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An experimental approach to linguistic representation

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Running head: An experimental approach to linguistic representation

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Abstract (short)

We argue that structural priming, or the tendency for people to repeat structural choices, provides an implicit method for investigating linguistic representations that should end the current reliance on acceptability judgments. Priming evidence supports a linguistic architecture involving a single ‘shallow’ level of syntax that is connected to a semantic level containing information about quantification, thematic relations, and information structure, as well as a phonological level. Many linguistic distinctions often used to support complex syntactic structure are instead captured by semantics; however, the syntactic level specifies some ‘missing’ elements. Structural priming further provides evidence about representational consistency across languages and language development.

Abstract (long)

Within the cognitive sciences, most researchers assume that it is the job of linguists to investigate how language is represented, and that they do so largely by building theories based on explicit judgments about patterns of acceptability – whereas it is the task of psychologists to determine how language is processed, and that in doing so, they do not typically question the linguists’ representational assumptions. We challenge this division of labor, by arguing that structural priming provides an implicit method of investigating linguistic representations that should end the current reliance on acceptability judgments. Moreover, structural priming has now reached sufficient methodological maturity to provide substantial evidence about such representations. We argue that evidence from speakers’ tendency to repeat their own and others’ structural choices supports a linguistic architecture involving a single ‘shallow’ level of syntax that is connected to a semantic level containing information about quantification, thematic relations, and information structure, as well as to a phonological level. Many of the linguistic distinctions that are often used to support complex (or multi-level) syntactic structure are instead captured by semantics; however, the syntactic level includes some specification of ‘missing’ elements that are not realized at the phonological level. We also show that structural priming provides evidence about the consistency of representations across languages and about language development. In sum, we propose that structural priming provides a new basis for understanding the nature of language.

Keywords: language production; linguistics; mental representation; psycholinguistics; semantics; structural priming; syntax

The cognitive science of language is concerned both with linguistic representations and with how those representations are used in processing. All researchers, whether nominally psychologists or linguists, should seek to address both questions. But in practice linguists have largely focused on representation and used a single method, acceptability judgments, to investigate it; whereas psychologists have not investigated representation but instead imported linguistic theories into their accounts. In this paper, we argue instead that researchers need not, and should not, be restricted to acceptability judgments when investigating linguistic representation.

This proposal is not new, but was previously just a theoretical possibility. But it now appears that structural priming – the tendency to repeat linguistic structure across utterances – allows researchers to investigate linguistic representations in a way that has many advantages over acceptability judgments. Most importantly, it has now reached maturity, in that there are hundreds of studies using this method and many of them are informative, not merely about language processing, but about linguistic representations themselves. In fact, we argue that evidence from structural priming supports quite specific proposals about linguistic structure (relating to syntax and semantics), so that it can be used to develop linguistic theory and discriminate among competing accounts. Thus the dominance of acceptability judgments can be ended, and the understanding of linguistic representation can develop to a greater extent than before.

This paper describes our theoretical claims, linguistic account, and applications. In Section 1, we motivate the use of structural priming to investigate mental representation and present the advantages of structural priming over acceptability judgments. In Section 2, we consider what the extensive evidence using this method tells us about linguistic representation. Section 3 discusses the implications of our account.

1. Why a psychological account of linguistic structure is now possible

A complete theory of human language requires characterization of both people's linguistic representations and the processes that operate over those representations. Thus issues of representation and processing are in principle of interest to both linguists and psychologists, albeit from different perspectives. In practice, however, linguistic representation (in particular with respect to syntactic and semantic structure) has for the last four decades largely been the domain of linguists and has primarily been studied using a single approach in which linguists or their informants make explicit metalinguistic judgments about the grammatical (or semantic) acceptability of individual sentences – henceforth, *acceptability judgments*. Such judgments constitute the dataset upon which theories of linguistic representation are based.

In this paper, we propose that the representations underlying language use need not be, and in fact should not be, investigated only via such judgments. Rather, we suggest that they can be examined directly through a behavioral measure that has been used widely in psychological research to investigate the representation of a range of types of information. This method is priming: If processing one stimulus affects the subsequent processing of another stimulus, then these stimuli share some aspect of their representation. Hence, *structural priming* effects, where processing one utterance affects the processing of another utterance that shares an aspect of linguistic structure but is otherwise unrelated, provide evidence about linguistic representation. In the classic demonstration, Bock (1986) had participants repeat active or passive sentences and then describe pictures depicting transitive events, and found that they were more likely to use a passive *target* sentence (e.g., *the church is being struck by lightning*) after repeating a passive *prime* sentence (*the referee was punched by one of the fans*) than after repeating an active (*one of the fans punched the referee*). As subsequent

studies have demonstrated, these effects appear to arise from repetition of aspects of abstract linguistic structure and occur largely outside of awareness (Pickering & Ferreira, 2008).

They cannot be explained in terms of repetition of particular words. Bock (1989) showed that participants tended to use ‘prepositional object’ (PO) dative sentences (*The girl is handing a paintbrush to the man*) rather than ‘double object’ (DO) sentences (*The girl is handing the man a paintbrush*) after a dative sentence that did not include *to* (*The secretary baked the cake for her boss*). Hence priming could not be due to word repetition (because the PO and DO target sentences share all words except *to*).

We can also rule out explanations couched entirely in terms of meaning. First, the alternative responses (e.g., PO and DO, or active and passive) denote the same events, in that they can both be used to describe the same picture. Second, Messenger et al. (2012) found priming between sentences describing different event types (e.g., Experiencer-Theme: *The king is being ignored by the bear*, and Agent-Patient: *The doctor gets licked by the cow*).

Additionally, Hartsuiker and Westenberg (2000) found that Dutch participants repeated the order of auxiliary and main verb (*was geblokkeerd*; ‘was blocked’ vs. *geblokkeerd was*; ‘blocked was’), even though they do not differ in meaning. Moreover, the effects cannot be explained by repetition of metrical structure, as *The girl is handing a paintbrush to the man* was not primed by *Susan brought a book to study*, though it was primed by the metrically equivalent *Susan brought a book to Stella* (Bock and Loebell 1990). Overall, these results are consistent with priming of representations that are specified for syntactic information but not semantic, lexical, or phonological information. This conclusion is supported by studies showing priming of many other syntactic constructions, such as noun-phrase structure (Cleland and Pickering 2003) and verb-particle placement (Konopka and Bock 2009).

However, priming is also informative about other aspects of linguistic structure, including many components of semantics including thematic roles, quantification, and information structure. It occurs in diverse languages (e.g., English, Mandarin, Basque) and between languages, and in children, non-native speakers, amnesiacs and aphasics, and has been found using many experimental methods as well as in natural conversation (see Pickering and Ferreira 2008).

It also occurs in comprehension, as indicated by choice of structure (e.g., Branigan, Pickering, and McLean 2005), reading time (e.g., Traxler, Tooley, and Pickering 2014), predictive eye movements (Arai, van Gompel, and Scheepers 2007; Thothathiri and Snedeker 2008a), event-related potentials (ERPs; Ledoux, Traxler, and Swaab 2007), and brain activity revealed by fMRI (Segaert et al. 2012). Priming of comprehension usually involves participants selecting between analyses that have different meanings (e.g., high- or low-attached prepositional phrases [PPs]; Branigan, Pickering, and McLean 2005), though experiments investigating predictions in ‘visual world’ paradigms and those using fMRI are exceptions. When both meaning and syntax differ across conditions, it becomes much harder to relate any priming effects to linguistic representation.

Importantly, structural priming occurs from comprehension to production (Branigan, Pickering, and Cleland 2000; Potter and Lombardi 1998) to a similar extent as within production (Bock et al. 2007; Tooley and Bock 2014), and it occurs from production to comprehension to a similar extent as within comprehension (Branigan, Pickering, and McLean 2005). Moreover, studies of priming effects within comprehension, within production, and between production and comprehension implicate common neural architectures (Menenti et al. 2011; Segaert et al. 2012; Segaert et al. 2013). These findings are particularly important for justifying the relevance of priming to representation. We

therefore believe we can use structural priming effects to develop a psychologically motivated theory of syntactic representation and the way in which it relates to semantic representation. But before sketching this account in Section 2, we need to justify why such an account is possible in principle.

1.1 The reality of linguistic representation

The nature of linguistic representation is of fundamental interest for experimental psychologists who are concerned with language, because people must represent linguistic structure in order to use language. Psychological theories of language must therefore specify the representations that speakers and hearers use, as well as the processes that operate over those representations, in the same way that theories of visual cognition specify the representations that perceivers construct as they interpret scenes (Biederman 1987).

Understanding the nature of linguistic representation has also been the central goal of most theoretical linguistics, at least since the publication of *Syntactic Structures* (Chomsky 1957). Linguists have attempted to provide grammars for natural languages (i.e., precise descriptions of the relationships that may hold between linguistic expressions). Some linguists view such grammars as characterizations of essentially ‘platonic’ objects that have nothing to do with the human mind (e.g., Katz 1981; see also Langendoen and Postal 1984). Any such ‘platonic’ linguistics is not our concern. But for most linguists, grammars are envisaged as the knowledge that underlies speakers’/hearers’ use of language: “...linguistics is that branch of psychology that focuses its attention on one specific cognitive domain and one faculty of mind, the language faculty” (Chomsky 1980, 4), and its primary aim is to construct a grammar that is psychologically real, in the sense that “...the grammar corresponds to the speaker’s internal representation of that domain” (Bresnan and Kaplan 1982, xxiii). Our concern is the nature of this internal representation.

But among linguists there are different views on the relationship between this representation and language processing (see Lewis and Phillips 2015). One possibility is that the grammar is drawn upon directly during processing. This is clearly the simplest approach, requiring the fewest additional assumptions. Under this approach, evidence about the representations that are involved in language processing is clearly relevant to linguistic theory – ‘linguistic’ and ‘psycholinguistic’ representations would be the same. (Any discrepancies between evidence from processing and acceptability judgments would be due to factors such as processing limitations that are explicable in terms of generally accepted cognitive assumptions; Lewis and Phillips 2015.)

Other linguists assume that the grammar is not used directly in processing, in other words that the grammar and the language processing system form two distinct systems. For these researchers, processing is assumed to involve linguistic representations, but the nature of those representations need not constrain their theories. The kinds of theory that might involve two systems of this kind might include theories that specify a form of ‘universal grammar’ that is available early in development and inputs into the grammars of specific languages but does not continue to be represented later in development (e.g., Clahsen and Muysken 1986), or theories in which underlying representations are compiled into different representations that are used during processing ‘on-line’ (e.g., Berwick and Weinberg 1984; Fodor 1983). Moreover, linguistically motivated theories tend to seek to describe the language using as parsimonious a representational system as possible (e.g., Chomsky 1995), an approach that will not necessarily be compatible with the representations used in language processing (e.g., Croft 2001; Jackendoff 2002).

But in all such cases, the representations that are used by the processor remain an object of enquiry that critically pertains to the speaker’s internal representation of the linguistic domain

(and any theory that assumes two systems of representation must explain how the two systems are related). Our goal is to consider alternative (experimental) methods to acceptability judgments that potentially address the linguistic representations that are implicated in language processing. Evidence from such methods cannot disprove the existence of other representations. But a theory that does not assume inaccessible representations is more parsimonious than one that does, and if the two representational systems are assumed only because of apparent incompatibility between acceptability judgment and processing data, then it is preferable to assume a single representation, and that different methods tap into the same representation in slightly different ways (see Lewis and Phillips 2015).

