) or the semantic level (the semantic boost; Cleland & Pickering, 2003). This alignment "percolates up" to what they call the level of the situation model (e.g., Johnson-Laird, 1983; Van Dijk & Kintsch, 1983) and hence promotes conversational success.

In Pickering and Branigan's (1998) terms, hearing a particular form in dialogue activates the relevant nodes (such as conceptual nodes, lemma nodes, and combinatorial nodes), and their residual activation (together with the strengthening of the links between relevant nodes) increases the likelihood that the speaker will subsequently use those nodes. Such a function of alignment helps explain why strong priming occurs from comprehension to production, with representational parity appearing necessary to explain the fact that people constantly and successfully switch between production and comprehension in dialogue (so that conversations do not normally involve pauses between turns) and that they can successfully complete each other's utterances (e.g., Garrod & Pickering, 2004). In fact, comprehenders might use comprehension-to-production priming to covertly activate the production system during comprehension and thus facilitate the prediction of upcoming linguistic material (Pickering & Garrod, 2007); if so, they would further facilitate switching from comprehension to production in dialogue. In addition, of course, priming of comprehension may have the function of promoting alignment, because it involves people interpreting language in the same way as each other. In conclusion, one function of priming may be to promote alignment, but we now consider whether it has additional functions as well.

Priming and fluency

One obvious possibility is that structural priming serves to promote ease of production or fluency, perhaps because it reduces the time or resources needed to plan utterances. Indeed, there is some evidence that speakers are faster when they have been primed than when they have not. Smith and Wheeldon (2001) had participants describe a moving display such as *The spoon and the car move up*, and found that they were about 50 ms faster if they had described another display as *The eye and the fish move apart* than if they had described a display as *The eye moves up and the fish moves down*. Other experiments helped rule out alternative explanations of the effect (in terms of conceptual priming or lemma access). The priming effect did not occur when the primed fragment was sentence final (*The dog moves above the house and the spoon*), suggesting that it is a short-lived and highly localized effect. Similarly, Wheeldon and Smith (2003) found no effect when prime and target were separated by one or three fillers. In addition, Corley and Scheepers (2002) found faster initiation of primed than unprimed dative sentences, using typed sentence production. Finally, 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 frequency in the language. These results suggest that priming may contribute somewhat to fluency. Priming of comprehension may also have a comparable effect, if fluency can be seen as reducing the time or resources needed to determine the structure or meaning of an utterance. Indeed, fluency provides a possible explanation of the facilitatory effects of priming on comprehension (e.g., Arai et al., 2007; Pickering & Traxler, 2008).

Priming and language learning

Structural priming clearly requires some form of memory, in that the effect of the prime must be stored for long enough that it can influence target processing. Recent investigations have revealed that at least under some circumstances, structural priming requires rather long-term

memory. In particular, Bock and Griffin (2000), following up on a more informal observation from Bock and Kroch (1989), had speakers repeat prepositional-object versus double-object prime sentences, or passive versus active prime sentences, and then elicited dative or transitive targets (respectively). Between prime and targets, speakers listened to and repeated between 0 and 10 "neutral" sentences (which were either intransitive sentences or predicate-adjective structures). Results revealed some variation in priming as a function of this *lag* manipulation, but most importantly, priming was as large when 10 sentences intervened between prime and target as when 0 or 1 sentence did. Bock et al. (2007) found similar effects when speakers only heard (and did not repeat) prime sentences. Also in spoken sentence completion, Branigan et al. (2000b) found no diminution of priming following an intervening sentence or an empty interval of the same length of time as the intervening sentence.

These findings, together with a few other properties of structural priming (noted below), has led to a view that it at least in part reflects the operation of an *implicit learning* mechanism. The core idea is that for people to produce and comprehend language, they must learn how their different linguistic and language-related representations relate or map onto one other. To produce or understand the word *cat*, a language user must learn that the meaning of domestic feline maps onto the word *cat* (which is a noun), which in turn maps onto the sound sequence /kæt/ and so forth. Everyday language experience can drive the learning of this knowledge, if retrieval of the word *cat* along with its meaning causes the connection or mapping between these representations to become strengthened. Though more abstract, implicit learning of syntax is similar: To produce or understand a passive structure, a language user must learn that certain meaning relationships (typically, of a patient having something done to it by an agent) map onto certain functional elements (subject and oblique objects), which map onto critical features of constituent sequences (how noun phrases and verb phrases are to be configured), and so forth. These mappings are acquired through experience, such that if a person produces or comprehends an utterance in which a particular meaning relationship is expressed through a particular processing sequence corresponding to constructing a passive or active structure, the mappings among the responsible representations should be strengthened, thereby allowing the same meaning relationships to be expressed through the same processing sequences and so the same syntactic features again. By this account, structural priming is a reflection of this extended process: Hearing or producing the prime strengthens the processing sequence that yielded the prime structure, and target processing reveals this strengthened knowledge.

As well as sometimes not decaying rapidly, structural priming has at least two other characteristics that are compatible with an implicit-learning account. First, it appears to be largely tacit. Lay language users have little idea that syntactic structures organize their sentences at all, let alone that those syntactic structures exhibit priming. Second, the priming effects themselves are incidental and automatic. The broad range of tasks (see above) that exhibit priming illustrate that no special task demands need be in place for priming to be observed. One demonstration revealed that instructions to focus on the meanings or wordings of sentences did affect degree of priming, though significant priming was always observed regardless of task instructions (Bock et al., 1992). The attentional effect may indicate that some component of priming is not incidental, or that such instructions may heighten attention to stimulus dimensions that modulate priming. Furthermore, no current evidence shows that any feature of structural priming is affected by nonlinguistic dual-task effort or interference, suggesting that structural priming is indeed an automatic phenomenon. Together, these characteristics of structural priming – that it is tacit, incidental, and automatic – fit especially well with the *implicit* part of the implicit-learning view – that experience with the relationships among linguistic and language-related representations automatically strengthens the knowledge of those relationships, leading to priming.

As noted, the learning component of the implicit-learning position requires that priming effects be long-lived. That said, this claim is not without controversy. Against the above-described evidence revealing long-lasting priming, Branigan et al. (1999) revealed that when speakers wrote prime and target sentences that shared a verb, priming effects were short-lived. In fact, effects were noticeably diminished when prime and target were separated by one neutral sentence, and were gone completely when four did. Levelt and Kelter (1982) similarly showed that priming effects were short-lived in their classic demonstration, as priming disappeared when just one clause intervened between the experimenter's question and the shopkeepers' answers. As mentioned above, Wheeldon and Smith (2003) revealed that speakers initiated their utterances (all of which used the repeated verb 'move') more quickly when targets were the same structures as primes, but that the effect disappeared with just one intervening trial.

How can studies revealing both short- and long-lived priming be reconciled? A critical factor seems to be whether there is lexical repetition from prime to target sentences. That is, experiments that revealed short-lived priming effects repeated verbs from prime to target sentences (e.g., Branigan et al., 1999), whereas experiments that revealed long-lived priming did not repeat verbs from prime to target sentences (e.g., Bock & Griffin, 2000). In accord with this, Hartsuiker, Bernolet, Schoonbaert, Speybroeck, and Vanderelst (in press) manipulated whether prime and target verbs were repeated or not and found a lexical boost when prime and target sentences were adjacent but not when they were separated by two or six sentences. It is not entirely obvious why long-term priming should be unaffected by verb repetition like this; V. S. Ferreira and Bock (2006) speculate the repeating verbs may move priming to have a more "episodic" basis (i.e., tied to the specific experience associated with the prime sentence, including all representational aspects of that experience), and that this episodic memory, like other forms of complex relational memory, may be more fragile and short-lived. Note that Hartsuiker et al. sometimes found that priming was smaller when prime and target were further separated (even when prime and target sentences had different verbs), in accord with Branigan et al. (1999) but contrary to Bock and Griffin (2000). In addition, some corpus studies suggest that the tendency to repeat decays, though such studies do not control for characteristics of the intervening material (Gries, 2005; Szmrecsanyi, 2006).

In three recent papers, Kaschak and colleagues have also studied long-term priming effects (Kaschak, 2007; Kaschak & Borreggine, in press; Kaschak, Loney, & Borreggine, 2006). Using typed sentence completion, they first had participants produce a block of sentences composed entirely of a single structure type (prepositional object sentences for one subject group, double object sentences for another), or a mixture of both, and then they were presented with standard prime-target pairs. Results showed that prime-target pairs exhibited standard structural priming when speakers previously saw a mixed block, but that priming was eliminated when speakers previously saw a block composed entirely of only one type of structure. But most relevantly, Kaschak and Borreggine manipulated the identity of the verbs used in the initial phase of the experiment and the target verbs. For example, either the PO sentences or the DO sentences in the initial exposure block used the same verb as in the prime-target sequence (primes and targets in the prime-target phase always shared verbs), or the PO and DO sentences in the initial phase had different verbs than in the prime-target phase. This manipulation had little effect, suggesting that long-term priming is not strongly associated with particular verbs. They did show some evidence of lexically specific effects for one verb (*lent*). They speculate that this may be due to the comparative oddness of this form, which leads to explicit memory for such sentences. Whereas Kaschak and colleagues' results are suggestive, it is also possible that any long-term verb-based effects are overcome by effects occurring during the completion of the prime-target pairs (which used the same verb).

In addition to being long-lived, tacit, and incidental, four other observations suggest that structural priming is at least in part an implicit-learning effect. The first, noted in Bock et al.

