

Chapter 24

Processing

Thomas Wasow 

Stanford University

Although not much psycholinguistic research has been carried out in the framework of HPSG, the architecture of the theory fits well with what is known about human language processing. This chapter enumerates aspects of this fit. It then discusses two phenomena, island constraints and relative clauses, in which the fit between experimental evidence on processing and HPSG analyses seems particularly good.

1 Introduction

Little psycholinguistic research has been guided by ideas from HPSG (but see Konieczny 1996 for a notable exception). This is not so much a reflection on HPSG as on the state of current knowledge of the relationship between language structure and the unconscious processes that underlie language production and comprehension. Other theories of grammar have likewise not figured prominently in theories of language processing, at least in recent decades.¹ The focus of this chapter, then, will be on how well the architecture of HPSG comports with available evidence about language production and comprehension.

My argument is much the same as that put forward by Sag et al. (2003: Chapter 9), and Sag & Wasow (2011, 2015), but with some additional observations about the relationship between competence and performance. I presuppose the “competence hypothesis” (see Chomsky 1965: Chapter 1), that is, that a theory

¹Half a century ago, the Derivational Theory of Complexity (DTC) was an attempt to use psycholinguistic experiments to test aspects of the grammatical theory that was dominant at the time. The DTC was discredited in the 1970s, and the theory it purported to support has long since been superseded. See Fodor et al. (1974) for discussion.



of language use (performance) should incorporate a grammar representing the knowledge of language (competence) that is drawn on in everyday comprehension and production, as well as in other linguistic activities, such as language games and the (often artificial) tasks employed in psycholinguistic experiments.

The primary reason for adopting the competence hypothesis is parsimony: a theory of language use is simpler if it does not have to repeat much the same information about the language in both its production and comprehension components. This information would include things like the vocabulary, the preferred word orders, and most of the rest of what linguists encode in their grammars. A performance theory that incorporates a grammar only needs to include such information once.² Moreover, to the extent that the theoretical constructs of the grammar play a role in modeling both production and comprehension, the overall theory is simpler.

There is also, however, an empirical reason for preferring a model with a good fit between competence and performance. As noted by Bresnan et al. (2001), preferences that are only statistical tendencies in some languages can show up in others as categorical requirements. The example they discuss in detail is the avoidance of clauses with third-person subjects but first- or second-person objects or obliques. In English, this is a powerful statistical tendency, which they document by showing that the passivization rate in the Switchboard corpus is very significantly lower when the agent is first- or second-person than when it is third-person. In Lummi (a Salish language of British Columbia), this preference is categorical: clauses with third-person subjects but first- or second-person objects or obliques are simply unacceptable. Hawkins (2004, 2014) argues that such examples are by no means exceptional, and formulates the following “Performance–Grammar Correspondence Hypothesis” (PGCH):

²There are of course some discrepancies between production and comprehension that need to be accounted for in a full theory of language use. For example, most people can understand some expressions that they never use, including such things as dialect-specific words or accents. But these discrepancies are on the margins of speakers’ knowledge of their languages. The vast majority of the words and structures that speakers know are used in both production and comprehension. Further, it seems to be generally true that what speakers can produce is a proper subset of what they can comprehend. Hence, the discrepancies can plausibly be attributed to performance factors such as memory or motor habits. See Gollan et al. (2011) for evidence of differences between lexical access in production and comprehension. See Momma & Phillips (2018) for arguments that the structure-building mechanisms in production and comprehension are the same. For a thoughtful discussion of the relationship between production and comprehension, see MacDonald (2013) and the commentaries published with it.

Grammars have conventionalized syntactic structures in proportion to their degree of preference in performance, as evidenced by frequency of use and ease of processing.³

There are two ways in which a processing model incorporating a grammar might capture this generalization. One is to give up the widespread assumption that grammars provide categorical descriptions, and that any quantitative generalizations must be extra-grammatical; see Francis (2021) for arguments supporting this option, and thoughtful discussion of literature on how to differentiate processing effects from grammar. For example, some HPSG feature structure descriptions might allow multiple values for the same feature, but with probabilities (adding up to 1) attached to each value.⁴ I hasten to add that fleshing out this idea into a full-fledged probabilistic version of HPSG would be a large undertaking, well beyond the scope of this chapter; see Linardaki (2006) and Miyao & Tsujii (2008) for work along these lines. But the idea is fairly straightforward, and would allow, for example, English to have *in its grammar* a non-categorical constraint against clauses with third-person subjects and first- or second-person objects or obliques.

The second way for a theory adopting the competence hypothesis to represent Hawkins's PGCH would be to allow certain generalizations to be stated either as grammatical constraints (when they are categorical) or as probabilistic performance constraints. This requires a fit between the grammar and the other components of the performance model that is close enough to permit what is essentially the same generalization to be expressed in the grammar or elsewhere. In the case discussed by Bresnan et al., for example, treating the constraint in question as part of the grammar of Lummi but a matter of performance in English would require that both the theory of grammar and models of production would include, minimally, the distinction between third-person and other per-

³In the Bresnan et al. example, I know of no experimental evidence that clauses with third-person subjects and first- or second-person objects are difficult to process. But a plausible case can be made that the high salience of speaker and addressee makes the pronouns referring to them more accessible in both production and comprehension than expressions referring to other entities. In any event, clauses with first- or second-person subjects and third-person objects are far more frequent than clauses with the reverse pattern in languages where this has been checked. Thus, the Bresnan et al. example falls under the PGCH, at least with respect to "frequency of use".

⁴I discussed this idea many times with the late Ivan Sag. He made it clear that he believed grammatical generalizations should be categorical. In part for that reason, this idea was not included in our joint publications on processing and HPSG.

sons, and the distinction between subjects and non-subjects. Since virtually all theories of grammar make these distinctions, this observation is not very useful in choosing among theories of grammar. I will return later to phenomena that bear on the choice among grammatical theories, at least if one accepts the competence hypothesis.

Since its earliest days, HPSG research has been motivated in part by considerations of computational tractability (see Flickinger, Pollard & Wasow 2024, Chapter 2 of this volume, for discussion). Some of the design features of the theory can be traced back to the need to build a system that could run on the computers of the 1980s. Despite the obvious differences between human and machine information processing, some aspects of HPSG's architecture that were initially motivated on computational grounds have turned out to fit well with what is known about human language processing. A prime example of that is the computational analogue to the competence hypothesis, namely the fact that the same grammar is used for parsing and generation. In Section 3, I will discuss a number of other high-level design properties of HPSG, arguing that they fit well with what is known about human language processing, which I summarize in Section 2. In Section 4, I will briefly discuss two phenomena that have been the locus of much discussion about the relationship between grammar and processing, namely island constraints and differences between subject and object relative clauses.