We therefore assume – in the absence of compelling evidence to the contrary – that there is a single representational system for language structure, which is implicated during language processing, and that people do not have other (inaccessible) mental representations of language structure. If any such representations were to exist, they would clearly be of interest. But they do not form part of our account, and it is for theories that propose such representations to motivate them and to specify the mapping between them and those used in processing.

To characterize the knowledge that speakers and hearers draw on, researchers from both experimental psychological and theoretical linguistic backgrounds might in principle use evidence from many different sources, including judgments of grammaticality and meaning, and evidence from language acquisition and ‘perceptual experiments’ (Chomsky 1965, 37). However, Chomsky is unconvinced by the use of processing evidence to investigate linguistic representation. In an important footnote, he says that “One common fallacy is to assume that if some experimental result provides counter-evidence to a theory of processing that includes

a grammatical theory T and parsing procedure P..., then it is T that is challenged and must be changed. The conclusion is particularly unreasonable in the light of the fact that in general there is independent (so-called ‘linguistic’) evidence in support of T while there is no reason at all to believe that P is true” (Chomsky 1981, 283, footnote 39.) This provides a justification for ignoring experimental data. And in practice, most linguists have adopted this approach. They have therefore tended to base their theories (particularly of syntax) primarily on evidence from acceptability judgments, and in particular have tended to ignore psychological data suggesting that people process sentences using representations that differ from those proposed by linguists (see Fodor, Bever, and Garrett 1974; Wasow and Arnold 2005).

1.2 Why acceptability judgments are not enough

Acceptability judgments involve native speakers of a language deciding whether sentences are acceptable or unacceptable. Traditionally, linguists who investigate whether sentences are grammatical or not usually refer to them as grammaticality judgments: Sentences judged grammatical should be licensed by the grammar; sentences that are judged ungrammatical should not be licensed by the grammar. Acceptability judgments are a convenient source of data, since all that is required is a native speaker. They can provide evidence about the set of possible sentences that comprise a language, and are also assumed to give evidence concerning the structure of speakers’ internalized knowledge of language (e.g., Chomsky 1986). Acceptability judgments have historically provided a fertile source of evidence for hypotheses about the nature of linguistic representation. But they pose many concerns.

Some are surmountable, and relate to how they have typically been used (e.g., Gibson and Fedorenko 2013). For example, linguists standardly ask a single informant about the acceptability of a few sentences. But it is possible to conduct acceptability judgments as a

well-controlled psycholinguistic experiment, using many (varied) sentences, using naïve participants, controlling for plausibility, and randomizing presentation order. It is also possible to control for effects of previous exposure or judgments (sentences appearing more or less acceptable when the construction is repeated; e.g., Levelt 1972; Luka and Barsalou 2005; Snyder 2000) – a phenomenon which is presumably related to structural priming.

Next, acceptability judgments face the problems associated with any explicit task. The informant's judgments may reflect decision-making biases. This concern is exacerbated when the informant is the researcher, or has knowledge of the theoretical questions under investigation. Moreover, the informant may not interpret terms such as *grammatical* or *acceptable* as the linguist intends. To all of these concerns, linguists may respond that traditional methods are adequate as they have not led to many errors (e.g., Sprouse, Schütze, and Almeida 2013) and because native-speaker linguists can immediately detect erroneous judgments that are used in theory-building (e.g., Phillips 2009), but controversy remains.

But acceptability judgments face more fundamental problems. Most obviously, they can only be used to study linguistic representations in certain populations, as they can only be elicited from speakers who are capable of making metalinguistic judgments. For example, they cannot be used with children younger than three (nor indeed with many three-year-olds; Ambridge and Rowland 2013; McDaniel and Smith Cairns 1998). Hence, acceptability judgments cannot be used to address some fundamental representational questions.

Another far-reaching problem is *source ambiguity* (Hofmeister et al. 2013). There is no reason to believe that acceptability judgments offer privileged access to linguistic representation in a way that other methods do not. Acceptability judgments are the results of linguistic and cognitive processes, by which people attempt to process sentences and then make metalinguistic judgments on the results of those acts of processing (e.g., someone

cannot understand a sentence or finds it jarring, therefore assumes it is unacceptable). Thus they implicate the same linguistic representations that are involved in all acts of processing. It is therefore not possible to tell whether any judgment of unacceptability reflects ungrammaticality, low probability, or unprocessability. For example, Bresnan (2007) found that acceptability judgments for sentences were affected by those sentences' probability of occurrence. Equally, people often judge center-embedded sentences (e.g., *the rat that the cat that the dog bit chased fled*) as unacceptable, yet most theorists follow Chomsky (1965) in assuming they are grammatical and that people's judgments reflect processing difficulty. Similarly, garden-path sentences (e.g., *the horse raced past the barn fell*) are often judged unacceptable, yet most theorists assume that this is because people initially misanalyze them and fail to recover (Bever, 1970). In these cases, linguists might argue that there are clear explanations for why they are judged unacceptable (complexity, confusability, ambiguity).

But in other cases, the explanation for why a sentence is unacceptable is more contentious, for example whether the unacceptability of *What did who visit?* reflects a syntactic violation (Chomsky 1995) or processing difficulty (Hofmeister et al. 2013). Conversely, linguists sometimes argue that acceptable sentences are not grammatical (e.g., *It was I*; Sobin 1997). In this respect, acceptability judgments are susceptible to the same challenges as processing data: The data are compatible with particular grammar-processor pairings, not just with particular grammars. An explanation of which sentences are acceptable and which are not therefore seems to require a theory of processing alongside a theory of grammaticality.

A more fundamental problem is that even if it could somehow be determined that a particular set of acceptability judgments indexed grammaticality, such judgments directly determine only set membership. That is, they determine weak generative capacity: which sentences are members of the set of sentences licensed by a grammar, and which sentences are not.¹

However, they cannot by themselves determine linguistic structure. To draw inferences about linguistic structure, they need to be combined with tests about constituency.

But as widely acknowledged, constituency structure tests are inconsistent and problematic in many ways. Textbooks introducing such tests standardly warn that they produce contradictory results. To give some examples: Coordination tests support the existence of constituents (e.g., an NP-NP constituent in *The woman gave the child a cake and the dog a bone*) that other tests such as topicalization and *it*-cleft do not (and in this case most linguistic theories ignore the coordination test). Ellipsis and question-short answer tests may support constituents (e.g., *baked a cake* in *I said he baked a cake and in fact he did so/What did he do? Baked a cake*) when topicalization and *it*-cleft tests do not (**I said he baked a cake and baked a cake he/*It is baked a cake that he*). Ellipsis tests yield obviously problematic results (e.g., *China is a country Tom wants to visit, and he will if he gets the money* suggests that *China...visit* is a constituent; Kempson, Meyer-Viol, and Gabbay 1999). These are not unusual or isolated examples, and even the most basic assumptions about constituency (e.g., the structure of simple transitive sentences) show different results for different tests. Moreover, the basic rationale for why these specific tests should tap constituent structure remains unclear (Berg 2009). In fact, it has been proposed that they are more appropriately considered as structural heuristics rather than structural diagnostics (Payne 2006).

Most importantly, the use of acceptability judgments, with or without the application of constituency tests, has yielded no consensus at all about linguistic representation. For example, theories associated with the transformational tradition (i.e., following accounts such as Chomsky 1981; Chomsky 1995) assume syntactic representations of considerable complexity, including many more branching nodes than words, a large number of empty categories, and extensive movement of constituents. Such representations can be interpreted

as involving many syntactic levels (if movement is interpreted as taking place in stages) and associations between the syntactic representations and other representations such as LF and PF, which themselves input into meaning and sound. These theories also make broad assumptions such as binary branching. In contrast, theories such as Head-Driven Phrase Structure Grammar (HPSG; Pollard and Sag 1994) make very different assumptions, with simpler, flatter trees, and few if any empty categories. Some theories assume grammatical functions play a central role (e.g., Lexical-Functional Grammar [LFG]; Kaplan and Bresnan 1982), whereas others do not. Other theories assign a key role to ‘constructions’ (e.g., Goldberg 1995) or allow overlapping constituents (e.g., Steedman, 2000). Additionally there is little agreement about whether there is a clear distinction between syntactic and lexical information, or whether most syntactic information is stored alongside lexical items. Acceptability judgments have not been able to adjudicate between these alternatives, except insofar as one set of rules or constraints that can generate the same set of sentences is “better” by some metric such as parsimony or learnability (and even on these grounds, there is disagreement).

In sum, acceptability judgments have been more successful in inspiring accounts of linguistic representation than in discriminating among those accounts. They have inherent and fundamental limitations, because judgments can easily be influenced by non-linguistic factors, they cannot be used at all with some populations, and most importantly they do not provide direct evidence about structure. Given these concerns, researchers concerned with linguistic representations should not rely solely on such judgments, and should call on additional methodologies that are directly sensitive to structure and that avoid the limitations discussed above.

1.3 Psycholinguistic approaches to linguistic representation

Is there a different approach to linguistic representation that is based more directly on psycholinguistic methods? Researchers have intermittently proposed that some form of experimental method may be informative about linguistic representation (and not merely processing). In the 1960s, psychologists attempted to relate processing difficulty to linguistic complexity (e.g., number of transformations; Chomsky 1965) using reaction time measures (McMahon 1963; Miller and McKean 1964; Miller 1962). But it proved very difficult to control for other potentially relevant factors. For example, a passive might take longer to process than an active because a passive involves an additional transformation (hence greater representational complexity), or alternatively because of length, word frequency, local or global ambiguity, and so on.

Other experimental studies tested for the existence of empty categories, as assumed by some linguistic theories (e.g., Chomsky 1981) but not others. McElree and Bever (1989) found that people were faster to decide whether a critical phrase had occurred in a sentence if an empty category (or ‘gap’) corresponding to the phrase occurred at the end of the sentence than if the sentence had no empty category. They argued that comprehenders reactivated the empty category at its location, and hence that empty elements are mentally represented (see also Nicol and Swinney 1989). But these results do not require empty categories and may instead be due to semantic processes. Pickering and Barry (1991) accordingly argued against the representation of empty categories in sentences such as *In which pot did you put the cup?*, because people appear to relate *in which pot* to the verb *put* as soon as they reach the verb (Sag and Fodor 1994; Traxler and Pickering 1996). But Gibson and Hickok (1993) proposed an account of their data in which people ‘project’ (i.e., predict) an empty category when they reach the verb. In accord with Chomsky (1981), Pickering and Barry’s data can be explained

by either a bottom-up parser (Parsing procedure P_1) using a grammar without empty categories (Grammatical Theory T_1), or a top-down parser (P_2) using a grammar with empty categories (T_2). More recent attempts to use processing evidence to adjudicate among competing linguistic theories of ellipsis, quantification, and scalar implicature have faced analogous problems (Lewis and Phillips 2015).