(1992), is that priming appears to be independent of *explicit* memory. That is, if in the same session, speakers are not only assessed for structural priming, but are asked to explicitly remember whether they encountered certain sentences, the sentences that cause priming are not the same as the sentences that speakers explicitly remember, nor vice versa. The second is that patients with medial-temporal lobe brain damage that causes anterograde amnesia (and thus severely impaired explicit memory) nonetheless show normal structural priming effects (V. S. Ferreira et al., 2005). The third is that priming may exhibit what has been called an *inverse-preference* effect. This refers to the fact that structures that are relatively less preferred in a production context seem to exhibit greater structural priming and vice versa. Under the assumption that systems learn more about representations that are not yet well known (which follows from error-based learning, a strategy typically used in incidental-learning algorithms), this fits with an implicit-learning view. A number of investigations reveal results consistent with such inverse-preference effects (Hartsuiker & Kolk, 1998b; Hartsuiker et al., 1999; Hartsuiker & Westenberg, 2000; Scheepers, 2003), though such inverse-preference effects might be due to how speakers process prime structures (as a learning account would predict) or how they process target structures. (Also, it should be noted that Kaschak and Borreggine [in press] reported long-term priming, but specifically did not observe any inverse preference effect.)

The final observation that supports the notion that priming reflects implicit learning is a series of large-scale simulation studies conducted by Chang and colleagues (Chang, 2002; Chang et al., 2006; Chang, Dell, Bock, & Griffin, 2000). These simulations are specific implementations of the implicit-learning approach, whereby models designed to learn through prior experience to generate linguistic utterances exhibit patterns of structural priming much like those observed in the literature. The patterns of performance these models capture include lexical independence (e.g., Bock, 1986; Pickering & Branigan, 1998), thematic independence (Bock & Loebell, 1990) and dependence (Chang et al., 2003), and patterns of preferential looking in child-language research (Hirsh-Pasek & Golinkoff, 1996; Naigles, 1990).

However, there is one prominent observation that the Chang et al. simulations cannot explain: the lexical boost. This raises what we above referred to as the “two locus” explanation for the lexical boost, namely, that the lexically independent and lexically exaggerated components of the structural priming effect are grounded in separate cognitive mechanisms. One possibility, mentioned above, is that because open-class lexical items (unlike syntactic structures, by most account) have semantic content, repeating open-class lexical items imparts an episodic and so non-implicit basis to the priming effect. This is consistent with the above-noted observation that whereas the lexically independent structural priming effect can be long lived (as would be needed for a learning account), the lexically dependent boost may not be.

That said, the two-locus account is difficult to fully evaluate without a stronger commitment to the cognitive basis of the lexically dependent boost. One possibility, consistent with one explanation described above for the differential boost observed from open- versus closed-class words, is that the lexical boost is actually a semantic boost. As noted, this explanation has difficulty with the fact that translation-equivalents boost priming significantly less than within-language repeated words, despite the semantic similarity of translation equivalents (Schoonbaert et al., 2007). In short, more theoretical and empirical work is necessary to explore the viability of the two-locus account.

One possibility is that priming involves two components, and that the Chang et al. simulations explain the abstract component of priming; such an account would of course contrast with Pickering and Branigan’s (1998) account, which assumes one locus to priming.

This point raises the issue of how best to describe the relationship between an implicit-learning view of structural priming and other explanations. Two related alternative explanations of structural priming include what is sometimes called an "activation" view (Pickering & Branigan, 1998), and what was above termed the "alignment" view (Pickering & Garrod, 2004). (We have already noted that the alignment view can be couched in terms of activation). The implicit-learning accounts on the one hand and the activation and alignment accounts on the other compete to explain the same data, using different theoretical assumptions. However, they do not necessarily contradict one another. Indeed, V. S. Ferreira and Bock (2006) lay out what they see as a complementarity to the two accounts. The implicit-learning account assumes that speakers need to learn the relationship between the meanings and structures of their language, and hence they strengthen their knowledge of the mappings between those levels of representation. The priming – the more likely use of a structure given a meaning – is an incidental outcome that can be used to measure the effect. The alignment account then takes this tendency to repeat structure as a starting point, because language users tend to experience the repetition of meaning when there is a repetition of structure. This in turn could lead to the development of a cognitively independent mechanism that uses priming to promote successful communication via becoming sensitive (in production and comprehension) to alignment. And so, upon accumulating enough experience of such form-meaning relationships, speakers will begin to be sensitive to the repetition of features at other levels of representation (e.g., lexical repetition yielding the lexical boost). Similarly, comprehenders will also become sensitive to form-meaning correspondences. In sum, implicit learning does not assume repetition, but can provide an independent explanation of it. At the same time, implicit learning does not specifically predict that learning should appear as repetition rather than in some other way, nor explain why lexical or semantic boosts occur; alignment does. Together, the accounts can provide a more complete explanation of the landscape of effects. Future research could illuminate the conflict or complementary between these accounts specifically by better characterizing the conditions under which priming is long-lived or decays (see Hartsuiker et al., in press), and whether long-term priming can ever show lexical dependence.

This discussion has thus far described how two seemingly different *functions* of priming might be reconciled. How might different mechanisms underlying each sort of account (e.g., Chang et al., 2006 and Pickering & Branigan, 1998) be similarly reconciled? Here it is important to note that the interactive-activation approach outlined by Pickering and Branigan is largely an account of priming within the grammatical encoding mechanism (i.e., within representations of words and combinatorial nodes), whereas Chang et al.'s approach is largely an account of priming between levels, most especially, from message-type levels of representation to representations that determine word order. This opens up the possibility that the two different sorts of mechanisms underlying priming may not be as incompatible as tends to be assumed.

Structural priming in different populations

Structural priming and language acquisition

It is reasonable to suppose that language acquisition involves a great deal of imitation, with children modeling their own utterances on utterances that they hear. This could enable children to learn how to properly use the structural properties of their language, or perhaps even to acquire those structural properties in the first place. We of course expect that structural priming occurs in children for structures that they are already familiar with (just as it does with adults), but we might also expect it to play a specific role in assisting the acquisition of new knowledge. It should also be able to indicate whether children have similar or different representations of structural knowledge as adults. Of course, priming may also promote alignment in children's dialogue (see Garrod & Clark, 1993).

Current research has focused on the extent to which children's language uses item-based schemas rather than abstract general knowledge about a construction (e.g., Fisher, 2002; Tomasello, 2000). For example, young children may use particular verbs extensively in a range of constructions but not others of apparently similar complexity. This suggests that they might store grammatical knowledge with individual lexical entries to a greater extent than adults do. It has become clear that this claim maps closely onto the relationship between syntax and the lexicon discussed above (e.g., Pickering & Branigan, 1998). A radical item-based account predicts that young children should display structural priming when relevant lexical items, particularly verbs, are repeated, but not otherwise.

Young children do appear susceptible to priming of structures. Huttenlocher et al. (2004) used a sentence-repetition and picture-description task to show that 4- and 5-year old children were more likely to produce both transitive and dative structures after being exposed to ten sentences involving one of the possible alternations than otherwise, always with different nouns and verbs than in target sentences. This suggests that these children do have abstract (lexically-non-specific) representations of these structures. Shimpi, Gamez, Huttenlocher, and Vasilyeva (2007) extended these results to 3-year old children, as well as showing priming for 4-year-old children without repetition. Thothathiri and Snedeker (in press-b) found priming of language comprehension in 3- and 4-year-old children with and without repetition, using the visual world paradigm (Thothathiri and Snedeker, in press-a). Branigan, McLean, and Jones (2005) found priming of complex noun phrase structure (adjective-noun vs. noun-relative clause order; see Cleland & Pickering, 2003) also without lexical repetition. This study used a single prime utterance and was therefore more similar to most adult priming studies. In a similar task, Savage et al. (2003) investigated transitive priming in 3-, 4-, and 6-year old children, and found reliable priming for all ages when lexical content was repeated (specifically, when primes and targets used the pronoun *it* to refer to all nominal arguments), but only the 6-year-olds showed priming without repeated lexical content. Savage, Lieven, Theakston, and Tomasello (2006) suggested that these results reflect longer-term learning by showing that processing five passive sentences can cause five-year-old children to produce more passives 30 days later, but only if children had an opportunity to produce primes one week after the original priming event and only if the five passive primes used different verbs (if all five had the same verbs, priming was not observed a week later). This suggests that long-term priming in 5-year-olds is not entirely abstract but instead has some lexically specific component to it.

In the above studies, some children may not have known one or the other construction before the experiment began. Thus, Huttenlocher et al. (2004) note that even their four-year olds with the strongest syntactic comprehension assessments very rarely spontaneously produced the passive or prepositional object structures they analyzed (and in the case of full passives, never produced them). Other studies have explicitly focused on learning of novel constructions. For example, Brooks and Tomasello (1999) presented children under 3 years old with passive or active exemplars with novel verbs. Prior to the experiment, these children did not generate passives spontaneously. They showed that when every child was trained only with active structures (on two different novel verbs), children were relatively unlikely to produce passive sentences with those same verbs. However, when each child was trained both with active structures and passive structures (each with separate nonce verbs), children were more likely to produce passives with nonce verbs that they heard only as actives. In other words, structural priming evidently encouraged the use of more abstract syntactic structures (see Fisher, 2002). If this technique can be equated with structural priming methods, it demonstrates priming at a very young age, and one that may contribute to the development of more adult-like grammatical skills (see also Whitehurst, Ironsmith, & Goldfein, 1974). Finally, repeated exposure to passives or ambiguous relative clauses in naturalistic contexts (story telling) can have long-term effects on production and comprehension of that construction (Cuetos, Mitchell, &

Corley, 1996; Vasilyeva, Huttenlocher, & Waterfall, 2006). This may have implications for educational practice.

Overall, the priming results are mixed, but suggest that children demonstrate both item-specific and abstract structural knowledge, as do adults. What is not clear is whether children are more sensitive to item-specific information than adults and whether there is a stage at which item-specific information dominates over abstract syntactic knowledge (which may occur when children have not had broad enough exposure to the language to have developed abstract knowledge). These are critical subjects of future research for better understanding of both structural priming and complex language acquisition.