2 Key facts about human language processing

In this section I review a number of well-known general properties of human language processing. Most of them seem evident from subjective experience of language use, but there is supporting experimental evidence for all of them.

2.1 Incrementality

Both language production and comprehension proceed incrementally, from the beginning to the end of an utterance. In the case of production, this is evident from the fact that utterances unfold over time. Moreover, speakers very often begin their utterances without having fully planned them out, as is evident from the prevalence of disfluencies. On the comprehension side, there is considerable evidence that listeners (and readers) begin analyzing input right away, without waiting for utterances to be complete. A grammatical framework that assigns structure and meaning to initial substrings of sentences will fit more naturally than one that doesn't into a processing model that exhibits this incrementality we see in human language use.

I hasten to add that there is also good evidence that both production and comprehension involve anticipation of later parts of sentences. While speakers may not have their sentences fully planned before they begin speaking, some planning of downstream words must take place. This is perhaps most evident from instances of nouns exhibiting quirky cases determined by verbs that occur later in the clause. For example, objects of German *helfen*, ‘help’, take the dative case, rather than the default accusative for direct objects. But in a sentence like (1), the speaker must know that the verb will be one taking a dative object at the time the dative case article *dem* is uttered.

- (1) Wir werden dem Kind bald helfen. (German)
 we will the.DAT child soon help
 ‘We will help the child soon.’

Likewise, in comprehension there is ample evidence that listeners and readers anticipate what is to come. This has been demonstrated using a variety of experimental paradigms. Eye-tracking studies (see Tanenhaus et al. 1995, Altmann & Kamide 1999, Arnold et al. 2007, among many others) have shown that listeners use semantic information and world knowledge to predict what speakers will refer to next.

Thus, a theory of grammar that fits comfortably into a model of language use should provide representations of initial substrings of utterances that can be assigned (partial) meanings and be used in predicting later parts of those utterances.

2.2 Non-modularity

Psycholinguistic research over the past four decades has established that language processing involves integrating a wide range of types of information on an as-needed basis. That is, the various components of the language faculty interact throughout their operation. A model of language use should therefore *not* be modular, in the sense of Jerry Fodor’s influential 1983b book, *The Modularity of Mind*.⁵

⁵Much of the psycholinguistic research of the 1980s was devoted to exploring modularity – that is, the idea that the human linguistic faculty consists of a number of distinct “informationally encapsulated” modules. While Fodor’s book was mostly devoted to arguing for modularity at a higher level, where the linguistic faculty was one module, many researchers at the time extended the idea to the internal organization of the linguistic faculty, positing largely autonomous mechanisms for phonology, morphology, syntax, semantics, and pragmatics, with the operations of each of these sub-modules unaffected by the operations of the others. The outcome of years of experimental studies on the linguistic modularity idea was that it was aban-

Some casual observations argue against modular language processing. For example, the famously ambiguous sentences (2a) and (2b) can be disambiguated in speech by the stress patterns.

- (2) a. I forgot how good beer tastes.
b. Dogs must be carried.

The two meanings of (2a) correspond to two different parses (one with *good* as part of the noun phrase *good beer* and the other with *how good* as a verb phrase modifier). The two meanings of (2b) have the same syntactic structure, but differ in whether the requirement is that all dogs be carried, or that everyone carry a dog. This interaction of prosody with syntax (in the case of (2a)) and with semantics (in the case of (2b)) is produced and perceived before the end of the utterance, suggesting that phonological information is available in the course of syntactic and semantic processing.

Moreover, non-linguistic knowledge influences the disambiguation in both of these cases. If (2a) is preceded by “I just finished three weeks without alcohol”, the natural interpretation of *good* is as a modifier of *tastes*; but following “I just finished three weeks drinking only Bud Light”, *good* is more naturally interpreted as a modifier of *beer*. In the case of (2b), only one interpretation (that anyone with a dog must carry it) is plausible, given our knowledge of the world. Indeed, most non-linguists fail to see the ambiguity of (2b) without a lengthy explanation.

More rigorous evidence of the non-modular character of language processing has been provided by a variety of types of experiments. The work of Michael Tanenhaus and his associates, using eye-tracking to investigate the time-course of sentence comprehension, played an important role in convincing most psycholinguists that human language understanding is non-modular. See, for example, Eberhard et al. (1995), McMurray et al. (2008), Tanenhaus et al. (1995), Tanenhaus et al. (1996), and Tanenhaus & Trueswell (1995). A recent survey of work arguing against modularity in language processing is provided by Spevack et al. (2018).

2.3 Importance of words

The individual properties of words play a central role in how people process phrases and sentences. Consider, for example, what is probably the most famous sentence in psycholinguistics, (3), due originally to Bever (1970: 320).

done by most psycholinguists. For an early direct response to Fodor, see Marslen-Wilson & Tyler (1987).

- (3) The horse raced past the barn fell.

The extreme difficulty that people who have not previously been exposed to (3) have comprehending it depends heavily on the choice of words. A sentence like (4), with the same syntactic structure, is far easier to parse.

- (4) The applicant interviewed in the morning left.

Numerous studies (e.g. Ford et al. 1982; Trueswell et al. 1993; MacDonald et al. 1994; Bresnan et al. 2007; Wasow et al. 2011) have shown that such properties of individual words as subcategorization preferences, semantic categories (e.g. animacy), and frequency of use can influence the processing of utterances.

2.4 Influence of context

Much of the evidence against modularity of the language faculty is based on the influences of non-linguistic context and world knowledge on language processing. The well-known McGurk effect (McGurk & MacDonald 1976) and the Stroop effect (Stroop 1935) demonstrate that, even at the word level, visual context can influence linguistic comprehension and production.

Linguistic context also clearly influences processing, as the discussion of examples (2a) and (2b) above illustrates. The same conclusion is supported by numerous controlled studies, including, among many others, those described by Crain & Steedman (1985), Altmann & Steedman (1988), Branigan (2007), Traxler & Tooley (2007), Matsuki et al. (2011), and Spevack et al. (2018). The last of these references concludes (p. 11), “when humans and their brains are processing language with each other, there is no format of linguistic information (e.g., lexical, syntactic, semantic, and pragmatic) that cannot be rapidly influenced by context.”