Other types of experimental work are in principle relevant to linguistic representation, but do not provide the basis for a general methodology for understanding linguistic representation. Sprouse, Wagers, and Phillips (2012) found that the acceptability of sentences violating island constraints (e.g., **What do you wonder whether John bought?*) is unrelated to measures of working-memory capacity, and therefore argued that such island constraints are likely to constitute part of grammar. Such research may constrain linguistic theories, but relates to quite specific phenomena. Some researchers have used patterns of agreement errors (*the road to the islands*; e.g., Bock and Miller 1991) to draw conclusions supporting linguistic frameworks incorporating movement and empty categories (Franck et al. 2010), but others assume that they are informative about processing mechanisms (e.g., the scope of utterance planning; Gillespie and Pearlmutter 2013). Research that uses young children's errors to infer their underlying representations runs into the same problem of distinguishing representational from processing explanations (Ambridge and Rowland 2013). Studies using ERPs show different signatures for implausible versus ungrammatical sentences (e.g., Kutas and Hillyard 1980; Osterhout and Holcomb 1992), but it is unclear whether there is a specifically semantic or syntactic component in the ERP wave-form (e.g., Kim and Osterhout 2005; Nieuwland, Martin, and Carreiras 2013). Likewise, fMRI studies do not unambiguously identify brain regions that are associated with particular levels of linguistic representation (Price 2010).

In fact, most psychologists of language have largely shied away from making claims about linguistic representation, and instead adopt the representations proposed by linguists. A classic example is Frazier's (1987) Garden-Path theory, which assumes that comprehenders initially select the syntactically simpler analysis of an ambiguous utterance. The theory makes specific syntactic assumptions (e.g., ternary branching structure is possible), which affect its predictions. But experiments concerned with the theory (e.g., Frazier and Rayner 1982) have not attempted to test whether these assumptions are correct. Many alternative accounts of parsing are, if anything, even less tempted to encroach on the territory of linguistic representation (e.g., MacDonald, Pearlmutter, and Seidenberg 1994).

In sum, linguists and psychologists agree that linguistic structure is mentally represented. But acceptability judgments are an imperfect and limited way of investigating such representations, and psychological approaches have not provided a general method for investigating linguistic representation. However, we now propose that structural priming is a very promising method that can be used systematically to address many linguistic questions.

1.4 Can structural priming be used to investigate linguistic representation?

Priming effects occur when processing a stimulus with particular characteristics affects subsequent processing of another stimulus with the same or related characteristics (Schacter 1987). Such effects are found pervasively throughout cognition. In visual perception, for example, object recognition can be facilitated by previous exposure to a stimulus with shared visual features (Biederman and Cooper 1991). Psychologists use such effects to investigate the nature of underlying representations. The logic underlying priming methodologies is that exposure to a *prime* stimulus facilitates (or inhibits) particular representations, making them more (or less) amenable to subsequent re-use if they can be applied to a subsequent *target* stimulus.² If processing of a stimulus *A* is affected by prior processing of *B* to a greater extent

than by prior processing of *C*, then the representation underlying *A* is more similar to the representation underlying *B* than it is to the representation underlying *C*. By careful investigation, we can determine how *A* and *B* are related, and use this relationship to inform a general theory of representation. For example, Biederman and Cooper manipulated the extent to which prime and target stimuli shared visual attributes such as vertices and convex/concave components, and used their results to propose a theory of visual object representation.

Such effects provide an implicit measure of representation that is independent of any explicit response (e.g., regarding well-formedness, presence of particular characteristics, similarity). They occur without awareness or explicit recall of the prime stimulus, and are generally believed to be automatic and resource-free (e.g., Dehaene et al. 1998; Forster and Davis 1984). In other words, priming effects arguably implicate a direct relationship between representation and behavior.

Priming paradigms have been extensively applied to language. For example, participants are faster at judging that a target stimulus is a word (e.g., *nurse*) if they have just responded to a semantically (or associatively) related prime word (*doctor*) than an unrelated word (*table*; Meyer and Schvaneveldt 1971). By manipulating the relationship between prime and target, researchers have constructed detailed models of the psychological representation of lexical entries (McNamara 2005). Accordingly, Marslen-Wilson et al. (1994) used evidence of priming between words that shared a semantically transparent stem (e.g., *observation-observant*), but not between words that had a common historical derivation but did not share a semantically transparent stem (e.g., *apart-apartment*), to argue that the former had a decomposable (bi-morphemic) representation whereas the latter did not. They noted that this psychological evidence contrasted with theoretical and historical linguistic analyses.

We argue that priming can similarly be used to investigate the representation of any aspect of linguistic structure. Thus we could demonstrate changes in some aspect of behavior (e.g., likelihood of a particular response, response time, patterns of brain activity) following a sentence with particular characteristics, and draw inferences about the representations that underlie the prime and target, without requiring participants to make any explicit judgment.

Experiments using structural priming paradigms avoid many problems typically associated with acceptability judgments. They standardly use many sentences and many naïve participants, control for plausibility differences and effects of previous exposure, and randomize presentation order (though we have noted that these controls can be applied to acceptability judgments). Because they use implicit behavioral measures, they can avoid decision-making biases and problems about informants' interpretation of *acceptable* and *unacceptable* (or *grammatical* and *ungrammatical*). For the same reason, they can be used to investigate representations in participants who cannot make appropriate metalinguistic judgments, or who are indeed unable to make any explicit response, for instance young children or language-impaired patients. Furthermore, because priming is based on the processor recognizing that two utterances are related, such experiments provide evidence that goes beyond set membership. Finally, investigations of priming between comprehension and production are directly informative about representation (rather than aspects of processing that are specific to production or comprehension).³

A possible concern is that priming between two sentences may tap into a level of representation that is distinct from another linguistic representation that is inaccessible to priming (e.g., a 'deep structure' as in Chomsky 1965). But as stated above, our goal is to characterize the linguistic representations that are implicated in language use (and we have argued against inaccessible representations; Section 1.1). And of course any such objection

equally applies to the use of acceptability judgments, which also involve processing, and might also fail to access such representations.

Another concern is identifying which aspect of structure priming taps into. For example, speakers might tend to repeat POs or DOs (Bock, 1986) because they are primed to repeat syntactic structure, or because they are primed to repeat aspects of meaning, thematic role order (e.g., Theme-Recipient vs. Recipient-Theme), or order of animate/inanimate entities, among other possibilities. In some cases, it is possible to exclude alternative explanations within an experiment. In other cases, we should seek converging evidence across experiments, whereby alternative explanations are systematically ruled out (as has been done for POs/DOs; see Sections 1.0 and 2).

A different concern is that structural priming may itself be susceptible to processing influences. Obviously it may not be sensitive to linguistic relationships under all conditions, for example if the target occurs too long after the prime. Participants may also sometimes fail to demonstrate priming because of processing limitations (e.g., children may sometimes be unable to produce complex structures, despite having the relevant linguistic representations). For these participants, it may be important to use priming paradigms that minimize processing requirements or do not require an overt response (e.g., using ERPs and fMRI; Ledoux, Traxler, and Swaab 2007; Segaert et al. 2012).

A more serious problem would occur if an effect that mimicked structural priming arose for reasons that are not informative about linguistic representation. In the case of acceptability judgments and when using comprehension data (e.g., reading times), we have noted that conclusions about linguistic representation (i.e., T) might depend on assumptions about processing (i.e., P). But it is hard to see how the explanation of priming could depend on processing assumptions.

Priming could also occur for reasons other than similarity of linguistic representation. For example, comprehending a garden-path sentence might be easier following another, unrelated garden-path sentence, because comprehenders are primed to adopt more complex or less frequent analyses. Equally, speakers might be more likely to produce a rare (or less felicitous) structure after encountering another rare (or less felicitous) structure. But such effects should be more general than effects due to structural priming, and could be distinguished with careful experimentation.

A final concern is that most demonstrations of priming in production relate to choices between sentence forms, and so rely on the existence of structural alternatives – it is hard to use priming in production to investigate the representation of sentences where no relevant alternative exists, or where one alternative is highly infrequent or infelicitous. But this simply means that priming in production cannot be used to investigate all structures. On some occasions, priming in comprehension may present an alternative.

1.5 Summary

There has been an historical division between a theoretical linguistic focus on representation and a psychological focus on processing. Research on representation has relied almost exclusively on acceptability judgments, which have provided a fertile source of data for developing hypotheses, but have many limitations and do not provide unambiguous diagnostics that can discriminate among alternative hypotheses. Most methods grounded in psychology (or neuroscience) have not themselves provided such diagnostics. However, we have argued that structural priming is different: It provides evidence that is directly informative about mental representation.

We propose that acceptability judgments can be used (with appropriate controls) alongside structural priming (and perhaps other experimental methods; see Section 1.3) as a means of developing representational hypotheses.⁴ But they should not be the final arbiters for discriminating among hypotheses. Instead, researchers should where possible use structural priming to test hypotheses. In many cases, evidence from structural priming will converge with evidence from acceptability judgments, and hence provide strong support for specific representational claims. In other cases, priming evidence will adjudicate between competing linguistic accounts (whether different analyses of the same construction within the same broad linguistic framework, or analyses that are based on very different linguistic assumptions). But where acceptability judgment and priming evidence do not converge, evidence from priming should be favored, especially when acceptability judgments do not produce clear evidence.

We have made this argument in principle. But we suggest that there is now sufficient evidence from structural priming experiments to outline a psychologically motivated account of syntactic aspects of linguistic representation, and their relationship to semantics and the lexicon. We base this account on specific structural priming findings, but argue that it is also compatible with traditional linguistic evidence and that it discriminates among theories based on such evidence.

2. An outline theory of syntax and its interfaces based on structural priming

To explain our account, we consider the representation of *A book was begun by every linguist*, under an interpretation in which each linguist began writing a (possibly) different book. We focus on information that appears relevant to syntactic representation (either as part of the syntactic representation itself, or by interfacing with the syntactic representation).

First, people must represent semantic information (roughly corresponding to the speaker's intended 'message'; Levelt, 1989). Importantly, this includes propositions represented in terms of predicates and their arguments. In our example, one proposition encodes a complex event structure involving the initiation of an event of writing. This writing event is associated with two thematic roles: an Agent that undertakes the act of writing, and a Theme that is written. The Agent of the writing act is also the Agent who initiates this act. There is also quantificational information that *every linguist* has wider scope than *a book*, and information structure specifying that *a book* is emphasized.

We also assume that people represent syntactic and lexical information about the words that are used and how they are arranged. Thus, people represent that the sentence includes the words *a* and *book*, in that order, as well as information about larger units of structure (e.g., that *a* and *book* form a constituent). Importantly, elements expressed in the message may not always straightforwardly correspond to elements expressed in the syntax and to lexical content (e.g., there is no word expressing the writing event; cf. Jackendoff 2002b). Finally, people represent the relationship between these different types of information and sound (phonology, intonation, etc.).