Bilingualism

Language researchers have been interested in bilingual syntax for a long time, considering such issues as whether second languages (henceforth, *L2*) are learned differently than first or native languages (*L1*; e.g., Johnson & Newport, 1989) and when and how bilinguals switch between languages in conversation (codeswitching; Myers-Scotton, 1997). However, the vast majority of work on bilingualism in psycholinguistics has focused on lexical representation and processing (e.g., Gollan & Kroll, 2001). Researchers have recently realized that structural priming provides a method for assessing syntactic representations and processes in bilinguals. Two important questions have been asked of bilinguals' syntactic knowledge: Do bilinguals represent and process the structure of L2 differently than they or monolinguals represent and process the structure of L1, and to what extent do bilinguals integrate their languages into a shared representational system?

The representation and processing of L2

Some theoretical approaches suggest that L1 and L2 speakers should produce sentences differently. For example, Ullman (2001) proposed that L1 speakers have largely declarative knowledge of the lexicon, but largely procedural knowledge of grammar (essentially, because it constitutes tacit rules about how to combine words). In contrast, he argued that L2 speakers' grammatical knowledge is much more declarative (they explicitly remember rules of grammar as "facts"), with this being particularly true when the L2 is weaker.

However, research in structural priming has given little support for such claims, with roughly the same patterns of priming between constructions occurring within L2 and within L1. This suggests that L1 and L2 are represented and processed in largely similar ways, at least with respect to those factors that structural priming appears sensitive to. Thus, Schoonbaert et al. (2007) found that Dutch L1 speakers were more likely to use an English prepositional-object construction after hearing an English prepositional-object construction than an English double-object construction (in dialogue). Indeed, they found a similar magnitude of priming in an equivalent experiment using Dutch L1 speakers and Dutch translations of the items, and Branigan et al. (2000a) also found similar effects with English L1 speakers and English items. This suggests that all sets of speakers distinguish the prepositional-object and double-object constructions. Moreover, all three experiments included conditions with and without verb repetition, and found comparable lexical boosts. McDonough (2006) also found priming of the prepositional-object form of the dative alternation in English for L2 English speakers (with various L1s, but predominantly Chinese). Finally, Bernolet, Hartsuiker, and Pickering (2007) found priming of English complex noun phrases (such as *the baby that is red*) with Dutch L1 speakers, thereby extending priming of noun-phrase structure (Cleland & Pickering, 2003) to L2 speakers.

Cross-linguistic priming and the integration of syntactic information

It is possible that bilinguals represent the structure of each language with entirely separate representational systems. For example, they might have procedural knowledge of L1 grammar but declarative knowledge of L2 grammar (cf. Ullman, 2001). Alternatively, they might have equivalent but entirely separate knowledge stores for each language. For example, a Spanish-English bilingual knows that both languages have a passive construction, but may simply have one store of knowledge underlying the Spanish passive (e.g., 9a) and another store underlying the English passive (e.g., 9b).

(9a) The truck is chased by the taxi.

(9b) El camión es perseguido por el taxi.

However, these examples show that Spanish and English passives appear quite similar. For example, the English words occur in the same order as their Spanish translations, and in both cases, the verb consists of an auxiliary followed by a past participle, the theme is the sentence-initial subject, and the agent occurs in the sentence-final prepositional phrase). Whatever linguistic differences (9a) and (9b) might have, they have similar surface form (as can be expressed, for example, using traditional phrase-structure rules), and we have noted that structural priming seems sensitive to surface linguistic similarity (Bock & Loebell, 1990; Bock et al., 1992; Pickering et al., 2002). Therefore, a bilingual might represent this structural knowledge with a single set of language-independent representations. Of course, the languages differ in other respects, so not all representations will not be shared (e.g., Spanish does not allow the DO form of the dative). It is therefore possible to model bilingual syntactic representations within an extension of Pickering and Branigan's (1998) lemma stratum, in which shared representations are "tagged" to for both languages, and non-shared representations are "tagged" for one or other language (Bernolet et al., 2007; Hartsuiker et al., 2004; Schoonbaert et al., 2007; see Hartsuiker & Pickering, in press).

Shared representations of bilinguals' different languages appear to have the advantage of economy and would allow the bilingual to use well-established L1 knowledge to support L2 performance. However, separate representations might reduce confusion about which language to use. It is of course possible that the degree of sharing might be greater for proficient bilinguals, for bilinguals who learned their L2 early (or learned both languages at once), or for bilinguals who speak typologically more closely related languages. Although we do not have answers to all these questions, there is good evidence for some sharing of representations for reasonably proficient bilinguals who speak related languages (i.e., Germanic languages, Romance languages, and Greek).

Loebell and Bock (2003) found priming between German (L1) and English (L2), in a picture description task for datives. Participants first repeated a prime sentence in either their first or their second language and then described a picture in the other language. They showed that the production of German dative sentences (10a, 11a) primed the subsequent production of the corresponding English datives (10b, 11b) and vice-versa.

(10a) Der kleine Junge schrieb seinem Brieffreund einen Brief. (DO - German) [The little boy wrote his pen pal a letter]

(10b) A boy is giving a girl a present. (DO - English)

(11a) Der kleine Junge schrieb einen Brief an seinem Brieffreund (PO - German) [The little boy wrote a letter to his pen pal]

(11b) A boy is giving a present to a girl. (PO-English)

Meijer and Fox Tree (2003) found similar effects for dative sentences for Spanish/English bilinguals using sentence recall (Potter & Lombardi, 1998). Participants were more likely to falsely remember English DO sentences as PO sentences after Spanish PO sentences than after Spanish sentences containing no prepositional object. Heydel and Murray (2000) briefly describe experiments in which participants judged whether a German prime sentence matched pairs of pictures (which was never the case for experimental items), then described the pictures in English. They found that English passives were more likely after German passives or German topicalized sentences (i.e., object-verb-subject order) than after German actives. But the search for similarities between the prime sentences and the target pictures may have caused strategic processing.

Hartsuiker et al. (2004) had Spanish-English bilinguals describe cards to each other in a dialogue game (see Branigan et al., 2000a). Participants first heard a prime description in their first language (Spanish) and then had to describe the subsequent picture using their second language (English). The experiment showed cross-linguistic priming for passive sentences: Spanish-English bilinguals tended to produce English passive sentences more often following a Spanish passive (such as 8b) than following a Spanish active or an intransitive sentence. Schoonbaert et al. (2007) investigated syntactic priming within and between languages, using dative sentences as target structures. They found priming in L1 (Dutch), in L2 (English), and between L1 and L2 in both directions, thus suggesting that cross-linguistic priming is largely unaffected by the direction of priming. Indeed, in the absence of verb repetition, priming was very similar in all four experiments. Within-language priming was enhanced when the verb was repeated between prime and target (as in Pickering & Branigan, 1998, Branigan et al., 2000a, and Cleland & Pickering, 2006) in L1 and L2. Cross-linguistic priming was enhanced when prime and target verbs were translation equivalents, but only when priming from L1 to L2. Using spoken sentence completion, Salamoura and Williams (2007) found no translation-equivalent boost from Greek to English, but their study separated prime and target by an intervening (English) fragment, and is therefore compatible with the evidence for the abstract nature of long-lived priming (e.g., Hartsuiker et al., in press).

Desmet and Declerq (2006) found priming from Dutch (L1) to English (L2) in Dutch-English bilinguals, investigating sentence alternatives like those tested by Scheepers (2003), namely sentences with ambiguous relative-clause attachments (e.g., *Someone shot the servant of the actress on the balcony*). The priming effects were similar within and between languages (though we have already noted that Scheepers' findings likely involve priming of meaning-level representations, because the alternatives speakers could produce differ propositionally). Finally, Salamoura and Williams (2006) had participants read individually presented Dutch verbs and then (following a filler) complete sentence fragments with dative verbs (e.g., *The hotel receptionist gave …*). Participants produced more prepositional-object completions when the Dutch verb could only be used with the prepositional-object construction than when it could only be used with the double-object construction. Their results therefore extend Melinger and Dobel's (2005) finding of single-verb priming to a cross-linguistic situation.

These results suggest that cross-linguistic priming may actually be similar in magnitude to within-language priming (Desmet & Declerq, 2006; Schoonbaert et al., 2007). Schoonbaert et al.'s experiments showed greater within-language priming using repeated verbs versus between-language priming using translation-equivalent verbs, but similar within- and between-language priming for sentences with unrelated verbs. Assuming that the effect with repeated verbs is due to the lexical boost (translation-equivalent verbs having different lemmas), the abstract syntactic priming effect may be very similar. Two recent studies also obtained very similar within- and between-language priming in within-participants designs (Pickering, McLean, Branigan, Cheung, & Peacock, 2008; Kantola & Van Gompel, 2008). Such results provide further support for shared syntactic representations in bilinguals.

In all the above demonstrations, the two languages formed the constructions in the same way, with the relevant constituents occurring in the same order. There is also much evidence that monolingual priming is very sensitive to word order (Hartsuiker et al., 1999; Hartsuiker & Westenberg, 2000; Pickering et al., 2002). Hence cross-linguistic priming might be equally sensitive to variations in word order. As noted above, Loebell and Bock (2003) found cross-linguistic priming of datives, where English and German have the same word order; but they found no priming of transitives, where English and German differ. For example, the German translation of (12a) is (12b), which literally means "the river was by the chemical waste poisoned":

(12a) The river was poisoned by the chemical waste.

(12b) Der Fluss wurde von dem chemischen Abfall vergiftet.

In other words, German places the prepositional phrase before the participle *vergiftet*; whereas English places the participle *poisoned* first. This difference may have led to the lack of priming. However, Loebell and Bock did not find any priming of transitives within German in a separate experiment.