2.5 Speed and accuracy of processing

A good deal of psycholinguistic literature is devoted to exploring situations in which language processing encounters difficulties, notably work on garden paths (in comprehension) and disfluencies (in production). Much more striking than the existence of these phenomena, however, is how little they matter in everyday language use. While ambiguities abound in normal sentences (see Wasow 2015 and also Bender & Emerson 2024: Section 2.2.2, Chapter 25 of this volume), comprehenders very rarely experience noticeable garden paths. Similarly, disfluencies in spontaneous speech occur in nearly every sentence but rarely disrupt communication.

People are able to use speech to exchange information remarkably efficiently. A successful account of human language processing must explain why it works as well as it does.

3 Features of HPSG that fit well with processing facts

In this section, I review some basic design features of HPSG, pointing out ways in which they comport well with the properties of language processing listed in the previous section.

3.1 Constraint-based

Well-formedness of HPSG representations is defined by the simultaneous satisfaction of a set of constraints that constitutes the grammar (Richter 2024: 99, Chapter 3 of this volume). This lack of directionality allows the same grammar to be used in modeling production and comprehension.

Consider, for instance, the example of quirky case assignment illustrated in (1) above. A speaker uttering (1) would need to have planned to use the verb *helfen* ‘help’ before beginning to utter the object NP. But a listener hearing (1) would encounter the dative case on the article *dem* before hearing the verb and could infer only that a verb taking a dative object was likely to occur at the end of the clause. Hence, the partial mental representations built up by the two interlocutors during the course of the utterance would be quite different. But the grammatical mechanism licensing the combination of a dative object with this particular verb is the same for speaker and hearer.

In contrast, theories of grammar that utilize sequential operations to derive sentences impose a directionality on their grammars. If such a grammar is then to be employed as a component in a model of language use (as the competence hypothesis stipulates), its inherent directionality becomes part of the models of both production and comprehension. But production involves mapping meaning onto sound, whereas comprehension involves the reverse mapping. Hence, a directional grammar cannot fit the direction of processing for both production and comprehension.⁶

⁶This was an issue for early work in computational linguistics that built parsers based on the transformational grammars of the time, which generated sentences using derivations whose direction went from an underlying structure largely motivated by semantic considerations to the observable surface structure. See, for example, Hobbs & Grishman (1975).

Branigan & Pickering (2017) argue at length that “structural priming provides an implicit method of investigating linguistic representations”.⁷ They go on to conclude (p. 14) that the evidence from priming supports “frameworks that ... assume nondirectional and constraint-based generative capacities (i.e., specifying well-formed structures) that do not involve movement”.⁸ HPSG is one of the frameworks they mention that fit this description.

3.2 Surface-oriented

The features and values in HPSG representations are motivated by straightforwardly observable linguistic phenomena. HPSG does not posit derivations of observable properties from abstract underlying structures. In this sense it is surface-oriented.

The evidence linguists use in formulating grammars consists of certain types of performance data, primarily judgments of acceptability and meaning. Accounts of the data necessarily involve some combination of grammatical and processing mechanisms. The closer the grammatical descriptions are to the observable phenomena, the less complex the processing component of the account needs to be.

For example, the grammatical theory of Kayne (1994), which posits a universal underlying order of specifier-head-complement, requires elaborate (and directional) transformational derivations to relate these underlying structures to the observable data in languages whose surface order is different (a majority of the languages of the world). In the absence of experimental evidence that the production and comprehension of sentences with different constituent orders involve mental operations corresponding to the grammatical derivations Kayne posits, his theory of grammar seems to be incompatible with the competence hypothesis.

Experimental evidence supports this reasoning. As Branigan & Pickering (2017: 9) conclude, “[P]riming 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 [...] Pollard & Sag (1994) [...]. It does not support a second, underlying level of syntactic structure or the

⁷Priming is the tendency for speakers to re-use linguistic elements that occurred earlier in the context; structural priming (which Branigan & Pickering sometimes call *abstract priming*) is priming of linguistic structures, abstracted from the particular lexical items in those structures.

⁸Branigan & Pickering’s conclusions are controversial, as is evident from the commentaries accompanying their target article.

syntactic representation of empty categories associated with the movement of constituents in some transformational analyses.”

3.3 Informationally rich representations

The feature structure descriptions of HPSG include all types of linguistic information relevant to the well-formedness and interpretation of expressions. This includes phonological, morphological, syntactic, semantic, and contextual information. They can also incorporate non-linguistic contextual information (e.g. social information), though this has not been extensively explored.

The cooccurrence of these different types of information within a single representation facilitates modeling production and comprehension processes that make reference to more than one of them. The architecture of the grammar is thus well suited to the non-modularity and context-sensitivity of language processing. It is interesting in this regard to consider the conclusions of two papers by psycholinguists who surveyed experimental evidence and inferred what types of grammatical information were essential for processing.

The following series of quotes captures the essence of what MacDonald et al. (1994) wrote regarding lexical representation, based on a survey of a wide range of psycholinguistic studies:

- “[T]he lexical representation for a word includes a representation of the word’s phonological form, orthographic form, semantics, grammatical features (including grammatical category), morphology (at least inflectional), argument structure, and X-bar structure.” (p. 684)
- “[T]he connection structure of the lexicon encodes relationships among different types of lexical information.”⁹ (p. 684)
- “In addition to constraints that hold between various aspects of lexical representations, sentence and discourse contexts also constrain lexical representations during processing [...]” (p. 686)

With the possible exception of “X-bar structure”, this sounds very much like a description of the types of information included in HPSG feature structure descriptions.

Over twenty years later, Branigan & Pickering (2017) came to the following conclusions about linguistic representations, based on priming studies:

⁹A reviewer asked what feature of HPSG this maps into. The answer is straightforward: a word’s phonological form, semantics, grammatical features, morphology, and argument structure are all represented together in one feature structure description, and the different pieces of the description may be linked through coindexing or tagging.

- “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 subphrases that constitute it (e.g., that the first NP comprises a determiner, adjective, and noun).” (p. 9)
- “[S]ome elements that are not phonologically represented may be syntactically represented.” (p. 10)
- “Other priming evidence similarly indicates that some semantically specified elements are not specified syntactically.” (p. 11)
- “[T]he semantic level of representation contains at least specifications of quantificational information, information structure, and thematic roles.” (p. 11)
- “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.” (p. 12)

The two lists are quite different. This is in part because the focus of the earlier paper was on lexical representations, whereas the later paper was on linguistic representations more generally. It may also be attributable to the fact that MacDonald et al. framed their paper around the issue of ambiguity resolution, while Branigan & Pickering’s paper concentrated on what could be learned from structural priming studies. Despite these differences, it is striking that the conclusions of both papers about the mental representations employed in language processing are very much like those arrived at by work in HPSG.