Our account has the following basic properties (see Figure 1). It distinguishes representations specifying semantics from those specifying syntax. There is a single semantic level of representation that encodes information about quantificational scope relations, information structure, and thematic structure, including 'missing' elements (i.e., elements that do not correspond to an element that is uttered). There is a single syntactic level of representation that draws on well-formedness constraints (or 'rules') specifying local relations with respect to linear order as well as hierarchical relations. The syntactic level of representation includes syntactic category information, but not semantic information (e.g., thematic roles) or lexical

content. There is no syntactic movement, but some elements that are not uttered are represented in the syntax. The syntactic level is separate from a single sound-based level of representation that encodes phonology, syllabic structure, and metrical information (which we refer to under the blanket term ‘phonological information’). We assume one sound-based level as there is insufficient evidence to discriminate different levels (see Sevald, Dell, and Cole 1995; Tooley, Konopka, and Watson 2014).

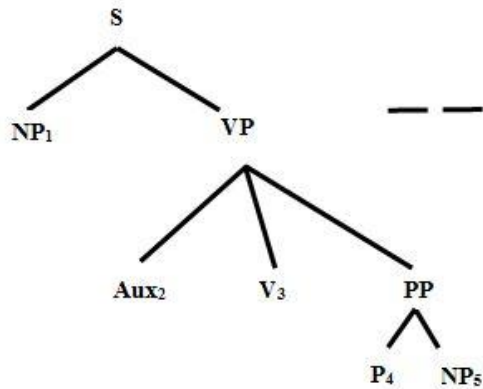
2.1 Syntactic representation

We begin by motivating the syntactic level of representation, as this is the level for which there is most evidence from priming. Our account assumes a single level of syntax that includes constituent structure. There are no separate levels containing, for example, reordered constituents (e.g., Deep Structure) or unordered constituents (e.g., incorporating hierarchical structure but not linear order). In addition, this level does not incorporate quantificational information (which instead forms part of the semantic representation).

Semantic representation:

$\forall_{\text{ENTITY}} [[\text{linguist}(\text{ENTITY})_5 \ \& \ \text{agent}(\text{ENTITY})_5] \rightarrow \exists_{\text{ENTITY}} [\text{book}(\text{ENTITY})_1$
 $\& \ \text{theme}(\text{ENTITY})_1 \ \& \ \text{emphasized}(\text{ENTITY})_1 \ \& \ \text{begin_EVENT/ENTITY/EVENTS}(\text{ENTITY}$
 $(\text{write_EVENT/ENTITY}(\text{ENTITY}))]$

Syntactic representation:



Phonological representation:

/ [ə 'bʊk]₁ [wəz]₂ [brɪ'ɡʌn]₃ [baɪ]₄ [ˈɛvri 'lɪŋgwɪst]₅ /

LEXICON

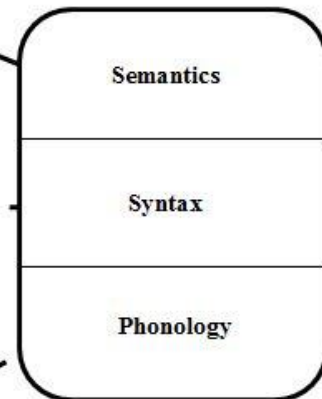


Figure 1. Outline model of the representation of *A book was begun by every linguist*, incorporating a single level of semantic representation, a single level of syntactic representation, and a single level of phonological representation. Dashed lines indicate bindings between components of semantic, syntactic and phonological structural representations, and the semantic, syntactic, and phonological components respectively of lexical entries. Subscripts indicate coindexation between levels.

First, syntactic representations do not contain semantic information. This claim is supported by evidence of priming between sentences involving different types of event, predicates, and entities. Bock and Loebell (1990) found that intransitive active sentences with a *by*-phrase expressing a location (*The foreigner was loitering by the broken traffic light*) primed transitive passive sentences where the *by*-phrase expressed an Agent (*The boy was woken by an alarm clock*), and Messenger et al. (2012) showed priming between passive sentences that involved different thematic roles (e.g., *The girl is being scared by the pig* and *The king is being ignored by the bear* both primed *The doctor gets licked by the cow*); as we discuss

below, these results cannot be explained by closed-class word repetition (see also Bock 1989). Both studies found the same magnitude of priming when primes and targets did not involve the same thematic roles as when they did.

Additionally, priming occurs when the alternatives involve no discernible semantic difference. Hartsuiker and Westenberg (2000) found structural priming for the order of the auxiliary and main verb in Dutch, even though they involve the same words and do not express different meanings. Konopka and Bock (2009) similarly showed priming for the position of the particle in meaning-identical sentences involving phrasal verbs (e.g., *pulled the sweater off* vs. *pulled off the sweater*). Ferreira (2003) found priming for the presence versus absence of the complementizer *that* (e.g., *the mechanic mentioned the car could use a tune-up* vs. *the mechanic mentioned that the car could use a tune-up*).

These studies also demonstrate that the relevant representations are not intrinsically bound to open-class lexical content: Priming occurs between sentences that share no such content. Nor are they bound to closed-class content (e.g., *The secretary baked a cake for her boss* and *The secretary brought a cake to her boss* primed *The girl is giving a paintbrush to the man* to the same extent; Bock 1989; see also Pickering and Branigan 1998). Other experiments show structural priming between sentences containing a mismatch between syntactic structure and the verb's subcategorization requirements (e.g., *The waitress exists the book to the monk* primes PO responses; Ivanova, Pickering, Branigan, et al. 2012; see also Ivanova, Pickering, McLean, et al. 2012) – if syntactic representations were bound to lexical content, priming should have occurred only when the syntactic properties of the words were compatible with the sentence structure.

The finding that priming occurs between sentences with different phonological content (e.g., *for-to* in Bock, 1989; *was showing-showed*; Pickering & Branigan, 1998) to the same extent

as priming between sentences with the same phonological content (*to-to*; *showed-showed*) also implies that syntactic representations do not contain word-level phonological information. Additionally, Bock and Loebell (1990) showed that priming did not occur based on metrical structure (e.g., *Susan bought a book for Susan* primed POs, but *Susan brought a book to study* did not).

Hence priming evidence supports the existence of abstract syntactic representations. It also suggests that these are ‘shallow’ and monostratal, in a way that corresponds at least roughly to the assumptions of Culicover and Jackendoff (2005) and many other non-transformational theories (e.g., Gazdar et al. 1985; Goldberg 1995; Pollard and Sag 1994; Steedman 2000). It does not support a second, underlying level of syntactic structure, or the syntactic representation of empty categories associated with the movement of constituents in some transformational analyses. Thus, Bock and Loebell’s (1990) finding of priming from intransitive (active) locatives to passives implies that these structures share syntactic representations, which we take to be noun phrase (NP; *the foreigner, the boy*), verb (including auxiliary; *was loitering, was woken*), and PP (*by the broken traffic light, by an alarm clock*). Our account contrasts with many syntactocentric linguistic theories, which assume distinct syntactic representations for passives and intransitive locatives. Specifically, transformational accounts assume that the passive involves an empty category associated with the subject (*the boy*) immediately after the verb (*woken*), whereas intransitive locatives do not involve an empty category. Converging evidence supporting our account comes from Flett’s (2006) finding that Spanish speakers tended to repeat the order of the subject and verb in unaccusative sentences to the same extent following unergative and unaccusative primes, which transformational accounts assume involve distinct syntactic representations (with unaccusatives but not unergatives involving subject movement and an associated empty category).

Similarly, priming from transitive locatives to POs implies that these constructions share syntactic representations (Bock and Loebell 1990), whereas many transformational accounts assume that they have different structures, with the PP appearing as a sister to the verb node in POs (because it is a complement) but as a sister to a higher V' node in locatives (because it is an adjunct). The only accounts in which POs and transitive locatives have the same representation are where the structure is shallow and simple, in the sense that there are nodes for the verb, NP, and PP, but nothing else. Likewise, Wittenberg (2014) found (bidirectional) priming between POs/DOs and 'light verb' sentences (e.g., *The kidnapper gives the government an ultimatum/an ultimatum to the government*), whereas transformational accounts assume distinct representations, with POs/DOs – unlike light verb sentences – involving a V-trace (Hale and Keyser 1993; Hale and Keyser 2002; see Wittenberg et al. 2014).

Syntactic representations are also monostratal in the sense that they represent hierarchical and linear relations simultaneously. Pickering, Branigan, and McLean (2002) showed that sentences involving the same hierarchical relations but different linear relations did not prime each other. Participants were no more likely to produce a PO (involving V NP PP order) following a 'shifted' PO (the same constituents in V PP NP order; e.g., *The racing driver showed to the helpful mechanic the damaged wheel*) than following an intransitive sentence. Pappert and Pechmann (2014) found similar results in German, where the shifted order is much less unusual.

The syntactic representations capture 'local' relationships between a 'mother' and its constituent 'daughter(s)' (e.g., a VP comprising a verb and two NPs), independent of the larger context in which the phrase appears (e.g., that the VP occurs within a subordinate clause), or the internal structure of the sub-phrases that constitute it (e.g., that the first NP

comprises a determiner, adjective, and noun).⁵ This assumption is consistent with any approach to grammar that distinguishes within- and between-phrasal relations, such as context-free grammars with maximal projections. It is motivated by evidence that priming occurs between sentences that share local structure but differ at other levels. Branigan et al. (2006) found priming when the prime involved a DO or PO structure in a main clause (e.g., *The racing driver showed the helpful mechanic the flat tyre*) and the target involved a subordinate clause (e.g., *The rumours alleged that the patient showed the doctor his scar*), and vice versa. In fact, priming occurred to the same extent whether the prime and target involved the same or different clause types, implying that the same representations were involved whenever a DO or PO structure was used, irrespective of the larger context (see also Melinger and Cleland 2011).

Likewise, priming occurs between sentences that differ in detailed structure (i.e., constituents' internal structure). Pickering and Branigan (1998) found PO/DO priming when the internal structure of complement NPs differed between prime and target (e.g., omission or inclusion of adjectives: *The racing driver showed the torn overall to the manager* primed *The patient showed his spots to the doctor*). Moreover, Fox Tree and Meijer (1999) found equivalent priming for POs and DOs whether the VPs in prime and target had the same internal structure (i.e., both included or did not include a subordinate relative clause) or different internal structure (i.e., one involved a subordinate relative clause and the other did not). This finding also demonstrates that priming is not based on a sequence of phrasal categories (i.e., without hierarchical structure).

Finally, traditional theories of language production make reference to grammatical functions such as subject (e.g., Garrett 1975), for example assuming that they have their own 'deep' level of representation (corresponding roughly to *F-structure* in LFG; Kaplan and Bresnan

1982) that is independent of constituent structure. Many linguistic theories also assume some form of representation of grammatical functions, even those that attempt to develop monostratal syntax (see Culicover and Jackendoff 2005, 152, 538). For *John loves Mary*, speakers might compute $\langle \text{John}_{\text{SUBJECT}}, \text{Mary}_{\text{DIRECT-OBJECT}}, \text{loves} \rangle$ as an unordered representation separate from $[\text{NP } \text{John}] [\text{VP } [\text{V } \text{loves}] [\text{NP } \text{Mary}]]$. Such a representation would be incompatible with our assumption of a single syntactic level.