More recently, Bernolet et al. (2007) found priming of complex noun phrases (Cleland & Pickering, 2003) within Dutch (L1), as noted above, and English (L2), but no cross-linguistic priming (in either direction). This lack of priming may occur because Dutch reverses the order of the verb and adjective (literally, *the sheep that red is*), and the constructions may then be represented distinctly. In contrast, they did find priming from German to Dutch, which do have the same word order. Similarly, Salamoura and Williams (2007) found priming from Greek to English for PO and DO sentences, but no priming of PO sentences from sentences in which the prepositional phrase preceded the noun phrase; in fact their results corresponded very closely to those of Pickering et al. (2002).

These results may help us determine which constructions are represented in the same way across languages. This may have implications for the study of comparative syntax (and potentially for the hunt for universal grammatical principles). More immediately, they provide evidence about the degree of sharing of grammar between languages, though it is important to note that all languages explored thus far (English, French, German, Dutch, Spanish, Greek) are genetically and typologically related. For very different languages, cross-linguistic priming between analogous structures might or might not occur (see the exploration of passive production in Odawa by Christianson & Ferreira, 2005). A working hypothesis is that bilinguals share as much grammatical information as they can, given the extent to which grammatical differences within a language are represented together.

Aphasia

A subject of theoretical and practical importance in the language sciences is aphasia –acquired language deficits that arise due to brain damage (typically stroke). Theoretically, behavioral patterns exhibited by patients with aphasia have been used to constrain and develop theories not just of the aphasic deficit, but of unimpaired language processing as well (e.g., Berndt, 2001). Practically, insights into the basis of aphasia and its treatment are of obvious value. Structural priming promises to contribute valuably on both fronts.

Two studies have looked at structural priming in participants with aphasia. Saffran and Martin (1997) assessed structural priming in five participants with varying aphasia subtypes. They used a procedure closely modeled after Bock (1986), where participants repeated auditorily presented dative, transitive, and neutral prime sentences (up to four times if necessary) and then described dative- and transitive-eliciting target pictures. Additionally, baseline levels of dative and transitive production were assessed with tests before and after the priming phase.

They revealed that only passive forms showed significant priming: Participants with aphasia produced more passive targets after passive primes, relative to after active or neutral primes. However, they also made many closed-class errors with passives (just as often after passive as active primes). Active structures and both dative structures did not exhibit significant priming. Saffran and Martin revealed a hint of longer-term priming as well: After the priming procedure, aphasic speakers produced numerically (though not statistically) more passives, and they produced more dative structures (of both types) as well.

Hartsuiker and Kolk (1998a) assessed 12 participants who were classified as having Broca's aphasia, as well as 12 matched controls. Participants again heard and repeated prime sentences (including intransitive and locatives as baseline primes) and described target pictures that elicited transitive and dative structures. To reduce lexical-access difficulties, the names of entities were printed adjacent to them. They tested participants under three instruction conditions: Participants were told to repeat sentences and describe pictures to support memory performance (as in Bock, 1986), to repeat and describe without a memory instruction, and to mimic the previous sentence's structure. Participants with aphasia were primed by passive, prepositional dative, and double-object datives, and about equally so under all three instruction conditions. In contrast, control participants did not exhibit priming, except when explicitly instructed to mimic prime structures. Again, evidence for a longer-term priming effect was revealed: In a block with no active or passive primes, participants with aphasia rarely produced passive structures, but in blocks with priming manipulations (which included both active and passive primes), participants with aphasia produced many more passives, even after active primes. An interesting aspect of Hartsuiker and Kolk's results is that patients with aphasia exhibited *more* priming than controls. Hartsuiker and Kolk offer three possible explanations for this: Controls may be closer to some asymptote for producing a structure, and so in general exhibit less priming (this account is compatible with both the activation and the learning-based theories outlined above); participants with aphasia may know fewer structures and so suffer less competition for production of primed structures (though the authors note that the diversity of aphasic participants' productions were similar to controls'); or participants may prime more if they have an overall reduced capacity for sentence production (e.g., if priming eases production), and aphasia may entail reduced capacity.

These studies show that when someone with aphasia exhibits difficulty producing a structure, a residual capability for producing that structure can remain. In both studies, participants with aphasia did not produce passives before the priming phase, but did produce passives during the priming phase. In addition, both studies suggest a long-term component to priming; this may be relevant to implicit-learning theories of syntactic priming, and may also suggest a fruitful path for the treatment of aphasia.

Implications and conclusions

The vigorous research program into structural priming has provided unprecedented insights into human language, and it promises to provide more in the future. These include:

The nature of production, comprehension, and their relationship

Our review of priming of production indicates that a large number of studies have provided insights into the representations involved in language production. We interpreted these results in terms of the mapping from message to syntax, the levels of syntactic encoding, and the nature of syntactic knowledge. These findings are generally interpreted in terms that are broadly consistent with theories of language production (e.g., Garrett, 1975; Levelt, 1989). We anticipate that future studies will refine our understanding of language production but are unlikely to revolutionize the way it is characterized. As an example, priming may help resolve

the issue of whether there is a distinction between the roles of open-class and closed-class words in production.

We noted that most accounts of language comprehension do not focus on levels of representation themselves, but instead consider the influences of semantics (and other factors) on the time-course of syntactic processing. These accounts have not been affected by the very recent evidence on priming of comprehension. However, we anticipate that they will shortly begin to affect such theories, and in particular help determine the nature of syntactic and other representations that are constructed during comprehension. If so, theories of comprehension may change quite radically in due course.

Priming occurs between comprehension and production, and so it is reasonable to hypothesize that comprehension and production involve the same representations (i.e., parity). The more this is true, the more it would be possible to use comprehension-to-production priming to test hypotheses about comprehension. However, it may be that the mapping between representations or their integration is different in production and comprehension. For example, comprehending a verb may naturally lead to activation of a lexically specified representation of the associated construction, making abstract priming harder to obtain than in comprehension. We therefore predict extensive priming between production and comprehension, with these directions of processing involving many common representations but distinct architectures. However, we also strongly advocate the development of techniques in which comprehension does not greatly precede production to more tightly yoke the acts of comprehension and production.

The ubiquity of priming

The extensive evidence for structural priming suggests that any level of representation can be primed. That is, priming does not appear to be limited to syntactic knowledge or even to processes linking syntactic and other levels of representation. Some work suggests abstract priming of levels “below” the syntactic, for instance of syllabic properties (e.g., Sevald et al., 1995; though cf. Roelofs & Meyer, 1998). But much less is known about meaning-level representations, and priming might prove very useful in determining what representations speakers construct during message planning (or listeners construct during later stages of comprehension). For instance, do speakers construct representations associated with rhetorical relations between propositions (e.g., causality) or formal-semantic properties of propositions (e.g., quantifier scope)? How might such representations relate to the representations constructed during concept combination? Structural priming may therefore help the development of a unified theory that takes us from intention to articulation or vice versa. It is also possible that it helps explain phenomena beyond the traditional boundaries of psycholinguistics in which priming may play a role, such as analogical reasoning (e.g., Leech, Mareschal, & Cooper, in press).

Priming and linguistics

Linguists have tended to ignore what they see as “psychological” methods of investigating syntax even if they believe that linguistics ultimately describes the nature of people’s mental representations (e.g., Chomsky, 1986). In contrast, psycholinguists have struggled to find methods to investigate the mental representation of syntax. Indeed much of the history of early psycholinguistics constituted attempts to use experimental methods to investigate syntactic theory, but most researchers agreed that the attempt was not successful (e.g., Fodor et al., 1974). Hence, almost all investigations of syntax have been conducted by linguists using introspective methods such as grammaticality judgments (e.g., Schütze, 1996). Is it possible that structural priming could become established as a new approach to experimental linguistics?

There are good reasons to assume that at least some of the representations accessed by priming are very similar to the representations assumed in linguistics. First, we noted that priming gives good evidence for syntactic knowledge (e.g., Bock, 1986) that uses representations that are independent of conceptual, lexical, and phonological knowledge. Such knowledge informs speakers how to form well-formed grammatical sentences in terms of the parts of speech of words, and how to convey certain aspects of relational meaning. This knowledge seems roughly akin to phrase structure rules in traditional linguistic theory, though we predict that future investigations will help discriminate among more sophisticated accounts of linguistic structure. In addition, the fact that priming occurs between comprehension and production is consistent with the claim that it accesses representations corresponding to linguistic knowledge. In our view, priming data appears compatible with views of syntax that involve comparatively simple representations which are unencumbered with hidden elements or inaudible copies (e.g., Culicover & Jackendoff, 2005). But whether structural priming ultimately affects the development of linguistic theory or not probably depends on the extent to which linguists are open to non-traditional forms of data.

If structural priming is seen as informing linguistic theory, it is important to realize that its effects are not limited to adult monolinguals native speakers. Instead, it can help determine the linguistic systems of children, L2 learners, bilinguals, and people with aphasia, and indeed show how such systems may be related to each other. In addition, cross-linguistic priming is potentially informative about the extent to which constructions in different languages should be analyzed in the same way. More speculatively, it might be informative about the existence and nature of “universal grammar.”

Communicative success

Communicative success likely comes from a range of strategies that interlocutors tacitly and intentionally deploy to build shared knowledge (e.g., Clark, 1996). Structural priming is an important example of such a tacit strategy: Speakers generally are not aware that they repeat the structural features of their interlocutors’ utterances, but they do, and this likely facilitates alignment between interlocutors (Pickering & Garrod, 2004). However, little is known about the way that structural priming interacts with intentional strategies to promote communicative success. To explicate this, we anticipate studies investigating the role of structural priming in different kinds of interactive tasks, for example to see the relationship between priming and task success.