3.4 Lexicalism

A great deal of the information used in licensing sentences in HPSG is stored in the lexical entries for words (see Müller & Wechsler 2014 and also Abeillé & Borsley 2024: Section 4, Chapter 1 of this volume). A hierarchy of lexical types permits commonalities to be factored out to minimize what has to be stipulated in individual entries, but the information in the types gets into the representations of phrases and sentences through the words that instantiate those types. Hence,

it is largely the information coming from the words that determines the well-formedness of larger expressions. Any lexical decomposition would have to be strongly motivated by the morphology.

Branigan & Pickering (2017: Section 2.3) note that grammatical structures (what some might call *constructions*) such as V-NP-NP can prime the use of the same abstract structure, even in the absence of lexical overlap. But they also note that the priming is consistently significantly stronger when the two instances share the same verb, a fact known as *the lexical boost*. They write, “To explain abstract priming, lexicalist theories must assume that the syntactic representations [...] are shared across lexical entries.” (p. 12) The types in HPSG’s lexicon provide just such representations. Branigan & Pickering go on to say that the lexical boost argues for “a representation that encodes a binding between constituent structure and the lemma [...] of the lexical entry for the head.” In HPSG, this “binding” is simply the fact that the word providing the lexical boost (say, *give*) is an instantiation of a type specifying the structures it appears in (e.g. the ditransitive verb type, see also Yi, Koenig & Roland 2019).

Similarly, the fact, noted in Section 2.3 above, that a given structure may be more or less difficult to process depending on word choice is unsurprising in HPSG, so long as the processor has access to information about individual words and not just their types.

Wittenberg and her collaborators (Wittenberg & Piñango 2011, Wittenberg et al. 2014) describe a number of experiments, both behavioral and neuroimaging and involving both comprehension and production, comparing the processing of light verb constructions like (5) with non-light counterparts like (6).

- (5) a. Henry took a walk.
b. Henry gave Elsa a kiss.
- (6) a. Henry took a spoon.
b. Henry gave Elsa a rose.

Although the light verb usages have higher corpus frequencies, the experiments consistently showed that the light verb uses took more processing effort. Wittenberg et al. use the results to argue for a lexicalist analysis of light verbs, attributing the extra processing complexity to the fact that the object of a light verb denotes an event, whose event structure must be combined with that of the light verb. The lexical approach to (Persian) light verb constructions was argued for by Müller (2010) for independent reasons. Wittenberg et al. use their results to argue for an analysis like Müller’s over both the Construction Grammar approach

of Goldberg (2003) and Hale & Keyser's (1993, 2002) Minimalist treatment. See also Godard & Samvelian (2024: Section 6), Chapter 11 of this volume.

3.5 Underspecification

HPSG allows a class of linguistic structures that share some feature values to be characterized by means of feature structure descriptions that specify only the features whose values are shared. Such underspecification is very useful for a model of processing (particularly a model of the comprehender) because it allows partial descriptions of the utterance to be built up, based on the information that has been encountered. This property of the grammar makes it easy to incorporate into an incremental processing model.

4 Two phenomena of interest

4.1 Island constraints

Ever since Ross's seminal dissertation (1967) introduced the notion of "island constraints", linguists have sought explanations for their existence, often suggesting that they were motivated by processing considerations (notably Grosu 1972; Fodor 1983a; Deane 1991). The basic idea is that island constraints restrict the search space the parser needs to consider in looking for a gap to match a filler it has encountered, thereby facilitating processing. This then raises the question of whether island constraints need to be represented in grammar (language particular or universal), or can be attributed entirely to processing and/or other factors, such as pragmatics.

In principle, this question is orthogonal to the choice among theories of grammar. But in recent years, a controversy has arisen between some proponents of HPSG and certain transformational grammarians, with the former (e.g. Chaves 2012; 2024, Chapter 15 of this volume; Hofmeister & Sag 2010; Hofmeister, Jaeger, Arnon, Sag & Snider 2013; Chaves & Putnam (2020)) arguing that certain island phenomena should be attributed entirely to extra-grammatical factors, and the latter (e.g. Phillips 2013 and Sprouse et al. 2012) arguing that island constraints are part of grammar.

I will not try to settle this dispute here. Rather, my point in this subsection is to note that a theory in which there is a close fit between the grammar and processing mechanisms allows for the possibility that some island phenomena should be attributed to grammatical constraints, whereas others should be explained in terms of processing. Indeed, if the basic idea that islands facilitate processing

is correct, it is possible that some languages, but not others, have grammaticalized some islands, but not others. That is, in a theory in which the grammar is a tightly integrated component of a processing model, the question of whether a particular island phenomenon is due to a grammatical constraint is an empirical one whose answer might differ from language to language.

Early work on islands (e.g. Ross 1967 and Chomsky 1973) assumed that, in the absence of negative evidence, island constraints could not be learned and hence must be innate and therefore universal. But cross-linguistic variation in island constraints, even between closely related languages, has been noted since the early days of research on the topic (see e.g. Erteschik-Shir 1973 and Engdahl & Ejerhed 1982).

This situation is what one might expect if languages differ with respect to the extent to which the processing factors that motivate islandhood have been grammaticalized. In short, a theory with a tight fit between its grammatical machinery and its processing mechanisms allows for hybrid accounts of islands that are not available to theories without such a fit.

One example of such a hybrid is Chaves's (2012) account of Ross's Coordinate Structure Constraint. Following much earlier work, Chaves distinguishes between the "conjunct constraint", which prohibits a gap from serving as a conjunct in a coordinate structure (as in **What did you eat a sandwich and?*) and the "element constraint", which prohibits a gap from serving as an element of a larger conjunct (as in **What did you eat a sandwich and a slice of?*). The conjunct constraint, he argues, follows from the architecture of HPSG and is therefore built into the grammar. The element constraint, on the other hand, has exceptions and, he claims, should be attributed to extra-grammatical factors. See Chaves (2024), Chapter 15 of this volume for a more detailed discussion of islands.