Some priming studies have been interpreted in terms of grammatical functions (see section 2.4). Bock, Loebell, and Morey (1992) argued that speakers repeat mappings of animacy features (encoded in semantic representations) to grammatical functions (e.g., inanimate to subject). But participants might also have repeated mappings of animacy features to word-order positions (e.g., inanimate to first NP). Chang, Bock, and Goldberg (2003) reported priming effects that could have reflected a tendency to repeatedly assign thematic roles (e.g., Location) to grammatical functions (e.g., direct object) or to word-order positions (e.g., immediately following the verb). Cai, Pickering, and Branigan (2012) found some evidence (in Mandarin) for separate priming from thematic roles to grammatical functions and from thematic roles to word-order positions, and argued that grammatical functions should be incorporated into the constituent structure representation (e.g., $[\text{NP } \text{John}_{\text{SUBJECT}}] [\text{VP } [\text{V } \text{loves}] [\text{NP } \text{Mary}_{\text{DIRECT-OBJECT}}]]$). However, priming has not resolved the status of grammatical functions (and we therefore do not incorporate them into Figure 1).

2.1.1 'Missing' elements

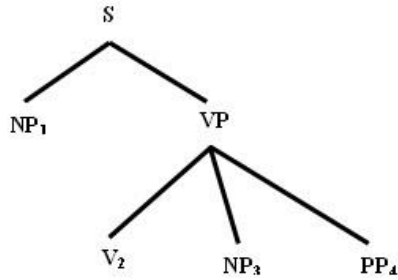
We have argued that priming evidence does not support the existence of empty categories associated with the movement of NPs or verbs in syntactic structure, and have proposed a monostratal account (involving a single level of syntax that is linked to a single level of semantics and a single level of phonology). But within this account, some elements that are

not phonologically represented may be syntactically represented. In fact, priming may allow us to determine cases where missing elements are syntactically represented and cases where they are not. More generally, priming potentially allows us to address the syntactic representation of sentences in which the semantics and phonology are misaligned: Does the syntax align with the former or the latter?

We first consider ellipsis. Syntactic accounts of ellipsis assume that elided elements are represented syntactically (as well as semantically; e.g., Hankamer 1979; Merchant 2001); semantic accounts assume that they are represented semantically but not syntactically (e.g., Fiengo and May 1994). Consider *The charity needed support so the man gave some money*, in which the semantic representation specifies the Agent (the man), Theme (some money), and Recipient (the charity), whereas the phonological representation specifies the Agent and Theme but not the Recipient. According to syntactic accounts, the syntactic representation includes a PP (e.g., V NP PP), so that it is aligned with the semantic representation (but not the phonological representation), as in Figure 2a; according to semantic accounts, it does not include a PP (e.g., V NP), so that it is aligned with the phonological representation (but not the semantic representation), as in Figure 2b.

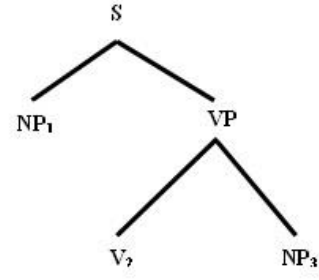
give₂ (**man** (x_{ENTITY})₁ & **agent** (x_{ENTITY})₁ &
money(y_{ENTITY})₃ & **theme**(y_{ENTITY})₃ &
charity(z_{ENTITY})₄ & **recipient**(z_{ENTITY})₄)

give₂ (**man** (x_{ENTITY})₁ & **agent** (x_{ENTITY})₁ &
money(y_{ENTITY})₃ & **theme**(y_{ENTITY})₃ &
charity(z_{ENTITY})₄ & **recipient**(z_{ENTITY})₄)



... [*the man*]₁ [*gave*]₂ [*some money*]₃

2a



... [*the man*]₁ [*gave*]₂ [*some money*]₃

2b

Figure 2. Accounts of the representation of the missing-argument sentence *The man gave some money*. The italicized sentences represent the phonological representation. In (a), the meaning and thematic role of the missing argument are specified in the semantic representation (top), and the missing argument is specified in the syntactic representation (center); in (b), the meaning and thematic role of the missing argument are specified in the semantic representation, but the missing argument is not specified in the syntactic representation. Subscripts indicate coindexation between levels.

Cai et al. (2015) found that missing (elided) NP arguments in Mandarin are syntactically represented. They showed that (full) DO targets were primed by DOs in which the Theme was missing (e.g., *Niuzai mai-le yiben shu hou song-gei-le shuishou*; ‘The cowboy bought a book and later gave the sailor [the book]’) to the same extent as by DOs in which the Theme was not missing (*Niuzai mai-le yiben shu hou song-gei-le shuishou naben shu*; ‘The cowboy bought a book and later gave the sailor the book’). Similarly, PO targets were equally primed by POs with or without the Theme. These results suggest that the missing element was represented in the syntactic structure in the same way as an overtly expressed element, as in Figure 2a, and are therefore consistent with syntactic accounts.

In contrast, Cai, Pickering, and Sturt (2013) found that elided VPs in Mandarin are not syntactically represented. They showed that (full) DO targets were not primed by DOs in

which the VP was elided (e.g., *Fuwuyuan xiang jie-gei shuishou naba qiang. Yinwei haipa reshi, chushi que bu xiang*, ‘The waitress would like to lend the sailor the gun. Being afraid of getting into trouble, the chef would not like to [lend the sailor the gun]’), compared to when the VP was overtly expressed (... *chushi que bu xiang jie-gei shuishou naba qiang*, ‘... the chef would not like to lend the sailor the gun’). These results suggest that the internal structure of the elided VP (V NP NP) was not syntactically represented, and are therefore consistent with semantic accounts.

Other priming evidence similarly indicates that some semantically specified elements are not syntactically specified. Raffray et al. (2014) examined sentences such as *The celebrity began drinking the champagne* (full VP sentence) and *The celebrity began the champagne* (coerced sentence). The semantic representation for both sentences specifies the nature of the predicate (i.e., drinking) involved in the event. However, Raffray et al. found that *The celebrity began the champagne* did not prime production of *The clerk began reading the report*, suggesting that the coerced sentence has no syntactic element corresponding to the missing predicate *drinking*. Instead it behaved like a non-coerced sentence such as *the celebrity began the speech* (in which there is no ‘missing’ predicate, as *the speech* refers to an event).

In addition, Pappert and Pechmann (2013) showed that PO/DO sentences (e.g., *Die Sekretärin backte ihrem Chef einen Kuchen* ‘The secretary baked her boss a cake’) primed benefactive sentences (e.g., *Der Soldat hob seinem Freund eine Zigarette auf*, ‘The soldier saved his pal a cigarette’), despite their semantic differences: PO/DO sentences involve a simple transfer event, whereas benefactives involve a complex event comprising a creation or preparation event and a potential transfer or change of possession event (Shibatani 1996). These results suggest that they are nevertheless syntactically represented in the same way.⁶

Overall, these results provide evidence for the syntactic representation of some but not all missing elements (i.e., elements that are semantically but not phonologically represented). Moreover, they imply that patterns of structural priming can determine which missing elements are syntactically represented and which are not. More generally, they suggest that priming can help determine the extent to which syntactic representations are aligned with semantic or phonological representations.

2.2 *Semantic representation*

Our model proposes that the semantic level of representation contains at least specifications of quantificational information, information structure, and thematic roles. We assume a single level of semantic representation, as most studies have focused on distinguishing different aspects of semantics from syntax and have not sought to distinguish among aspects of semantics. We first consider the representation of quantificational information and its relation to thematic roles. Raffray and Pickering (2010) reported that priming is sensitive to a level of semantic representation specifying quantifier scope (see also Chemla and Bott 2015; Feiman and Snedeker 2016; Viau, Lidz, and Musolino 2010). They presented participants with doubly quantified prime sentences such as *Every kid climbed a tree*, which are ambiguous between a universal-wide interpretation (Every kid climbed a potentially different tree) and an existential-wide interpretation (Every kid climbed the same tree), together with a disambiguating picture that forced one or other interpretation. When they then read a different doubly quantified target sentence that also involved a universally quantified Agent and existentially quantified Patient (*Every hiker climbed a hill*), participants tended to interpret it in the same way.

Participants did not tend to repeat the interpretation of *Every hiker climbed a hill* after active primes such as *A kid climbed every tree*, hence they did not simply repeat whether *a* referred

to one or potentially more than one entity. In contrast, they tended to repeat the interpretation of *Every hiker climbed a hill* after passive primes such as *A tree was climbed by every kid*. So they repeated the use of an agentive noun with *a* to refer to a single entity, even when this noun had a different grammatical function (i.e., subject versus oblique object) and was in a different linear position (i.e., first versus second NP). Participants therefore repeated mappings of scope to quantified thematic roles. Overall, these results support a semantic representation that encodes both quantificational and thematic information (but in which thematic roles are unordered). Critically, they do not support an account in which logical form (encoding quantification) constitutes a distinct level of representation between syntactic representation and final interpretation (e.g., May 1985).

We also assume that the semantic representation contains a specification of information structure. By information structure, we mean the way in which information is packaged with respect to the current context, for example to reflect which information is known to the listener or is emphasized (e.g. Chafe 1976; Halliday 1967; Lambrecht 1994; Vallduvi 1992). In our account, information structure is specified with respect to thematic roles, for example that the Patient is emphasized (roughly corresponding to topic, theme, or given information, depending on theoretical framework).

In support of this claim, Vernice, Pickering, and Hartsuiker (2012) showed that Dutch speakers repeated emphasis of particular thematic roles across sentences in the absence of syntactic or lexical repetition. They were more likely to produce passives with Patient-Agent order, which emphasized the Patient (e.g., *Het meisje wordt overspoeld door de golf*; ‘The girl is being soaked by the wave’), after Patient-emphasis *WH*-cleft sentences with Agent-Patient order (*Degegne die hij slaat is de cowboy*; ‘The one who he is hitting is the cowboy’) than after Agent-emphasis *WH*-cleft sentences with Patient-Agent order (*Degegne die hem*

slaat is de cowboy; ‘The one who is hitting him is the cowboy’). These results further support a representation containing unordered thematic roles, and imply that these roles are specified with respect to information structure (see also Bernolet, Hartsuiker, and Pickering 2009).

In all these studies, priming occurred between sentences that involved different entities and/or different predicates, implying that the relevant representations were abstracted over these elements. Other priming evidence similarly supports a semantic representation framed in terms of abstract predicates, event components, and entities (Bunger, Papafragou, and Trueswell 2013; Raffray et al. 2014; see section 2.4).

2.3 Structural representations and the lexicon

So far we have been concerned with characterizing the nature of syntactic and semantic representations, based on evidence of priming between sentences that share different aspects of structure in the absence of lexical repetition. These results provide evidence for at least some abstract representation of both syntactic and semantic structure. But additionally, a particularly robust finding is that various types of structural priming are considerably enhanced by repetition of the head of the local tree (the so-called *lexical boost*; e.g., Branigan, Pickering, and Cleland 2000; Cleland and Pickering 2003; Hartsuiker et al. 2008; Pickering and Branigan 1998).⁷ Both the existence of abstract priming and the lexical boost are informative about the lexical basis for linguistic representation.