Language learning

If structural priming at least in part reflects the strengthening of the knowledge that connects meaning to syntax to form, that strengthening may play a critical role in language acquisition (both first and second language learning) as well as treatment of language disorders (both of the acquired and developmental variety). Therefore, it should prove informative about therapies for language disorders and for approaches to language learning. There is something of a mystery about the fact that people must learn lexically specific properties of words such as verb biases (e.g., Trueswell, Tanenhaus, & Kello, 1993), yet long-term priming appears to be largely abstract (Hartsuiker et al., in press). There is clearly need for further experimental work investigating long-term priming, in monologue and dialogue, in children and adults. To better understand priming and language learning, we need direct comparisons between priming during first- and second-language acquisition and priming in mature native and non-native speakers. Such studies should also help determine the relationship between the role of priming in promoting communicative successs and the role of priming in promoting learning.

Priming and language change

If structural priming reflects developments in speakers' linguistic knowledge, then an additional question concerns the relationship between structural priming and language change. Insights about language change will help us better understand the language acquisition process and to trace the historical development of languages. This is typically done by trying to better understand the features of a language that become more common (e.g., some exceptional pattern that becomes regular and productive) and the features of a language that wane or disappear (e.g., Kroch, 1989). Priming can inform the processes of change that occur intergenerationally (via acquisition) or intragenerationally (i.e., long-term changes in adults). One approach is to study priming in groups to see how communicative systems emerge and develop (Garrod & Doherty, 1994; see Barr, 2004; Galantucci, 2005; Selten & Warglien, 2007).

We close with a few suggestions regarding how research using structural priming might be carried out to best effect in the future: First, we note that the technique of structural priming offers two key benefits. One is a benefit of any sort of priming paradigm, and that is a greater level of experimental control. Priming paradigms are inherently *within-item* – they involve comparisons among observations of processing the same target event, depending on different priming experience. This is in contrast to most other behavioral techniques, which are *between-item* – they involve comparisons among observations of processing different target events. Second, similar patterns of priming occur under different experimental conditions, such as isolated picture descriptions, sentence-onset completion, memory-based production, interactive dialogue, and even in corpora of naturally occurring text.

Next, we urge caution in interpreting structural priming data. The findings clearly indicate that language processing involves at least some abstract syntactic knowledge. However, this does not mean that whenever structural priming is observed, it is always caused by abstract syntactic knowledge. We have noted that structural priming may be ubiquitous, and that possibly all levels of linguistic representation might show forms of priming. This implies that if a study aims to draw conclusions about syntactic knowledge per se, additional steps must be taken to ensure that priming reflects that syntactic rather than non-syntactic knowledge.

We believe that a key issue to consider in future investigations using structural priming is whether (open-class) content is repeated between prime and target sentences, causing what has been termed the lexical boost. This boost is generally large and has been extensively replicated, and appears central to the interaction of abstract and lexically specific information. It may be that priming with and without content repetition (or meaning repetition; Cleland & Pickering, 2003) is qualitatively similar. However, this review has identified a few possible dissociations with content repetition, including possible interactions with longevity (with content repetition causing shorter-term priming) and the conditions under which priming is observed in comprehension (which sometimes appears to require content repetition). Researchers should therefore carefully consider whether to repeat content or not.

Most importantly, we feel that it is critical that investigations *using* structural priming should not primarily be cast as investigations *about* structural priming. Sometimes, structural priming is merely a dependent variable, when patterns of priming are used to infer the operation of certain kinds of representations or processes (e.g., when priming suggests the use of phrase-structure rules, or the absence of a dominance-only level of representation). In these cases, the central issue is the representational or processing feature under investigation, and how that feature plays out in current theories of language processing. Other times, the persistence or repetition-benefit reflected by structural priming is itself of interest, for example, in investigations of alignment or implicit learning. Of course, structural priming by itself is an interesting phenomenon. But using the powerful insights that come from structural priming

investigations to better understand language knowledge and language use will provide enduring gains.

As we have shown, a great deal of recent research has used structural priming to investigate a range of issues in the psychology of language. Of course, this is not an accident: Structural priming has proved to be a strong, versatile, and resilient phenomenon. It is informative about the mechanisms that underlie language use in many different populations, and appears to facilitate both language learning and communication. We predict that it will remain a central psycholinguistic method for many years to come.

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References

Altmann GTM, Kamide Y. Incremental interpretation at verbs: Restricting the domain of subsequent reference. Cognition 1999;73:247–264. [PubMed: 10585516]

Arai M, Van Gompel RPG, Scheepers C. Priming ditransitive structures in comprehension. Cognitive Psychology 2007;54:218–250. [PubMed: 16973144]

Barr DJ. Establishing conventional communication systems: Is common knowledge necessary? Cognitive Science 2004;28:937–962.

Bates, E.; MacWhinney, B. Functionalist approaches to grammar. In: Wanner, E.; Gleitman, LR., editors. Language acquisition: The state of the art. Cambridge: Cambridge University Press; 1982. p. 173-218.

Berndt, RS. Sentence production. In: Rapp, B., editor. The handbook of cognitive neuropsychology: What deficits reveal about the human mind. New York: Psychology Press; 2001. p. 375-396.

Bernolet S, Hartsuiker RJ, Pickering MJ. Shared syntactic representations in bilinguals: Evidence for the role of word-order repetition. Journal of Experimental Psychology: Learning, Memory, and Cognition 2007;33:931–949.

Bever TG, McElree B. Empty categories access their antecedent during comprehension. Linguistic Inquiry 1988;19:35–43.

Biber, D. Variation across speech and writing. Cambridge: Cambridge University Press; 1988.

Bock JK. Syntactic persistence in language production. Cognitive Psychology 1986;18:355–387.

Bock, JK. Coordinating words and syntax in speech plans. In: Ellis, A., editor. Progress in the psychology of language. Vol. 3. London: Erlbaum; 1987. p. 337-390.

Bock K. Closed-class immanence in sentence production. Cognition 1989;31:163–186. [PubMed: 2721134]

Bock K. Structure in language: Creating form in talk. American Psychologist 1990;11:1221–1236. [PubMed: 2268091]

Bock K, Dell GS, Chang F, Onishi KH. Persistent structural priming from language comprehension to language production. Cognition 2007;104:437–458. [PubMed: 16973143]

Bock K, Griffin ZM. The persistence of structural priming: Transient activation or implicit learning? Journal of Experimental: General 2000;129:177–192.

Bock, JK.; Kroch, AS. The isolability of syntactic processing. In: Carlson, GN.; Tanenhaus, MK., editors. Linguistic structure in language processing. Dordrecht, The Netherlands: Kluwer; 1989. p. 157-196.

Bock K, Loebell H. Framing sentences. Cognition 1990;35:1–39. [PubMed: 2340711]

Bock K, Loebell H, Morey R. From conceptual roles to structural relations: Bridging the syntactic cleft. Psychological Review 1992;99:150–171. [PubMed: 1546115]

Branigan, HP.; McLean, JF.; Jones, MW. A blue cat or a cat that is blue? Evidence for abstract syntax in young children's noun phrases. In: Brugos, A.; Clark-Cotton, MR.; Ha, S., editors. The proceedings of the 29th annual Boston University conference on language development. Somerville, MA: Cascadilla Press; 2005. p. 109-121.

Branigan HP, Pickering MJ, Cleland AA. Syntactic priming in written production: Evidence for rapid decay. Psychonomic Bulletin & Review 1999;6:635–640. [PubMed: 10682206]

Branigan HP, Pickering MJ, Cleland AA. Syntactic co-ordination in dialogue. Cognition 2000a;75:B13–B25. [PubMed: 10771277]

Branigan HP, Pickering MJ, Liversedge SP, Stewart AJ, Urbach TP. Syntactic priming – Investigating the mental representation of language. Journal of Psycholinguistic Research 1995;24:489–506.

Branigan HP, Pickering MJ, McLean JF. Priming prepositional-phrase attachment during language comprehension. Journal of Experimental Psychology: Learning, Memory, and Cognition 2005;31:468–481.

Branigan HP, Pickering MJ, McLean JF, Cleland AA. Syntactic alignment and participant role in dialogue. Cognition 2007;104:163–197. [PubMed: 16876778]

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 & Cognition 2000b;28:1297–1302.

Branigan HP, Pickering MJ, Tanaka M. Contributions of animacy to grammatical function assignment and word order during production. Lingua 2008;118:172–189.

Brennan SE, Clark HH. Conceptual pacts and lexical choice in conversation. Journal of Experimental Psychology: Learning, Memory, and Cognition 1996;22:1482–1493.

Bresnan, J.; Kaplan, RM. Introduction: Grammars as mental representations of language. In: Bresnan, J., editor. The mental representation of grammatical relations. Cambridge, MA: MIT Press; 1982. p. xvii-lii.

Brooks PJ, Tomasello M. Young children learn to produce passives with nonce verbs. Developmental Psychology 1999;35:29–44. [PubMed: 9923462]

Bühler, K. Sprachtheorie. Jena, Germany: Fischer Verlag; 1934.

Cameron R, Flores-Ferrán N. Perseveration of subject expression across regional dialects of Spanish. Spanish in Context 2004;1:41–65.

Caramazza A, Hillis AE. Lexical organization of nouns and verbs in the brain. Nature 1991;349:788–790. [PubMed: 2000148]

Carey PW, Mehler J, Bever TG. Judging the veracity of ambiguous sentences. Journal of Verbal Learning and Verbal Behavior 1970;9:243–254.

Carlson K. The effects of parallelism and prosody in the processing of gapping structures. Language and Speech 2001;44:1–26. [PubMed: 11430186]

Chambers CG, Smyth R. Structural parallelism and discourse coherence: A test of centering theory. Journal of Memory and Language 1998;39:593–608.

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 K. 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;29:217–229. [PubMed: 10709186]

Chomsky, N. Aspects of the theory of syntax. Cambridge, MA: MIT Press; 1965.

Chomsky, N. Lectures on government and binding. Dordrecht, The Netherlands: Foris; 1981.

Chomsky, N. Knowledge of language: Its nature, origin, and use. New York: Praeger; 1986.