4.2 Subject vs. object relative clauses

One of the most discussed phenomena in the literature on human sentence processing is the difference in processing complexity between relative clauses (RCs) in which the gap is the subject and those in which the gap is the object – or, as they are commonly called, "subject RCs" and "object RCs"; see, among many others, Wanner & Maratsos (1978), Gibson (1998), Traxler et al. (2002), and Gennari & MacDonald (2008). Relative clause processing complexity has been shown to be influenced by a number of factors other than the grammatical function of the gap, including the animacy and pronominality of the overt NP in the RC, as well as

the frequency, animacy, and discourse properties of the head of the RC.¹⁰ When these factors are controlled for, however, most psycholinguists accept that it has been established that subject RCs are generally easier to process than object RCs, at least in English.¹¹

One approach to explaining this asymmetry has been based on the distance between the filler and the gap (see, among others, Wanner & Maratsos 1978; Gibson 1998; Hawkins 2004). In languages like English, with basic SVO clause order and RCs that follow the nouns they modify, the distance between the filler (the relativizer or head noun) and the gap is greater for an object gap than for a subject gap. If holding a filler in memory until the gap is encountered puts an extra burden on the processor, this could explain why object RCs are harder to process than subject RCs. This distance-based account makes an interesting prediction for languages with different word orders. In languages like Japanese with SOV order and RCs that precede the nouns they modify, the distance relationships are reversed – that is, the gaps in object RCs are closer to their fillers than those in subject RCs. The same is true of Chinese, with basic SVO order and RCs that precede the nouns they modify. So the prediction of distance-based accounts of the subject/object RC processing asymmetry is that it should be reversed in these languages.

The experimental evidence on this prediction is somewhat equivocal. While Hsiao & Gibson (2003) found a processing preference for object RCs over subject RCs in Chinese, their findings were challenged by Lin & Bever (2006) and Vasishth et al. (2013), who claimed that Chinese has a processing preference for subject RCs. In Japanese, Miyamoto & Nakamura (2003) found that subject RCs

¹⁰The stimuli in the experimental studies on this topic always have RCs with one overt NP, either in subject or object position and a gap corresponding to the other grammatical function. In most of the studies, that NP is non-pronominal and animate. See Reali & Christiansen (2007) and Roland et al. (2012) for evidence of the role of these factors in processing complexity.

¹¹This processing difference corresponds to the top end of the “accessibility hierarchy” that Keenan & Comrie (1977) proposed as a linguistic universal. Based on a diverse sample of 50 languages, they proposed the hierarchy below, and hypothesized that any language allowing RC gaps at any point in the hierarchy would allow RC gaps at all points higher (to the left) on the hierarchy.

- (i) Subject > Direct Object > Indirect Object > Oblique > Genitive > Object of Comparison

Keenan & Comrie speculated that the generality of this hierarchy of relativizability lay in processing, specifically on the comprehension side. The extensive experimental evidence that has been adduced in support of this idea in the intervening decades has been concentrated on subject RCs vs. (direct) object RCs. The remainder of the hierarchy remains largely untested by psycholinguists.

were processed more easily than object RCs. The issue remains controversial, but, for the most part, the evidence has not supported the idea that the processing preference between subject RCs and object RCs varies across languages with different word orders.

The most comprehensive treatment of English RCs in HPSG is Sag (1997). Based entirely on distributional evidence, Sag's analysis treats (finite) subject RCs as fundamentally different from RCs whose gap does not function as the subject of the RC. The difference is that the *SLASH* feature, which encodes information about long-distance dependencies in HPSG, plays no role in the analysis of subject RCs. Non-subject RCs, on the other hand, involve a non-empty *SLASH* value in the RC.¹²

Sag deals with a wide variety of kinds of RCs. From the perspective of the processing literature, the two crucial kinds are exemplified by (7a) and (7b), from Gibson (1998: 2).

- (7) a. The reporter who attacked the Senator admitted the error.
- b. The reporter who the Senator attacked admitted the error.

A well-controlled experiment on the processing complexity of subject and object RCs must have stimuli that are matched in every respect except the role of the gap in the RC. Thus, the conclusion that object RCs are harder to process than subject RCs is based on a wide variety of studies using stimuli like (7). Sag's analysis of (7a) posits an empty *SLASH* value in the RC, whereas his analysis of (7b) posits a non-empty *SLASH* value.

There is considerable experimental evidence supporting the idea that unbounded dependencies – that is, what HPSG encodes with the *SLASH* feature – add to processing complexity; see, for example, Wanner & Maratsos (1978), King & Just (1991), Kluender & Kutas (1993), and Hawkins (1999). Combined with Sag's HPSG analysis of English RCs, this provides an explanation of the processing preference of subject RCs over object RCs. On such an account, the question of which other languages will exhibit the same preference boils down to the question of which other languages have the same difference in the grammar of subject and object RCs. At least for English, this is a particularly clear case in which the architecture of HPSG fits well with processing evidence.

¹²The idea that at least some subject gaps differ in this fundamental way from non-subject gaps goes back to Gazdar (1981: 171–172).

5 Conclusion

This chapter opened with the observation that HPSG has not served as the theoretical framework for much psycholinguistic research. The observations in Sections 2 through 4 argue for rectifying that situation. The fit between the architecture of HPSG and what is known about human sentence processing suggests that HPSG could be used to make processing predictions that could be tested in the lab.

To take one example, the explanation of the processing asymmetry between subject and object RCs offered above is based on a grammatical difference in the HPSG analysis: all else being equal, expressions with non-empty *SLASH* values are harder to process than those with empty *SLASH* values. Psycholinguists could test this idea by looking for other cases of phenomena that look superficially very similar but whose HPSG analyses differ with respect to whether *SLASH* is empty. One such case occurs with pairs like Chomsky's (1977: 103) famous minimal pair in (8).

- (8) a. Chris is eager to please.
b. Chris is easy to please.

Under the analysis of Pollard & Sag (1994: Section 4.3), *to please* in (8b) has a non-empty *SLASH* value but an empty *SLASH* value in (8a). Processing (8a) should therefore be easier. This prediction could be tested experimentally, and modern methods such as eye-tracking could pinpoint the locus of any difference in processing complexity to determine whether it corresponds to the region where the grammatical analysis involves a difference in *SLASH* values.

The current disconnect between theoretical investigations of language structure and psycholinguistic studies is an unfortunate feature of our discipline. Because HPSG comports so well with what is known about processing, it could serve as the basis for a reconnection between these two areas of study.