Abstract syntactic priming provides evidence for a representation of syntax that is independent of lexical representation. The existence of priming between, say, *give the woman a book* and *send the girl a letter* indicates that the representation of grammatical information (here, about the DO structure) cannot be entirely localized to specific lexical entries. This is incompatible with one interpretation of lexicalist theories such as categorial grammars (Steedman 2000) and HPSG (Pollard and Sag 1994). Such theories assume a few very

general rules (e.g., function application, function composition, function substitution; Steedman 1987), but such rules cannot be the locus of abstract priming as the same rules are applied across alternations such as DO and PO. To explain abstract priming, lexicalist theories must assume that the syntactic representations (e.g., VP/NP/NP in categorial grammar) are shared across lexical entries. Similarly, evidence of abstract semantic priming (e.g., emphasizing the Patient, or producing coerced structures) implies that such information is not purely localized to lexical entries.

The existence of the lexical boost, however, also argues against an extreme structuralist account in which lexical information is not part of the central syntactic component, for example an account in which lexical entries are merely ‘slotted in’ to a representation derived entirely from abstract (lexically unspecified) syntactic well-formedness constraints. Thus there must be a representation that encodes a binding between constituent structure and the lemma (syntactic component) of the lexical entry for the head. For the sentence *The man gives the book to the woman*, this representation is [V[*give*] NP PP]VP, where *give* is a lemma (and not a complete lexical entry that additionally encodes semantic and phonological information). Importantly, the binding between *V* and the lemma *give* is the same type of binding that connects representations at different levels of structure (e.g., the syntactic and semantic representations associated with *The man gives the book to the woman*), rather than the links that connect components of the syntactic representation itself (e.g., linking *VP* and *V*). Repetition of the lemma and the syntactic well-formedness constraint that licenses the constituent structure (e.g., *give* and $VP \rightarrow V\ NP\ PP$) then leads to an enhanced priming effect.⁸

This account accords with the finding that the lexical boost appears to be due to repetition of a particular lemma (e.g., *give*), rather than a lemma that is instantiated for particular feature

values (e.g., *give* [+SING, +PRES, +PROG]). Pickering and Branigan (1998) found a lexical boost whenever the verb lemma was repeated, irrespective of whether the prime and target verbs shared tense, number, and aspect features (e.g., *The racing driver was showing the torn overall to the mechanic* yielded the same lexical boost as *The racing driver showed the torn overall to the mechanic* for the target *The patient showed his wound to the doctor*). Such results occur because the binding is between the constituent structure rule and a lexical entry without reference to features such as tense, but presumably with reference to syntactic category (to ensure that only well-formed bindings occur).

Little is known about priming of unbounded dependencies, and an interesting question is whether a constituent such as *the book that the doctor gave to the patient* would prime a PO, which would indicate whether a missing and an expressed NP differ in terms of a feature or a syntactic category. This distinction can be seen in two versions of GPSG. In both versions, *the doctor gave to the patient* is captured by $VP/NP \rightarrow V\ NP/NP\ PP$ and $NP/NP \rightarrow \emptyset$.

According to Gazdar et al. (1985; see also HPSG; Pollard and Sag 1994), the slash-category /NP is simply a feature ‘missing NP’. It is therefore similar to other features such as number (although it differs in having internal structure), and we have already noted that priming appears unaffected by feature differences. Thus this account predicts that priming should occur in this case just as it does from a PO prime. But according to Gazdar (1981), slash categories differ at the categorical level from other categories. Hence priming should be eliminated (or at least reduced) in this case. We know of no evidence that distinguishes these accounts.

Similarly to syntactic priming, abstract semantic priming provides evidence for a representation of semantics that is independent of lexical representation. But there is also evidence for a lexical boost to semantic priming, even when the relevant elements are not

present in the phonological representation. Raffray et al. (2014) found priming of coerced sentences when the events that the prime and target sentences described involved different entities and different coerced predicates (e.g., *The celebrity began the champagne* primed *The clerk began the report*; see section 2.4), implying the existence of semantic representations that were abstracted over these elements. However, they found a boost to priming when the coerced predicate was repeated between prime and target, even though the associated verb was not expressed: *The celebrity began the champagne* (coerced predicate: drink) was a stronger prime than *The caretaker began the stairs* (coerced predicate: sweep) for *The banker began the tea* (coerced predicate: drink). These results suggest the existence of bindings between lexical items (whether expressed or not) and semantic representations.

2.4 Structural representations and their interfaces

An account of structural representations must also specify mappings between levels of representation. Evidence from priming supports a range of mappings between information encoded in the semantic representation and information encoded in the syntactic representation: between thematic roles and grammatical functions, between thematic roles and word order, between animacy and syntactic structure, and between event structures and syntactic structures.

Cai, Pickering, and Branigan (2012) showed priming of mappings between thematic roles and grammatical functions. After hearing a Mandarin topicalized PO such as *Naben shu niuzai song le gei shuishou*, ‘The book, the cowboy gave [it] to the sailor’, participants tended to produce POs (e.g., *Jingcha song-le yiding maozi gei shibing*; ‘The policeman gave a hat to the soldier’), in which the same thematic roles were mapped to the same grammatical functions (Theme to direct object and Recipient to oblique object) but different word order positions.

They also showed priming between thematic roles and word order: Participants also tended to produce POs (with Theme-Recipient order) after hearing a topicalized DO (which also has Theme-Recipient order; e.g., *Naben shu niuzai song-gei le shuishou*; ‘The book, the cowboy gave the sailor [it]’). Köhne, Pickering, and Branigan (2014) similarly showed that German participants tended to produce sentences with Theme-Recipient order following a prime with Theme-Recipient order (e.g., *Der Mann verspricht die Putzhilfe der Ehefrau*; ‘The man promises the cleaning woman the wife’). Additionally, Chang, Bock, and Goldberg (2003) found priming that was compatible with thematic-function mappings or thematic-order mappings.⁹ Bock, Loebell, and Morey (1992) found that participants were more likely to produce descriptions in which an animate entity was a sentence-initial subject (e.g., *The boy is woken by the alarm clock*) after reading and repeating sentences with an animate sentence-initial subject (*Five people carried the boat*, or *Five people were carried by the boat*) than an inanimate sentence-initial subject (*The boat carried five people*, or *The boat was carried by five people*). These results are compatible with priming of animacy-function or animacy-order mappings. However, other research has not found priming of animacy to syntactic structure mappings (Bernolet, Hartsuiker, and Pickering 2009; Carminati et al. 2008; Huang et al. 2016).

Bunger, Papafragou, and Trueswell (2013) and Raffray et al. (2014) showed priming of mappings between components of event structures and syntactic structures. The former researchers demonstrated that speakers repeated mappings of components of motion events to syntactic structure. Participants who had read sentences in which information about the manner of a motion event was mapped onto the sentence-initial subject of the sentence (e.g., *The zebra on the motorcycle entered the garage*) were more likely to produce descriptions in which information about the manner of an unrelated event was similarly encoded in the

sentence-initial subject (e.g., *The driver is going into the cave*) than participants in a control condition (who were not exposed to primes).

Raffray et al. (2014) investigated utterances expressing complex events in which speakers had a choice of how to map a complex event (e.g., the clerk beginning to read the report) onto syntactic structure. Specifically, the complex event involved three semantic elements: an event lacking a (subordinate) event (the clerk beginning); an event lacking an entity (the clerk reading); and an entity (the report). Speakers could map these semantic elements to two or three syntactic elements in the VP (i.e., V NP: *began the report*; or V V-ing NP: *began reading the report*). They were more likely to produce sentences such as *The clerk began the report* after sentences that similarly involved mappings to two syntactic elements (e.g., *The celebrity began the champagne*) than after sentences that expressed the same meaning (e.g., *The celebrity began drinking the champagne*) or used the same syntactic structure (e.g., *The celebrity began the speech*) but did not involve the same mappings. In conclusion, priming can uncover the relationship between misaligned syntactic and semantic representations, just as it can uncover the nature of syntactic and semantic representations themselves.

3. Implications and predictions

Section 2 discussed the implications of research on structural priming for many aspects of linguistic representation in adult native speakers. We now consider how our proposals relate to current theoretical linguistic frameworks. We then consider priming in bilingualism as a means of understanding structural representations across languages, and priming in children as a means of understanding structural representations during language development. We conclude by addressing broader implications and predictions of our proposals.

3.1. Implications for linguistic theory

We have argued that structural priming supports separate representations encoding semantic, syntactic, and phonological information. The single semantic level includes quantificational, information-structural, and thematic information, including information pertaining to elements that are not overtly expressed. The single syntactic level is specified in terms of grammatical categories (and does not include semantic, lexical, or phonological information). It captures local relations specifying linear order and hierarchical relations. It represents some missing elements, but there is no syntactic movement.

Our account is therefore incompatible with ‘mainstream generative grammar’ (see Culicover and Jackendoff 2005) – the framework that is derived from early transformational grammar (Chomsky 1965) via Government and Binding Theory (Chomsky 1981) and the Minimalist Program (Chomsky 1995). This framework assumes that the generative capacity of language is strictly associated with the grammar. An initially abstract syntactic structure is altered sequentially through movement of elements (transformations). The resulting surface syntactic structure forms the input into both Logical Form (a ‘covert’ level of syntactic representation that interfaces with semantic representations encoding sentence meaning) and Phonetic Form (which is concerned with sound-based aspects of the sentence).

The assumption of autonomous syntax, into which phonological content is subsequently inserted, fits with evidence of priming between sentences without shared lexical content (e.g., Bock 1989). The assumption that speakers may syntactically represent some elements that they do not utter fits with evidence that sentences with missing arguments prime sentences without missing arguments (Cai et al. 2015). But in other respects ‘mainstream generative grammar’ is incompatible with priming evidence about linguistic representation. Most

fundamentally, priming studies provide no evidence for movement or a wide range of associated empty elements (e.g., traces, copies, or multiply dominated elements).

The clearest example involves passive sentences. Under a mainstream generative account, passives involve movement of the underlying object to subject position in the surface structure (leaving an NP trace or equivalent), whereas intransitive (active) locatives do not. Hence the two sentence types involve very different representations. The mainstream account is therefore incompatible with evidence that intransitive locatives prime passives (Bock and Loebell 1990), and that unergatives prime unaccusatives (Flett 2006). For similar reasons, it is inconsistent with evidence that transitive locatives prime POs (Bock and Loebell 1990), that POs and DOs prime ‘light verb’ sentences and vice versa (Wittenberg 2014). The assumption of a syntactic level of Logical Form (i.e., without specifications of meaning) is also incompatible with priming evidence for abstract semantic representations that specify quantifier scope (Chemla and Bott 2015; Raffray and Pickering 2010). Overall, the findings from structural priming do not support ‘mainstream generative grammar’.