Christianson K, Hollingworth A, Halliwell JF, Ferreira F. Thematic roles assigned along the garden path linger. Cognitive Psychology 2001;42:368–407. [PubMed: 11368528]

Christianson K, Ferreira F. Conceptual accessibility and sentence production in a free word-order language (Odawa). Cognition 2005;98:105–135. [PubMed: 16307955]

Clark, E. The principle of contrast: A constraint on language acquisition. In: MacWhinney, B., editor. Mechanisms of language acquisition. Hillsdale, NJ: Erlbaum; 1987. p. 1-33.

Clark, HH. Using language. Cambridge: Cambridge University Press; 1996.

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;49:214–230.

Cleland AA, Pickering MJ. Do writing and speaking employ the same syntactic representations? Journal of Memory and Language 2006;54:185–198.

Corley M, Scheepers C. Syntactic priming in English sentence production: Categorical and latency evidence from an internet-based study. Psychonomic Bulletin & Review 2002;9:126–131. [PubMed: 12026944]

Culicover, PW.; Jackendoff, R. Simpler syntax. Oxford: Oxford University Press; 2002.

Cuetos F, Mitchell DC. Cross-linguistic differences in parsing: Restrictions on the use of the late closure strategy in Spanish. Cognition 1988;30:73–105. [PubMed: 3180704]

Cuetos, F.; Mitchell, DC.; Corley, MMB. Parsing in different languages. In: Carreiras, M.; Garca-Albea, J.; Sabastian-Galles, N., editors. Language processing in Spanish. Mahwah, NJ: Erlbaum; 1996. p. 145-187.

Desmet T, Declercq M. Cross-linguistic priming of syntactic hierarchical configuration information. Journal of Memory and Language 2006;54:610–632.

Deutsch A, Bentin S. Attention mechanisms mediate the syntactic priming effect in auditory word identification. Journal of Experimental Psychology: Learning, Memory, and Cognition 1994;34:595–607.

Dooling DJ. Rhythm and syntax in sentence perception. Journal of Verbal Learning and Verbal Behavior 1974;13:255–264.

Estes Z. Attributive and relational processes in nominal combination. Journal of Memory and Language 2003;48:299–349.

Estes Z, Jones LL. Priming via relational similarity: A copper horse is faster when seen through a glass eye. Journal of Memory and Language 2006;55:89–101.

Estival D. Syntactic priming of the passive in English. Text 1985;5:7–21.

Ferreira F, Clifton C. The independence of syntactic processing. Journal of Memory and Language 1986;25:348–368.

Ferreira VS. The persistence of optional complementizer production: Why saying ‘that’ is not saying ‘that’ at all. Journal of Memory and Language 2003;48:379–398.

Ferreira VS, Bock JK. The functions of structural priming. Language and Cognitive Processes 2006;21:1011–1029. [PubMed: 17710210]

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.

Fisher C. The role of abstract syntactic knowledge in language acquisition: A reply to Tomasello (2000). Cognition 2002;82:259–278. [PubMed: 11747864]

Fodor, JA.; Bever, TG.; Garrett, MF. The psychology of language. New York: McGraw-Hill; 1974.

Ford, M. Sentence planning units: Implications for the speaker’s representation of meaningful relations underlying sentences. In: Bresnan, J., editor. The mental representation of grammatical relations. Cambridge, MA: MIT Press; 1982. p. 797-827.

Ford M, Holmes VM. Planning units and syntax in sentence production. Cognition 1978;6:35–53.

Fox Tree JE, Meijer PJA. Building syntactic structure in speaking. Journal of Psycholinguistic Research 1999;28:71–90. [PubMed: 9949715]

Frazier, L. Sentence processing: A tutorial review. In: Coltheart, M., editor. Attention and performance XII: The psychology of reading. Hillsdale NJ: Erlbaum; 1987. p. 559-586.

Frazier L, Fodor JD. The sausage machine: A new two-stage parsing model. Cognition 1978;6:291–325.

Frazier L, Munn A, Clifton C Jr. Processing coordinate structures. Journal of Psycholinguistic Research 2000;29:343–371. [PubMed: 10953824]

Frazier L, Rayner K. Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. Cognitive Psychology 1982;14:178–210.

Frazier L, Taft L, Clifton C, Roeper T, Ehrlich K. Parallel structure: A source of facilitation in sentence comprehension. Memory & Cognition 1984;12:421–430.

Frisch S, beim Graben P, Schlesewsky M. Parallelizing grammatical functions: P600 and P345 reflect different costs of reanalysis. International Journal of Bifurcation and Chaos 2004;14:531–549.

Gagné CL. Relation and lexical priming during the interpretation of noun-noun combinations. Journal of Experimental Psychology: Learning, Memory, and Cognition 2001;27:236–254.

Gagné CL. Lexical and relational influences on the processing of novel compounds. Brain and Language 2002;81:723–735. [PubMed: 12081434]

Gagné CL, Shoben EJ. Priming relations in ambiguous noun-noun combinations. Memory & Cognition 2002;30:637–646.

Gagné CL, Spalding TL, Ji H. Re-examining evidence for the use of independent relational representations during conceptual combination. Journal of Memory and Language 2005;53:445–455.

Galantucci B. An experimental study of the emergence of human communication systems. Cognitive Science 2005;29:737–767.

Garrett, MF. The analysis of sentence production. In: Bower, GH., editor. The psychology of learning and motivation. Vol. 9. New York: Academic Press; 1975. p. 133-177.

Garrod S, Anderson A. Saying what you mean in dialogue: A study in conceptual and semantic co-ordination. Cognition 1987;27:181–218. [PubMed: 3691025]

Garrod S, Clark A. The development of dialogue co-ordination skills in schoolchildren. Language and Cognitive Processes 1993;8:101–126.

Garrod S, Doherty G. Conversation, co-ordination and convention: An empirical investigation of how groups establish linguistic conventions. Cognition 1994;53:181–215. [PubMed: 7842633]

Garrod S, Pickering MJ. Why is conversation so easy? Trends in Cognitive Sciences 2004;8:8–11. [PubMed: 14697397]

Gazdar, G.; Klein, E.; Pullum, G.; Sag, I. Generalized phrase structure grammar. Cambridge, MA: Harvard University Press; 1985.

Giles, H.; Coupland, N.; Coupland, J. Accomodation theory: Communication, context and consequences. In: Giles, H.; Coupland, J.; Coupland, N., editors. Contexts of accommodation: Developments in applied sociolinguistics. Cambridge: Cambridge University Press; 1991. p. 1-68.

Goldberg, AE. Constructions: A construction grammar approach to argument structure. Chicago: University of Chicago Press; 1995.

Gollan, TH.; Kroll, JF. The handbook of cognitive neuropsychology: What deficits reveal about the human mind/brain. Hove, England: Psychology Press; 2001. Bilingual lexical access; p. 321-345.

Gries, STh. 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;49:537–555.

Grober EH, Beardsley W, Caramazza A. Parallel function strategy in pronoun assignment. Cognition 1978;6:117–133. [PubMed: 679645]

Hare, ML.; Goldberg, AE. Structural priming: Purely syntactic?. In: Hahn, M.; Stones, SC., editors. Proceedings of the 21st Annual Meeting of the Cognitive Science Society. Mahwah, NJ: Erlbaum; 1999. p. 208-11.

Hartsuiker RJ, Bernolet S, Schoonbaert S, Speybroeck S, Vanderelst D. Syntactic priming persists while the lexical boost decays: Evidence from written and spoken dialogue. Journal of Memory and Language. in press

Hartsuiker RJ, Kolk HHJ. Syntactic facilitation in agrammatic sentence production. Brain and Language 1998a;62:221–254. [PubMed: 9576823]

Hartsuiker RJ, Kolk HHJ. Syntactic persistence in Dutch. Language and Speech 1998b;41:143–184. [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, Pickering MJ. Language integration in bilingual sentence production. Acta Psychologica. in press

Hartsuiker RJ, Pickering MJ, Veltkamp E. Is syntax separate or shared between languages? Cross-linguistic syntactic priming in Spanish-English bilinguals. Psychological Science 2004;15:409–414. [PubMed: 15147495]

Hartsuiker RJ, Westenberg C. Word order priming in written and spoken sentence production. Cognition 2000;75:B27–B39. [PubMed: 10771278]

Haywood S, Pickering MJ, Branigan HP. Do speakers avoid ambiguities during dialogue? Psychological Science 2005;16:362–366. [PubMed: 15869694]

Heydel, M.; Murray, WS. Conceptual effects in sentence priming: A crosslinguistic perspective. In: De Vincenzi, M.; Lombardo, V., editors. Cross-linguistic perspectives on language processing. Dordrecht, The Netherlands: Kluwer; 2000. p. 227-254.

Hirsh-Pasek, K.; Golinkoff, RM. The origins of grammar: Evidence from early language comprehension. Cambridge, MA: MIT Press; 1996.

Huttenlocher J, Vasilyeva M, Shimpi P. Syntactic priming in young children. Journal of Memory and Language 2004;50:182–195.

Jackendoff, RS. Semantic interpretation in generative grammar. Cambridge, MA: MIT Press; 1972.

Johnson JS, Newport EL. Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. Cognitive Psychology 1989;21:60–99. [PubMed: 2920538]

Johnson-Laird, PN. Mental Models: Toward a cognitive science of language, inference and consciousness. Cambridge, MA: Harvard University Press; 1983.

Kantola L, Van Gompel RPG. Between- and within-language priming is the same: Evidence for shared bilingual syntactic representations. 2008Unpublished manuscript

Kaschak MP. What this construction needs is generalized. Memory & Cognition 2006;34:368–379.

Kaschak MP. Long-term structural priming affects subsequent patterns of language production. Memory & Cognition 2007;35:925–937.