Acknowledgments

A number of people made valuable suggestions on a preliminary outline and an earlier draft of this chapter, leading to improvements in content and presentation, as well as the inclusion of previously overlooked references. In particular, I received helpful comments from (in alphabetical order): Emily Bender, Bob Borsley, Rui Chaves, Danièle Godard, Jean-Pierre Koenig, and Stefan Müller. Grateful

as I am for their advice, I take sole responsibility for any shortcomings in the chapter.

References

- Abeillé, Anne & Robert D. Borsley. 2024. Basic properties and elements. In Stefan Müller, Anne Abeillé, Robert D. Borsley & Jean-Pierre Koenig (eds.), *Head-Driven Phrase Structure Grammar: The handbook*, 2nd revised edn. (Empirically Oriented Theoretical Morphology and Syntax 9), 3–45. Berlin: Language Science Press. DOI: 10.5281/zenodo.13644935.
- Altmann, Gerry T. M. & Yuki Kamide. 1999. Incremental interpretation at verbs: Restricting the domain of subsequent reference. *Cognition* 73(3). 247–264. DOI: 10.1016/S0010-0277(99)00059-1.
- Altmann, Gerry & Mark Steedman. 1988. Interaction with context during human sentence processing. *Cognition* 30(3). 191–238. DOI: 10.1016/0010-0277(88)90020-0.
- Arnold, Jennifer E., Carla L. Hudson Kam & Michael K. Tanenhaus. 2007. If you say *thee uh* you are describing something hard: The on-line attribution of disfluency during reference comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 33(5). 914–930. DOI: 10.1037/0278-7393.33.5.914.
- Barwise, Jon & Robin Cooper. 1981. Generalized quantifiers and natural language. *Linguistics and Philosophy* 4(2). 159–219. DOI: 10.1007/BF00350139.
- Barwise, Jon & John Perry. 1983. *Situations and attitudes*. Cambridge, MA: MIT Press. Reprint as: *Situations and attitudes* (The David Hume Series of Philosophy and Cognitive Science Reissues). Stanford, CA: CSLI Publications, 1999.
- Bender, Emily M. & Guy Emerson. 2024. Computational linguistics and grammar engineering. In Stefan Müller, Anne Abeillé, Robert D. Borsley & Jean-Pierre Koenig (eds.), *Head-Driven Phrase Structure Grammar: The handbook*, 2nd revised edn. (Empirically Oriented Theoretical Morphology and Syntax 9), 1181–1229. Berlin: Language Science Press. DOI: 10.5281/zenodo.13645044.
- Bever, Thomas G. 1970. The cognitive basis for linguistic structures. In John R. Hayes (ed.), *Cognition and the development of language*, 279–362. New York, NY: Wiley & Sons, Inc.
- Branigan, Holly. 2007. Syntactic priming. *Language and Linguistics Compass* 1(1–2). 1–16. DOI: 10.1111/j.1749-818X.2006.00001.x.

- Branigan, Holly & Martin Pickering. 2017. An experimental approach to linguistic representation. *Behavioral and Brain Sciences* 40. 1–61. DOI: 10.1017/S0140525X16002028.
- Bresnan, Joan, Anna Cueni, Tatjana Nikitina & Harald Baayen. 2007. Predicting the dative alternation. In Gerlof Bouma, Irene Krämer & Joost Zwarts (eds.), *Cognitive foundations of interpretation*, 69–94. Amsterdam: KNAW.
- Bresnan, Joan, Shipra Dingare & Christopher D. Manning. 2001. Soft constraints mirror hard constraints: Voice and person in English and Lummi. In Miriam Butt & Tracy Holloway King (eds.), *Proceedings of the LFG '01 conference, University of Hongkong*, 13–32. Stanford, CA: CSLI Publications. <http://csli-publications.stanford.edu/LFG/6/pdfs/lfg01bresnanetal.pdf> (10 February, 2021).
- Carpenter, Bob. 1992. *The logic of typed feature structures* (Cambridge Tracts in Theoretical Computer Science 32). Cambridge: Cambridge University Press. DOI: 10.1017/CBO9780511530098.
- Chaves, Rui P. 2012. On the grammar of extraction and coordination. *Natural Language & Linguistic Theory* 30(2). 465–512. DOI: 10.1007/s11049-011-9164-y.
- Chaves, Rui P. 2024. Island phenomena and related matters. In Stefan Müller, Anne Abeillé, Robert D. Borsley & Jean-Pierre Koenig (eds.), *Head-Driven Phrase Structure Grammar: The handbook*, 2nd revised edn. (Empirically Oriented Theoretical Morphology and Syntax 9), 713–773. Berlin: Language Science Press. DOI: 10.5281/zenodo.13644997.
- Chaves, Rui P. & Michael T. Putnam. 2020. *Unbounded dependency constructions: Theoretical and experimental perspectives* (Oxford Surveys in Syntax and Morphology 10). Oxford: Oxford University Press.
- Chomsky, Noam. 1965. *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.
- Chomsky, Noam. 1973. Conditions on transformations. In Stephen R. Anderson & Paul Kiparsky (eds.), *A Festschrift for Morris Halle*, 232–286. New York, NY: Holt, Rinehart & Winston.
- Chomsky, Noam. 1977. On *wh*-movement. In Peter W. Culicover, Thomas Wasow & Adrian Akmajian (eds.), *Formal syntax: Proceedings of the 1976 MSSB Irvine Conference on the Formal Syntax of Natural Language, June 9 - 11, 1976*, 71–132. New York, NY: Academic Press.
- Cooper, Robin & Jonathan Ginzburg. 2015. Type theory with records for natural language semantics. In Shalom Lappin & Chris Fox (eds.), *The handbook of contemporary semantic theory*, 2nd edn. (Blackwell Handbooks in Linguistics), 375–407. Oxford, UK: Wiley-Blackwell. DOI: 10.1002/9781118882139.ch12.