Our account is more compatible with a broad range of alternative frameworks that eschew syntactocentrism, and instead assume non-directional and constraint-based generative capacities (i.e., specifying well-formed structures) that do not involve movement and in which syntactic structure is ‘shallow’ and not limited to binary branching. Such frameworks include the Parallel Architecture (Culicover and Jackendoff 2005; Jackendoff 2002), HPSG (Pollard and Sag 1994), and Construction Grammar (Goldberg 1995).¹⁰

We focus here on the Parallel Architecture (Culicover and Jackendoff 2005; Jackendoff 2002); see Jackendoff (2007) for an accessible and psycholinguistically oriented discussion. This framework assumes separate generative capacities for semantics, syntax, and phonology, and proposes that they are linked via interfaces, or mappings, that involve input from the

lexicon. So *the girl was chased by the dog* might have the syntactic representation S[NP[Det N]VP[Aux V PP], the semantic representation CHASED[DOG, GIRL]_{-[TOPIC]}¹¹ and the phonological representation /ðəgɜ:l wəz tʃeɪs dbaɪ ðə dɒg/. The syntactic representation occurs through combination of ‘constraints’ (stored fragments of structure) such as S[NP VP] and NP[Det N]. Culicover and Jackendoff (2005) also proposed a further tier of syntactic structure that captures grammatical function information associated with the ordering of NP arguments. Lexical entries comprise constraints (again, stored fragments of structure) such as DEF - Det - /ðə / and GIRL - N - /gɜ:l/ that play a role in the composition of sentence structure. They act as interface rules constraining relations between semantic, syntactic, and phonological representations. Such constraints yield coindexation of elements at different linguistic levels in parallel, for example DEF1 GIRL2, NP[Det1 N2], and /ðə/1 /gɜ:l/2 (with the indices indicating the links between representational levels). All linguistic representations (whether semantic/syntactic/phonological or lexical) are stored in long-term memory.

In many respects, this account is compatible with priming evidence. The assumption that speakers and listeners access the same local syntactic constraints that are independent of semantics or phonology (e.g., VP[V NP PP] for a PO) is consistent with abstract syntactic priming over local structures. Shallow syntactic structure and the associated assumption that many detailed distinctions are made in the semantics rather than syntax (and that there is no movement) are compatible with priming between intransitive locatives and passives.

Association of a lexical entry with a syntactic constraint (e.g., linking the entry for *give* with the PO constraint) accounts for the lexical boost. The assumption of a grammatical function tier as part of syntactic structure is consistent with priming of thematic-function mappings.

The assumptions of abstract semantic representations based on events, predicates, and entities, which may include elements not represented in the syntax, together with interface

constraints between semantics and syntax, are compatible with priming of semantic-syntactic mappings in sentences involving complement coercion and motion events (Raffray et al. 2014; Bunker, Papafragou, and Trueswell 2013).

This account is less compatible with evidence about the relationship between hierarchical relations and word order. Priming evidence suggests that hierarchical relations and word order are encoded in a single representation, because sentences with the same hierarchical relations but different word orders do not prime each other (Pappert and Pechmann 2014; Pickering, Branigan, and McLean 2002). In contrast, Culicover and Jackendoff (2005) proposed that there are independent constraints on hierarchical relations (constituency) and word order, as in GPSG (Gazdar et al. 1985) and HPSG (Pollard and Sag 1994). They argued that separating these constraints allows important generalizations, for example about regularities of phrasal ordering that are independent of hierarchical structure (e.g., about head position). Though these generalizations may be important, priming suggests that they do not reflect the representations used in language processing (see discussion in Section 1.1).

Additionally, the Parallel Architecture account assumes that thematic structure, quantification, and information structure involve different tiers within semantics. Current priming evidence supports semantic representations that are specified for thematic roles in conjunction with quantification (Raffray and Pickering 2010; priming of patients taking wide scope) and information structure (Vernice et al. 2012; priming of patients receiving emphasis). However it does not discriminate whether these constitute one integrated semantic representation (as we have assumed) or multiple semantic representations for thematic roles, quantification, and information structure that are linked to each other (as in the Parallel Architecture account). Further research might distinguish these accounts by investigating

whether priming involving two semantic components (e.g., quantification and information structure) is independent of another component (e.g., thematic roles).

More generally, structural priming has implications for linguistic theory in offering a means of adjudicating between alternative analyses that cannot be determined using other methods. For example, it may be able to resolve long-standing debates about the appropriate representation of English ‘small clause’ structures (e.g., *He called the boy a liar*, for which acceptability judgments support both a structure in which *the boy* and *a liar* do not form a constituent, and a structure in which they do; see Matthews 2007): Under the former account, a sentence such as *He called the boy a liar* should prime a sentence such as *The doctor gave the pharmacist the pills*, whereas under the latter account it should not. Similarly, it could resolve the ongoing controversy about Chinese *bei*-passives (e.g., *Nashan de men bei niuzai chuai-huai-le*; ‘That door by the cowboy was kicked in’, for which acceptability judgments and constituency tests support both an analysis in which *bei* heads a prepositional phrase, and an analysis in which it heads a verb phrase; see Huang, Li, and Li 2009).

3.2 Structural priming and representation across languages

Our account is based on evidence from a range of languages with different characteristics (e.g., English, German, Mandarin, Basque). Importantly, structural priming occurs in all languages that have been investigated, including American Sign Language (Hall, Ferreira, and Mayberry 2014), and appears to exert similar effects. Moreover, priming evidence supports very similar representations for structures across languages. For example, Mandarin (a language unrelated to English) has an alternation that appears similar to the English PO/DO alternation, and Cai et al. (2011) found very similar priming as in English, with a comparable magnitude of priming and lexical boost. Likewise, evidence from Basque (a language with ergative properties) supports syntactic representations that – like those found

in English – are independent of lexical, thematic and morphological content (Santesteban et al. 2015). Evidence from typologically distinct languages therefore suggests that our account is not restricted to a small range of Western Indo-European languages with quite specific characteristics.

Many studies have shown strong priming in non-native speakers, even for structures that do not exist in their native language, and that priming has similar characteristics in natives and non-natives (e.g., occurring for the same constructions, and demonstrating the lexical boost; Cai et al. 2011; Flett, Branigan, and Pickering 2013; Kantola and van Gompel 2011; Salamoura and Williams 2006; Schoonbaert, Hartsuiker, and Pickering 2007). Current evidence therefore suggests that linguistic representation is similar for natives and non-natives. It of course remains possible that native and non-native linguistic representations differ in subtle ways (e.g., in relation to unbounded dependencies; Clahsen and Felser 2006).

Strikingly, structural priming occurs between languages, with effects often being similar to those within languages. It occurs between many pairs of languages with differing degrees of similarity (e.g., German and English: Loebell and Bock 2003; Dutch and English: Bernolet, Hartsuiker, and Pickering 2009; Spanish and English: Hartsuiker, Pickering, and Veltkamp 2004; Korean and English: Shin and Christianson 2009; Mandarin and Cantonese: Cai et al. 2011; Greek and English: Salamoura and Williams 2007). These studies of course demonstrate abstract structural priming (as the words are different across languages). But more interestingly, they imply that bilinguals not only use a common representational vocabulary across languages, but also the same structural representations where possible (and these representations are the same as those of monolinguals). One relevant restriction on structure sharing is word order: Between-language priming is reduced or eliminated when the structures have different word orders across languages (e.g., English: *the shark that is red*

vs. Dutch: *de haai die rood is*; ‘the shark that red is’; Bernolet, Hartsuiker, and Pickering 2007). This restriction follows from our assumption that syntactic representations are specified for both hierarchical and linear relations. Other studies of between-language priming support our claims that semantic representations encode thematic information and information structure (e.g., Bernolet, Hartsuiker, and Pickering 2009; Fleischer, Pickering, and McLean 2012).

More speculatively, structural priming might allow researchers to detect linguistic universals that are accessible in adult speakers (i.e., not just as an ‘initial state’ that disappears during development). For example, priming has not been demonstrated with agglutinative languages. Our account assumes abstract syntactic structure, independent of lexical or morphological content, and hence that priming will occur between examples of the same structure where the verb involves considerable morphological differences. For instance, a sentence with an NP PP V syntactic representation would prime another sentence with the same representation even if the verb contained many different morphemes, as is possible in an agglutinative language (e.g., Turkish). But if such priming does not occur (or is affected by morphological overlap), it would suggest that syntactic representations are morphosyntactically specified in such languages, so that there is no single well-formedness constraint $VP \rightarrow NP PP V$, but rather different ones depending on the form of the verb.

Another possibility is that constituent structure is not universal (e.g., Evans and Levinson 2009). For example, some researchers have argued that some languages (e.g., Walpiri) are ‘non-configurational’ and do not have hierarchical constituent structure (Hale 1983; Austin and Bresnan 1996). If so, they should not give rise to constituent structure priming within or between languages (though careful comparisons are clearly needed to control for other sources of priming such as thematic order priming).

We propose that a thorough analysis of priming across a full range of languages (e.g., agglutinative and isolating languages, languages with ergative characteristics, ‘non-configurational’ languages, sign languages) is necessary to determine the extent to which our account holds universally, or whether different types of languages involve different representational structures. If our account does not hold universally, then it may still be possible to establish that some properties are universal and some vary across languages. For example, all languages might involve a distinction between semantic and syntactic representations, but in some languages syntactic representations might include ‘missing’ elements and in some languages they might not. Priming might therefore allow us to develop a cognitive representational approach to language typology.

3.3 Structural priming and language development

Research on language development has – perhaps more strongly than research on adult language – recognized the importance of priming as a means of investigating structural representation (Bencini and Valian 2008; Messenger et al. 2012; Rowland et al. 2012; Savage et al. 2003). Structural priming occurs in children across age groups (e.g., 3-year-olds: Bencini and Valian 2008; 6- and 9-year-olds: Messenger, Branigan, and McLean 2012; 3-4-year-olds and 5-6-year-olds: Rowland et al. 2012; 3-, 4- and 6-year-olds: Savage et al. 2003; 7-8- and 11-12-year-olds: van Beijsterveldt and van Hell 2009), in comprehension as well as production (4-year-olds: Thothathiri and Snedeker 2008b), in different languages (e.g., English-speaking 4-5-year-olds: Huttenlocher, Vasilyeva, and Shimpi 2004; Spanish-speaking 4- and 5-year-olds: Gámez et al. 2009; Russian-speaking 5-6-year-olds: Vasilyeva and Waterfall 2012), and populations, including bilinguals (between languages; 5-6-year-olds: Vasilyeva et al. 2010), deaf children (11-12-year-olds: van Beijsterveldt and van Hell 2009), children with Specific Language Impairment (4-6-year-olds: Garraffa, Coco, and

Branigan 2015; Leonard 2000; Miller and Deevy 2006; 6-7-year-olds: Riches 2012), and children with an Autistic Spectrum Disorder (8-13-year-olds: Allen et al. 2011; Hopkins, Yuill, and Keller 2016). Of course, some of these children cannot make grammaticality or acceptability judgments, and so it would simply not be possible to investigate their structural representations if researchers relied on these methods.

Evidence from these studies suggests that from a relatively young age, children's structural representations are similar to adults'. Like adults, 3- and 4-year-olds appear to have abstract syntactic representations that are not specified for lexical or thematic content (e.g., Bencini and Valian 2008; Huttenlocher, Vasilyeva, and Shimpi 2004; Messenger et al. 2012; Rowland et al. 2012). Rowland et al. showed that they tended to produce DOs after hearing and repeating DOs involving different nouns and verbs (e.g., Prime: *The king brought the queen a puppy* – Target: *Dora gave Boots a rabbit*). Messenger et al. (2012) showed they were primed to produce passives involving Patient/Agent thematic roles (e.g., *The witch was hugged by the cat*) to the same extent when the prime involved Experiencer/Theme roles (e.g., *The girl was shocked by the tiger*) and Theme/Experiencer roles (e.g., *The girl was ignored by the tiger*). There is some evidence of a lexical boost in children (3-4-year-olds: Branigan and McLean 2016; 7-8-year-olds: van Beijsterveldt and van Hell 2009).