Kaschak MP, Borregine KL. Is long-term structural priming affected by patterns of experience with individual verbs? Journal of Memory and Language. in press

Kaschak MP, Glenberg AM. This construction needs learned. Journal of Experimental Psychology: General 2004;133:450–467. [PubMed: 15355149]

Kaschak MP, Loney RA, Borregine KL. Recent experience affects the strength of structural priming. Cognition 2006;99:B73–B82. [PubMed: 16115618]

Kempen, G. Conceptualizing and formulating in sentence production. In: Rosenberg, S., editor. Sentence production: Developments in research and theory. Hillsdale, NJ: Erlbaum; 1977. p. 259-274.

Kroch A. Reflexes of grammar in patterns of language change. Language Variation and Change 1989;1:199–244.

Lambrecht, K. Information structure and sentence form. Cambridge: Cambridge University Press; 1994.

Lashley, KS. The problem of serial order in behavior. In: Jeffress, LA., editor. Cerebral mechanisms in behavior. New York: Wiley; 1951. p. 112-136.

Ledoux K, Traxler MJ, Swaab TY. Syntactic priming in comprehension: Evidence from event-related potentials. Psychological Science 2007;18:135–143. [PubMed: 17425534]

Leech R, Mareschal D, Cooper RP. Analogy as relational priming: A developmental and computational perspective on the origins of a complex cognitive skill. Behavioral and Brain Sciences. in press

Levelt, WJM. Speaking: From intention to articulation. Cambridge, MA: MIT Press; 1989.

Levelt WJM, Kelter S. Surface form and memory in question answering. Cognitive Psychology 1982;14:78–106.

Levelt WJM, Roelofs A, Meyer AS. A theory of lexical access in speech production. Behavioral and Brain Sciences 1999;22:1–75. [PubMed: 11301520]

Loebell H, Bock K. Structural priming across languages. Linguistics 2003;41:791–824.

Luka BJ, Barsalou LW. Structural facilitation: Mere exposure effects for grammatical acceptability as evidence for syntactic priming in comprehension. Journal of Memory and Language 2005;52:436–459.

McClelland JL, St John M, Taraban R. Sentence comprehension: A parallel distributed processing approach. Language and Cognitive Processes 1989;4:287–335.

MacDonald MC, Pearlmutter NJ, Seidenberg MS. The lexical nature of syntactic ambiguity resolution. Psychological Review 1994;101:676–703. [PubMed: 7984711]

McDonough K. Interaction and syntactic priming: English L2 speakers' production of dative constructions. Studies in Second Language Acquisition 2006;28:179–207.

McNamara, TP. Semantic priming: Perspectives from memory and word recognition. Hove, England: Psychology Press; 2005.

Meeuwissen M, Roelofs A, Levelt WJM. Naming analog clocks conceptually facilitates naming digital clocks. Brain and Language 2004;90:434–440. [PubMed: 15172559]

Mehler J, Carey P. Role of surface and base structure in the perception of sentences. Journal of Verbal Learning and Verbal Behavior 1967;6:335–338.

Mehler J, Carey P. The interaction of veracity and syntax in the processing of sentences. Perception & Psychophysics 1968;3:109–111.

Meijer PJA, Fox Tree JE. Building syntactic structures in speaking: A bilingual exploration. Experimental Psychology 2003;50:184–195. [PubMed: 12874987]

Melinger A, Dobel C. Lexically-driven syntactic priming. Cognition 2005;98:B11–B20. [PubMed: 15925357]

Meyer DE, Schvaneveldt RW. Facilitation in recognising pairs of words: Evidence of a dependence between retrieval operations. Journal of Experimental Psychology 1971;90:227–234. [PubMed: 5134329]

Miller GA, Isard SD. Some perceptual consequences of linguistic rules. Journal of Verbal Learning and Verbal Behavior 1963;2:217–228.

Myers-Scotton, C. Duelling languages: Grammatical structure in codeswitching. Vol. 2. Oxford: Clarendon Press; 1997.

Naigles LR. Children use syntax to learn verb meanings. Journal of Child Language 1990;17:357–374. [PubMed: 2380274]

Noppeney U, Price CJ. An fMRI study of syntactic adaptation. Journal of Cognitive Neuroscience 2004;16:702–713. [PubMed: 15165357]

Novick J, Kim AE, Trueswell J. Studying the grammatical aspects of word recognition: Lexical priming, parsing and syntactic ambiguity resolution. Journal of Psycholinguistic Research 2003;32:57–75. [PubMed: 12647563]

Pardo JS. On phonetic convergence during conversational interaction. Journal of the Acoustical Society of America 2006;119:2382–2393. [PubMed: 16642851]

Pickering M, Barry GD. Sentence processing without empty categories. Language and Cognitive Processes 1991;6:229–259.

Pickering MJ, Branigan HP. The representation of verbs: Evidence from syntactic priming in language production. Journal of Memory and Language 1998;39:633–651.

Pickering MJ, Branigan HP. Syntactic priming in language production. Trends in Cognitive Sciences 1999;3:136–141. [PubMed: 10322467]

Pickering MJ, Branigan HP, McLean JF. Constituent structure is formulated in one stage. Journal of Memory and Language 2002;46:586–605.

Pickering MJ, Garrod S. Toward a mechanistic psychology of dialogue. Behavioral and Brain Sciences 2004;27:169–225. [PubMed: 15595235]

Pickering MJ, Garrod S. Do people use language production to make predictions during comprehension? Trends in Cognitive Sciences 2007;11:105–110. [PubMed: 17254833]

Pickering MJ, McLean JF, Branigan HP, Cheung YT, Peacock AK. Do bilinguals inhibit the syntax of the non-target language?. 2007Unpublished manuscript

Pickering MJ, Traxler MJ. Grammatical repetition and garden-path effects: Syntactic priming in on-line sentence comprehension. 2008Unpublished manuscript

Pickering, MJ.; Van Gompel, RPG. Sentence processing. In: Gernsbacher, MA.; Traxler, MJ., editors. Handbook of psycholinguistics. San Diego: Academic Press; 2006. p. 455-503.

Pollard, C.; Sag, IA. Head-driven phrase structure grammar. Chicago: University of Chicago Press; 1994.

Potter MC, Lombardi L. Syntactic priming in immediate recall of sentences. Journal of Memory and Language 1998;38:265–282.

Raffray CN, Pickering MJ, Branigan HP. Priming the interpretation of noun-noun combinations. Journal of Memory and Language 2007;57:380–395.

Rawson KA. Exploring automaticity in text processing: Syntactic ambiguity as a test case. Cognitive Psychology 2004;49:3330369.

Roelofs A. A spreading-activation theory of lemma retrieval in speaking. Cognition 1992;42:107–142. [PubMed: 1582154]

Roelofs A. Testing a non-decompositional theory of lemma retrieval in speaking: Retrieval of verbs. Cognition 1993;47:59–87. [PubMed: 8482071]

Roelofs A, Meyer AS. Metrical structure in planning the production of spoken words. Journal of Experimental Psychology: Learning, Memory, and Cognition 1998;24:922–938.

Saffran EM, Martin N. Effects of structural priming on sentence production in aphasics. Language and Cognitive Processes 1997;12:877–882.

Salamoura A, Williams JN. Lexical activation of cross-language syntactic priming. Bilingualism: Language and Cognition 2006;9:299–307.

Salamoura A, Williams JN. Processing verb argument structure across languages: Evidence for shared representations in the bilingual lexicon. Applied Psycholinguistics 2007;28:627–660.

Savage C, Lieven E, Theakston A, Tomasello M. Testing the abstractness of children's linguistic representations: Lexical and structural priming of syntactic constructions in young children. Developmental Science 2003;6:557–567. [PubMed: 18259588]

Savage C, Lieven E, Theakston A, Tomasello M. Structural priming as implicit learning in language acquisition: The persistence of lexical and structural priming in 4-year-olds. Language Learning and Development 2006;2:27–50.

Scheepers C. Syntactic priming of relative clause attachments: Persistence of structural configuration in sentence production. Cognition 2003;89:179–205. [PubMed: 12963261]

Scheepers, C.; Crocker, MW. Constituent order priming from listening to comprehension: A visual-world study. In: Carreiras, M.; Clifton, C., Jr, editors. The online study of sentence comprehension: Eyetracking, ERPs, and beyond. New York: Psychology Press; 2004. p. 167-185.

Scherre MMP, Naro A. Marking in discourse: 'Birds of a feather'. Language Variation and Change 1991;3:23–32.

Schober MF. Spatial perspective-taking in conversation. Cognition 1993;47:1–24. [PubMed: 8482069]

Schenkein, J. A taxonomy for repeating action sequences in natural conversation. In: Butterworth, B., editor. Language production. Vol. 1. London: Academic Press; 1980. p. 21-47.

Schoonbaert S, Hartsuiker RJ, Pickering MJ. The representation of lexical and syntactic information in bilinguals: Evidence from syntactic priming. Journal of Memory and Language 2007;56:153–171.

Schütze, C. The empirical base of linguistics: Grammaticality judgments and linguistic methodology. Chicago: University of Chicago Press; 1996.

Selten R, Warglien M. The emergence of simple languages in an experimental communication game. Proceedings of the National Academy of Sciences 2007;104:7361–7366.

Sevald CA, Dell GS. The sequential cuing effect in speech production. Cognition 1994;53:91–127. [PubMed: 7805353]

Sevald CA, Dell GS, Cole JS. Syllable structure in speech production: Are syllables chunks or schemas? Journal of Memory and Language 1995;34:807–820.

Sheldon A. The role of parallel function in the acquisition of relative clauses in English. Journal of Verbal Learning and Verbal Behavior 1974;13:272–281.

Shimpi PM, Gámez PB, Huttenlocher J, Vasilyeva M. Syntactic priming in 3- and 4-year-old children: Evidence for abstract representations of transitive and dative forms. Developmental Psychology 2007;43:1334–1346. [PubMed: 18020815]

Smith M, Wheeldon L. Syntactic priming in spoken sentence production: An online study. Cognition 2001;78:123–164. [PubMed: 11074248]

Smyth R. Grammatical determinants of ambiguous pronoun resolution. Journal of Psycholinguistic Research 1994;23:197–229.