- Copestake, Ann, Dan Flickinger, Carl Pollard & Ivan A. Sag. 2005. Minimal Recursion Semantics: An introduction. *Research on Language and Computation* 3(2–3). 281–332. DOI: 10.1007/s11168-006-6327-9.
- Costa, Francisco & António Branco. 2012. Backshift and tense decomposition. In Stefan Müller (ed.), *Proceedings of the 19th International Conference on Head-Driven Phrase Structure Grammar, Chungnam National University Daejeon*, 86–106. Stanford, CA: CSLI Publications. DOI: <https://doi.org/10.21248/hpsg.2012.6>.
- Crain, Stephen & Mark Steedman. 1985. On not being led up the garden path: The use of context by the psychological syntax processor. In David R. Dowty, Lauri Karttunen & Arnold M. Zwicky (eds.), *Natural language parsing* (Studies in Natural Language Processing), 320–358. Cambridge, UK: Cambridge University Press. DOI: 10.1017/CBO9780511597855.
- Deane, Paul. 1991. Limits to attention: A cognitive theory of island phenomena. *Cognitive Linguistics* 2(1). 1–63. DOI: 10.1515/cogl.1991.2.1.1.
- Devlin, Keith. 1992. *Logic and information*. Cambridge: Cambridge University Press.
- Eberhard, Kathleen M., Michael J. Spivey-Knowlton, Julie C. Sedivy & Michael K. Tannenhaus. 1995. Eye movements as a window into real-time spoken language comprehension in natural contexts. *Journal of Psycholinguist Research* 24(6). 409–436. DOI: 10.1007/BF02143160.
- Engdahl, Elisabet & Eva Ejerhed. 1982. *Readings on unbounded dependencies in Scandinavian languages*. Stockholm: Almqvist & Wiksell International.
- Engdahl, Elisabet & Enric Vallduví. 1996. Information packaging in HPSG. In Claire Grover & Enric Vallduví (eds.), *Studies in HPSG* (Edinburgh Working Papers in Cognitive Science 12), 1–32. Edinburgh: Centre for Cognitive Science, University of Edinburgh. <ftp://ftp.cogsci.ed.ac.uk/pub/CCS-WPs/wp-12.ps.gz> (10 February, 2021).
- Erteschik-Shir, Nomi. 1973. *On the nature of island constraints*. Cambridge, MA: MIT. (Doctoral dissertation).
- Fernández, Raquel & Jonathan Ginzburg. 2002. Non-sentential utterances: A corpus study. *Traitement Automatique de Langues* 43(2). 13–42.
- Flickinger, Dan, Carl Pollard & Thomas Wasow. 2024. The evolution of HPSG. In Stefan Müller, Anne Abeillé, Robert D. Borsley & Jean-Pierre Koenig (eds.), *Head-Driven Phrase Structure Grammar: The handbook*, 2nd revised edn. (Empirically Oriented Theoretical Morphology and Syntax 9), 47–92. Berlin: Language Science Press. DOI: 10.5281/zenodo.13645008.

- Fodor, Janet Dean. 1983a. Phrase structure parsing and the island constraints. *Linguistics and Philosophy* 6(2). 163–223. DOI: 10.1007/BF00635643.
- Fodor, Jerry A. 1983b. *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: MIT Press.
- Fodor, Jerry A., Thomas G. Bever & Merrill F. Garrett. 1974. *The psychology of language: An introduction to psycholinguistics and Generative Grammar* (McGraw-Hill series in psychology). New York, NY: McGraw-Hill Book Co.
- Ford, Marilyn, Joan Bresnan & Ronald Kaplan. 1982. A competence-based theory of syntactic closure. In Joan Bresnan (ed.), *The mental representation of grammatical relations* (MIT Press Series on Cognitive Theory and Mental Representation), 727–796. Cambridge, MA: MIT Press.
- Francis, Elaine J. 2021. *Gradient acceptability and linguistic theory* (Oxford Surveys in Syntax and Morphology). Oxford: Oxford University Press.
- Gazdar, Gerald. 1981. Unbounded dependencies and coordinate structure. *Linguistic Inquiry* 12(2). 155–184.
- Gennari, Silvia P. & Maryellen C. MacDonald. 2008. Semantic indeterminacy in object relative clauses. *Journal of Memory and Language* 58(2). 161–187. DOI: 10.1016/j.jml.2007.07.004.
- Gibson, Edward. 1998. Linguistic complexity: Locality of syntactic dependencies. *Cognition* 68(1). 1–76. DOI: 10.1016/S0010-0277(98)00034-1.
- Ginzburg, Jonathan. 1994. An Update Semantics for dialogue. In Harry Bunt, Reinhard Muskens & Gerrit Rentier (eds.), *Proceedings of the 1st International Workshop on Computational Semantics*, 235–255. Tilburg: ITK, Tilburg University.
- Ginzburg, Jonathan. 2011. Situation semantics and the ontology of natural language. In Claudia Maienborn, Klaus von Heusinger & Paul Portner (eds.), *Semantics: An international handbook of natural language meaning*, vol. 1 (Handbücher zur Sprach- und Kommunikationswissenschaft / Handbooks of Linguistics and Communication Science (HSK) 33), 830–851. Berlin: Mouton de Gruyter. DOI: 10.1515/9783110226614.830.
- Ginzburg, Jonathan. 2012. *The interactive stance: Meaning for conversation* (Oxford Linguistics). Oxford: Oxford University Press.
- Ginzburg, Jonathan, Raquel Fernández & David Schlangen. 2014. Disfluencies as intra-utterance dialogue moves. *Semantics and Pragmatics* 7(9). 1–64. DOI: 10.3765/sp.7.9.
- Ginzburg, Jonathan & Ivan A. Sag. 2000. *Interrogative investigations: The form, meaning, and use of English interrogatives* (CSLI Lecture Notes 123). Stanford, CA: CSLI Publications.