Interestingly, there is no evidence of a stronger lexical boost in young children compared to older children and adults (3-4-year-olds: Peter et al. 2015; Rowland et al. 2012), as might be expected on an account in which early grammars involve 'islands' of information associated with individual verbs, that is, partly lexicalized syntactic structures (Tomasello 1992). These priming studies therefore contribute important evidence to the debate about the extent to which children's early structural representations are abstract versus lexically specified (e.g., Fisher 2001; Goldberg 2006; Pinker 1989; Tomasello 2003).

Importantly, structural priming experiments have also provided evidence to discriminate specific theoretical linguistic accounts (motivated by error and frequency data) of young children's syntactic representations. Messenger et al.'s (2012) demonstration of priming between Experiencer-Theme and Agent-Patient passive sentences provided evidence that 3-4-year-olds' have an abstract representation of passive structure that is not semantically restricted (contra Maratsos et al. 1985). Likewise, Messenger, Branigan, and McLean's (2011) demonstration of priming between short passives and full passives suggests that 3-4-year-olds do not represent short passives in a distinct way from full passives (for example, as an adjectival phrase; Borer and Wexler 1987; Horgan 1976).

Children's semantic representations also appear similar to adults'. For example, Gámez et al. (2009) and Vasilyeva and Waterfall (2012) showed priming of thematic emphasis in Spanish-speaking 4-5-year-olds and Russian-speaking 5-6-year-olds (with passive structures priming patient-emphasized structures), suggesting that children have a thematically specified representation of information structure. Viau, Lidz, and Musolino (2010) found priming of abstract quantified representations, with respect to the scope of negation, in 4-year-olds' comprehension. Children were more likely to adopt a negation-wide interpretation of *Every horse didn't jump a fence* after hearing a sentence with a negation-wide interpretation than after a sentence with negation-narrow interpretation, even when the prime differed in syntax and quantifier order (e.g., *Not every horse jumped over a pig*). These findings all suggest that at least from age three, children and adults have similar representational structures at each level, and similar interfaces between levels. However, it is clearly necessary to test further structures, as well as younger children if possible.

3.4 Further implications

We have argued that the method of structural priming is informative about linguistic representation with reference to evidence from monolingual adults but also bilingual adults and children. Other relevant evidence relates to atypical populations, including demonstrations of structural priming in aphasia (Hartsuiker and Kolk 1998; Saffran and Martin 1997), Specific Language Impairment (Garraffa, Coco, and Branigan 2015; Leonard et al. 2000), and amnesia (Ferreira et al. 2008). For example, aphasic speakers may produce passives (although often containing morphological errors) after repeating unrelated passives, despite not producing such structures spontaneously. Such findings suggest that structural representations may be intact even if not evinced in patients' spontaneous language behavior (and may be relevant to therapy). More theoretically, priming evidence can be used to determine the structure of linguistic representations in language pathologies. Additionally, the neural underpinnings of priming are not well understood (though see Menenti et al. 2011; Noppeney and Price 2004; Segaert et al. 2012; Segaert et al. 2013), but priming is likely to be informative about neurolinguistic representation.

We further propose that structural priming can similarly be used to investigate other aspects of cognition involving structured representations. These may include representations of the results of complex human activities involving domains such as music, mathematics, or artificial languages. In such cases, the representations may of course be derivative of linguistic representations (though it is also possible that they developed independently). For example, Scheepers et al. (2011) showed that people tended to repeat their interpretation of complex arithmetical expressions that lacked brackets (in other words, copying the bracketing from prime to target) and moreover that language and arithmetic could prime each other. Similar priming occurred between language and music (van der Cavey and Hartsuiker 2016).

Another relevant domain is gesture, where evidence suggests that people repeat gesture patterns (Mol et al. 2012). There is, however, no clear priming evidence about the structure of complex gestures expressing events (see Goldin-Meadow et al. 2008). Additionally, it may be possible to investigate priming of structured animal calls (Schlenker et al. 2014). In these cases, there is either little evidence about structure or else it is simply assumed that some ‘standard’ representation (e.g., musical or mathematical notation) is adequate for explaining cognitive representations. Priming may be informative about these representations and indeed the relationships between such representations across domains.

Finally, we return to priming of comprehension – the tendency for comprehension to be affected by comprehension (or production) of previous utterances that share aspects of structure. We have not focused on it because the data are much more limited and less clearly established than priming of production (e.g., there are contradictions concerning when priming occurs without verb repetition; Arai, van Gompel, and Scheepers 2007; Thothathiri and Snedeker 2008a), and because experimental conditions often differ extensively in both form and meaning (e.g., main clause vs. reduced relatives; see Traxler, Tooley, and Pickering 2014).¹³ But priming of comprehension occurs when prime and target differ primarily in form (e.g., active/passive, PO/DO) and the effects reveal shared processes with priming of production (Segaert et al. 2013). Priming in comprehension can be informative about the representation of structures in the absence of alternatives (i.e., when participants do not choose between alternative structures), in a way that appears hard to demonstrate in production. It may also be valuable for investigating populations whose ability to produce language is restricted (e.g., very young children, some aphasics). Importantly, we propose that priming in comprehension is likely to become a technique of similar importance to priming in production for determining linguistic representation.¹⁴

4. Conclusion

Many linguists assume that acceptability judgments are pretty much the only valid means of obtaining data that are informative about linguistic representation. Instead, we have argued that structural priming can provide a valid method with many advantages, and have shown how experimental psychology (and not just traditional linguistics) can be informative about the nature of language. We have now reached the stage at which structural priming is a mature method that provides extensive evidence about representation. Thus, we have used that evidence to develop a general approach to linguistic representation. This account is largely (but not entirely) compatible with a parallel linguistic architecture (e.g., Culicover and Jackendoff 2005), though the data support the existence of some empty elements in the syntactic representation. Structural priming provides evidence about linguistic representation that informs linguistic theory, processing accounts that are based on such theories, and claims about development and language universals. It is a method that has truly come of age, and should help integrate linguistics and the psychology of language, as part of the cognitive sciences of language.

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Notes

¹ Judgments may be non-binary, with sentences being judged more-or-less acceptable, most obviously when elicited using magnitude estimation tasks (Bard, Robertson, and Sorace 1996) or Likert scales, but even researchers who eschew these methods usually assume that some sentences are ‘questionable’ or ‘marginal’. However, these judgments still relate to set membership.

² Priming effects can also be inhibitory (e.g., Goldinger, Luce, and Pisoni 1989), and speakers may on occasion avoid linguistic repetition (see Szmrecsanyi 2006). However, structural priming studies have so far focused on facilitatory effects.

³ Some models of language processing assume that the representations proposed by traditional linguistic theories are an approximation to statistical generalizations (that emerge with experience; see Seidenberg 2007). If so, structural priming effects are informative about these generalizations. For example, the evidence that priming occurs between sentences with different lexical content implies that some such generalizations are not tied to particular words.

⁴ The historical division of labor means that priming experiments concerned with representational questions have typically investigated hypotheses generated on the basis of acceptability judgments. But priming experiments are not parasitic on acceptability judgments, any more than any new scientific method is parasitic on an older method that addressed the same issues. Acceptability judgments are chronologically primary to priming experiments (in the history of the language sciences), but are not theoretically primary.

⁵ Scheepers (2003) found that when people completed sentences such as *The assistant announced the score of the candidate that* they tended to repeat whether they attached the modifier to the first or the second NP (e.g., *was the highest* vs. *was the oldest*). Another

experiment ruled out a purely semantic explanation. Arguably, the sentence types involve the same set of context-free phrase structure rules (in particular, an NP consists of an NP followed by a complementized sentence). One possible explanation is that priming may occur over larger elements of structure than strictly local trees. If so, people may represent frequent or important ‘chunks’ of more global structure as well as local relations (see Culicover and Jackendoff 2005). However, this explanation provides no evidence against the existence of locally defined representations (Branigan et al. 2006).

⁶ Griffin and Weinstein-Tull (2003) found that people were more likely to produce *Alison wished the bad news to be a mistake* (vs. *Alison wished that the bad news was a mistake*) after *Rover begged his owner to be more generous with food* than after *The teaching assistant reported the exam to be too difficult*. The primes have the same constituent order (NP V NP Vinf). They differ in semantics (*report* takes one argument (the event (*difficult(exam)*), yielding *report(difficult(exam))*), whereas *begged* takes two (the entity *owner* and the event *generous(owner)*), yielding *begged(owner, generous(owner))*); but the two version of the target have the same semantics (so this cannot be the locus of priming). A possible explanation is that priming takes place over a syntactic representation in which an argument can be represented twice. Thus, *his owner* is represented twice, corresponding to its semantic representation as an argument of *begged* and as an argument of *generous*; whereas *the exam* is represented once, as an argument of *difficult*. This explanation assumes that the syntactic representation includes missing elements. The authors, however, interpret the priming in terms of a mapping between semantic and syntactic representations, and we cannot distinguish the accounts.

⁷ The lexical boost is not solely due to semantic similarity between prime and target, though such similarity enhances priming (Cleland and Pickering 2003): Cross-linguistic priming (see section 3.2) using translation-equivalent verbs is smaller than would be expected if the lexical

boost resulted purely from semantic repetition (Bernolet, Hartsuiker, and Pickering 2012; Cai et al. 2011; Schoonbaert, Hartsuiker, and Pickering 2007).

⁸ For convenience, we use $X \rightarrow YZ$ to express declarative (non-directional) well-formedness constraints on representations.

⁹ We argued above that the lack of priming between sentences with V PP NP and V NP PP constituent order (Pappert and Pechmann 2014; Pickering, Branigan, and McLean 2002) supports a monostratal account of syntactic representation. Compatible with Cai, Pickering, and Branigan (2012), there is no effect of unordered constituent structure, and the thematic-order and thematic-function effects cancel each other out.

¹⁰ A challenge for Construction Grammar is the evidence that priming seems unaffected by whether prime and target involve the same construction (form-meaning pairing) or not. Thus Konopka and Bock (2009) found equivalent priming within and between non-idioms (e.g., *The graduating senior sent his application in*) and idioms (e.g., *The teenager shot his mouth off*), which constitute different constructions in Construction Grammar. An explanation of such findings in terms of Construction Grammar would have to assume that the form component of constructions can be primed, and that priming takes place between different constructions that share form components to the same extent as it does within a construction. Hence priming could not be used to support the existence of form-meaning pairings.

¹¹ In Culicover and Jackendoff's (2005) account, information structure forms a separate tier of semantic representation from propositional structure.

¹³ Many studies demonstrate facilitation following repeated presentation of a construction, for example reduced processing times for strong garden path sentences (Fine et al. 2013) or marginally unacceptable sentences (Kaschak and Glenberg 2004), and a higher likelihood of judging marginally unacceptable sentences as acceptable (Luka and Barsalou 2005). But the

relationship between such studies and structural priming studies involving individual prime-target pairs is unclear.

¹⁴ Priming may affect response times in production (Corley and Scheepers 2002; Smith and Wheeldon 2001), but current evidence overwhelmingly relates to structure choice.

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