Snyder W. An experimental investigation of syntactic satiation effects. Linguistic Inquiry 2000;31:575–582.

Steedman, MJ. The syntactic process. Cambridge, MA: MIT Press; 2000.

Stevenson RJ, Nelson AWR, Stenning K. The role of parallelism in strategies of pronoun comprehension. Language and Speech 1995;38:393–418.

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.

Szmrecsanyi, B. Morphosyntactic persistence in spoken English: A corpus study at the intersection of variationist sociolinguistics, psycholinguistics, and discourse analysis. Berlin/New York: Mouton de Gruyter; 2006.

Tanenhaus MK, Spivey-Knowlton MJ, Eberhard KM, Sedivy JC. Integration of visual and linguistic information in spoken language comprehension. Science 1995;268:1632–1634. [PubMed: 7777863]

Tannen D. Repetition in conversation: Toward a poetics of talk. Language 1987;63:574–605.

Tannen, D. Talking voices: Repetition, dialogue and imagery in conversational discourse. Cambridge: Cambridge University Press; 1989.

Thothathiri M, Snedeker J. Give and Take: Syntactic priming during spoken language comprehension. Cognition. in press-a

Thothathiri M, Snedeker J. Syntactic priming during language comprehension in three- and four-year-old children. Journal of Memory and Language. in press-b

Tomasello M. Do young children have adult syntactic competence? Cognition 2000;74:209–253. [PubMed: 10640571]

Travis C. Genre effects on subject expression in Spanish: Priming in narrative and conversation. Language Variation and Change 2007;19:101–135.

Traxler MJ. Lexically independent priming in online sentence comprehension. Psychonomic Bulletin & Review 2008;15:149–155. [PubMed: 18605495]

Traxler MJ. Structural priming among prepositional phrases: Evidence from eye-movements. Memory & Cognition. in press

Traxler MJ, Tooley KM. Lexical mediation and context effects in sentence processing. Brain Research 2007;1146:59–74. [PubMed: 17112486]

Traxler MJ, Tooley KM. Priming in on-line sentence comprehension: Strategic or syntactic? Language and Cognitive Processes. in press

Traxler MJ, McElree B, Williams RS, Pickering MJ. Context effects in coercion: Evidence from eye movements. Journal of Memory and Language 2005;53:1–25.

Trueswell JC, Kim AE. How to prune a garden path by nipping it in the bud: Fast priming of verb argument structure. Journal of Memory and Language 1998;39:102–123.

Trueswell JC, Tanenhaus MK, Garnsey SM. Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. Journal of Memory and Language 1994;33:285–318.

Trueswell JC, Tanenhaus MK, Kello C. Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. Journal of Experimental Psychology: Learning, Memory, and Cognition 1993;19:528–553.

Ullman T. The neural basis of lexicon and grammar in first and second language: the declarative/procedural model. Bilingualism: Language and Cognition 2001;4:105–122.

van Dijk, TA.; Kintsch, W. Strategies in discourse comprehension. New York: Academic Press; 1983.

van Gompel RPG, Pickering MJ, Pearson J, Jacob G. The activation of inappropriate analyses in garden-path sentences: Evidence from structural priming. Journal of Memory and Language 2006;55:335–362.

Vasilyeva M, Huttenlocher J, Waterfall H. Effects of language intervention on syntactic skill levels in preschoolers. Developmental Psychology 2006;42:164–174. [PubMed: 16420126]

Watson, M.; Pickering, MJ.; Branigan, HP. Proceedings of the 26th Annual Conference of the Cognitive Science Society. Mahwah, NJ: Erlbaum; 2004. Alignment of reference frames in dialogue.

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;18:431–442.

Whitehurst GJ, Ironsmith M, Goldfein M. Selective imitation of the passive construction through modeling. Journal of Experimental Child Psychology 1974;17:288–302.

Wicha NYY, Orozco-Figueroa A, Reyes I, Hernandez A, de Barreto LG, Bates EA. When zebras become painted donkeys: Grammatical gender and semantic priming interact during picture integration in a spoken Spanish sentence. Language and Cognitive Processes 2005;20:553–587.

Wisniewski EJ, Love BC. Relations versus properties in conceptual combination. Journal of Memory and Language 1998;38:177–202.

Wright B, Garrett M. Lexical decisions in sentences: Effects of syntactic structure. Memory & Cognition 1984;12:31–45.

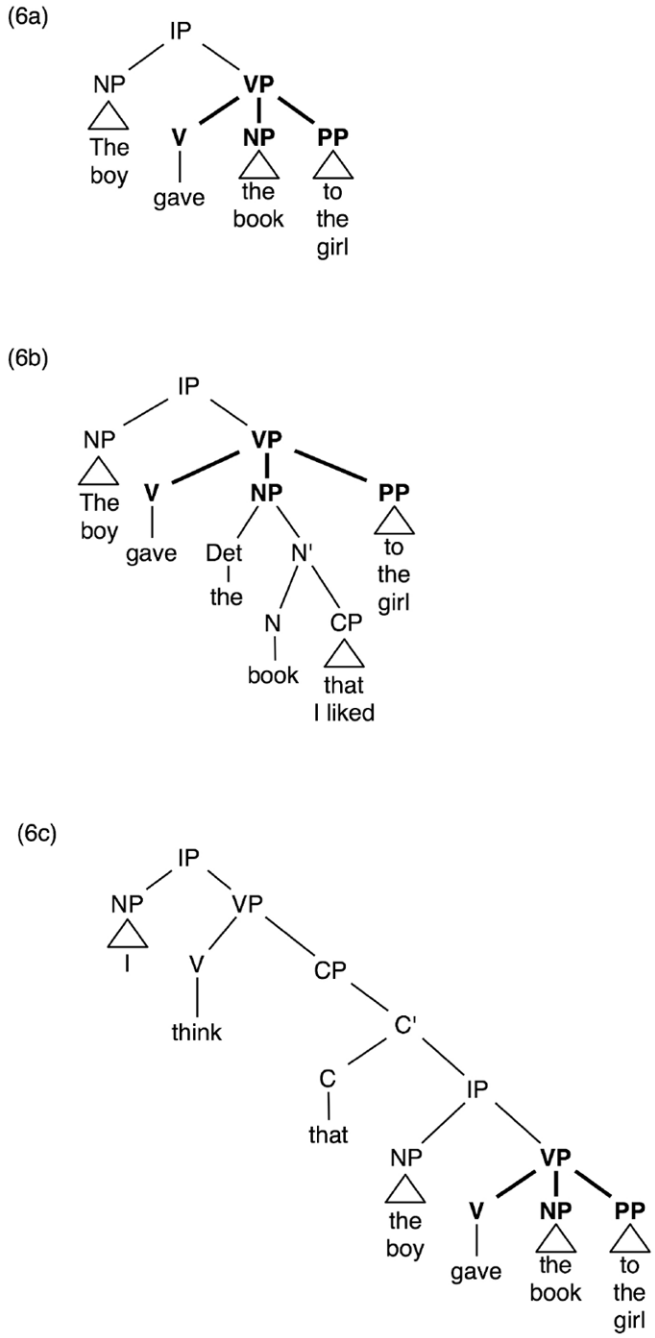

Figure 1.
Phrase structure trees for (6a) a simple prepositional-object structure, (6b) a prepositional-object structure with modified object argument, and (6c) a prepositional-object structure in an embedded clause.

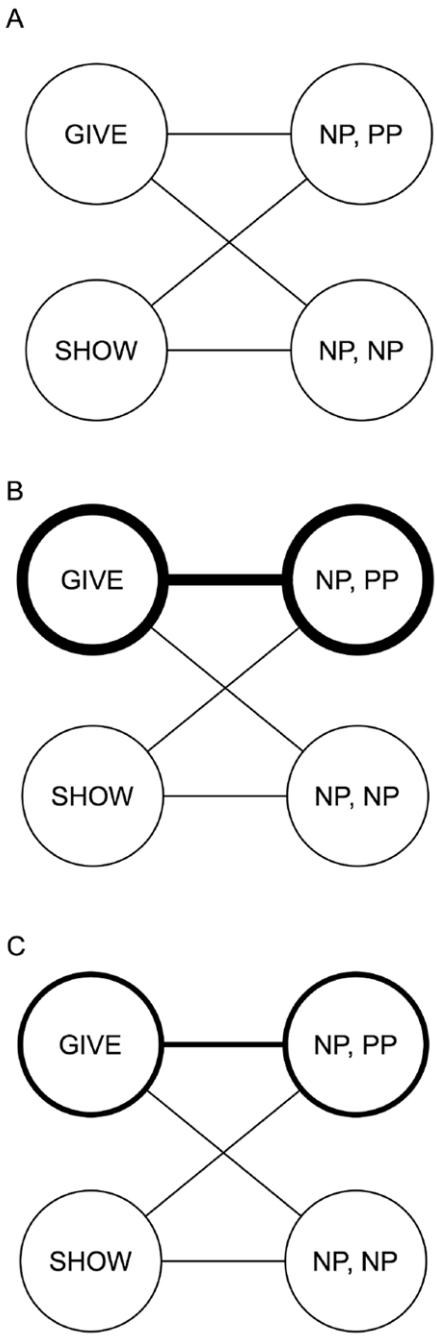

Figure 2.
Model of structural priming as proposed by Pickering and Branigan (1998), illustrating priming from a prepositional dative sentence with the main verb *give*. "GIVE" and "SHOW" nodes represent lexical items, and "NP, PP" and "NP, NP" nodes are combinatorial representations. Thickness of the lines represent the degree of activation of the corresponding knowledge. Panel A: Before priming. Panel B: As the prime is produced. Panel C: After the prime is produced.