- Godard, Danièle & Pollet Samvelian. 2024. Complex predicates. In Stefan Müller, Anne Abeillé, Robert D. Borsley & Jean-Pierre Koenig (eds.), *Head-Driven Phrase Structure Grammar: The handbook*, 2nd revised edn. (Empirically Oriented Theoretical Morphology and Syntax 9), 443–518. Berlin: Language Science Press. DOI: 10.5281/zenodo.13645043.
- Goldberg, Adele E. 2003. Words by default: The Persian Complex Predicate Construction. In Elaine J. Francis & Laura A. Michaelis (eds.), *Mismatch: Form-function incongruity and the architecture of grammar* (CSLI Lecture Notes 163), 117–146. Stanford, CA: CSLI Publications.
- Gollan, Tamar H., Timothy J. Slattery, Diane Goldenberg, Eva Van Assche, Wouter Duyck & Keith Rayner. 2011. Frequency drives lexical access in reading but not in speaking: The frequency-lag hypothesis. *Journal of Experimental Psychology: General* 140(2). 186–209. DOI: 10.1037/a0022256.
- Green, Georgia M. 1996. The structure of CONTEXT: The representation of pragmatic restrictions in HPSG. In James H. Yoon (ed.), *Proceedings of the 5th Annual Meeting of the Formal Linguistics Society of the Midwest* (Studies in the Linguistic Sciences 24), 215–232. Urbana, IL: Department of Linguistics, University of Illinois.
- Grosu, Alexander. 1972. *The strategic content of island constraints* (Working Papers in Linguistics 13). Columbus, OH: Department of Linguistics, Ohio State University.
- Hale, Ken & Samuel Jay Keyser. 2002. *Prolegomenon to a theory of argument structure* (Linguistic Inquiry Monographs 39). The MIT Press. DOI: 10.7551/mitpress/5634.001.0001.
- Hale, Kenneth & Samuel Jay Keyser. 1993. On argument structure and the lexical expression of syntactic relations. In Kenneth Hale & Samuel Jay Keyser (eds.), *The view from building 20: Essays in linguistics in honor of Sylvain Bromberger* (Current Studies in Linguistics 24), 53–109. Cambridge, MA: MIT Press.
- Halliday, Michael A. K. 1967. Notes on transitivity and theme in English. Part II. *Journal of Linguistics* 3(2). 199–244.
- Hawkins, John A. 1999. Processing complexity and filler-gap dependencies across grammars. *Language* 75(2). 244–285. DOI: 10.2307/417261.
- Hawkins, John A. 2004. *Efficiency and complexity in grammars* (Oxford Linguistics). Oxford: Oxford University Press. DOI: 10.1093/acprof:oso/9780199252695.001.0001.
- Hawkins, John A. 2014. *Cross-linguistic variation and efficiency* (Oxford Linguistics). Oxford: Oxford University Press. DOI: 10.1093/acprof:oso/9780199664993.001.0001.

- Hobbs, Jerry R. & Ralph Grishman. 1975. The automatic transformational analysis of English sentences: An implementation. *International Journal of Computer Mathematics* 5(1–4). 267–283. DOI: 10.1080/00207167608803117.
- Hofmeister, Philip, T. Florian Jaeger, Inbal Arnon, Ivan A. Sag & Neal Snider. 2013. The source ambiguity problem: Distinguishing the effects of grammar and processing on acceptability judgments. *Language and Cognitive Processes* 28(1–2). 48–87. DOI: 10.1080/01690965.2011.572401.
- Hofmeister, Philip & Ivan A. Sag. 2010. Cognitive constraints and island effects. *Language* 86(2). 366–415. DOI: 10.1353/lan.0.0223.
- Hsiao, Franny & Edward Gibson. 2003. Processing relative clauses in Chinese. *Cognition* 90(1). 3–27. DOI: 10.1016/S0010-0277(03)00124-0.
- Jackendoff, Ray S. 1972. *Semantic interpretation in Generative Grammar* (Current Studies in Linguistics 2). Cambridge, MA: MIT Press.
- Johnson, David E. & Shalom Lappin. 1999. *Local constraints vs. economy* (Stanford Monographs in Linguistics). Stanford, CA: CSLI Publications.
- Kamp, Hans & Uwe Reyle. 1993. *From discourse to logic: Introduction to modeltheoretic semantics of natural language, formal logic and Discourse Representation Theory* (Studies in Linguistics and Philosophy 42). Dordrecht: Kluwer Academic Publishers. DOI: 10.1007/978-94-017-1616-1.
- Kathol, Andreas, Adam Przepiórkowski & Jesse Tseng. 2011. Advanced topics in Head-Driven Phrase Structure Grammar. In Robert D. Borsley & Kersti Börsjars (eds.), *Non-transformational syntax: Formal and explicit models of grammar: A guide to current models*, 54–111. Oxford: Wiley-Blackwell. DOI: 10.1002/9781444395037.ch2.
- Kayne, Richard S. 1994. *The antisymmetry of syntax* (Linguistic Inquiry Monographs 25). Cambridge, MA: MIT Press.
- Keenan, Edward L. & Bernard Comrie. 1977. Noun phrase accessibility and Universal Grammar. *Linguistic Inquiry* 8(1). 63–99.
- Kempson, Ruth. 2011. Formal semantics and representationalism. In Claudia Maienborn, Klaus von Stechow & Paul Portner (eds.), *Semantics: An international handbook of natural language meaning*, vol. 1 (Handbücher zur Sprach- und Kommunikationswissenschaft / Handbooks of Linguistics and Communication Science (HSK) 33), 216–241. Berlin: Mouton de Gruyter. DOI: 10.1515/9783110226614.216.
- King, Jonathan & Marcel Adam Just. 1991. Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language* 30(5). 580–602. DOI: 10.1016/0749-596X(91)90027-H.

- King, Paul. 1999. Towards truth in Head-Driven Phrase Structure Grammar. In Valia Kordoni (ed.), *Tübingen studies in Head-Driven Phrase Structure Grammar* (Arbeitspapiere des SFB 340 des SFB 340 132), 301–352. Tübingen: Universität Tübingen. <http://www.sfs.uni-tuebingen.de/sfb/reports/berichte/132/132abs.html> (10 February, 2021).
- Kluender, Robert & Marta Kutas. 1993. Bridging the gap: Evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience* 5(2). 196–214. DOI: 10.1162/jocn.1993.5.2.196.
- Konieczny, Lars. 1996. *Human sentence processing: A semantics-oriented parsing approach*. IIG-Berichte 3/96. Universität Freiburg. (Dissertation).
- Levine, Robert D. & Walt Detmar Meurers. 2006. Head-Driven Phrase Structure Grammar: Linguistic approach, formal foundations, and computational realization. In Keith Brown (ed.), *The encyclopedia of language and linguistics*, 2nd edn., 237–252. Oxford: Elsevier Science Publisher B.V. (North-Holland). DOI: 10.1016/B0-08-044854-2/02040-X.
- Lin, Chien-Jer Charles & Thomas G. Bever. 2006. Subject preference in the processing of relative clauses in Chinese. In Donald Baumer, David Montero & Michael Scanlon (eds.), *Proceedings of the 25th West Coast Conference on Formal Linguistics*, 254–260. Somerville, MA: Cascadilla Proceedings Project.
- Linardaki, Evita. 2006. *Linguistic and statistical extensions of data oriented parsing*. University of Essex. (Doctoral dissertation).
- MacDonald, Maryellen C. 2013. How language production shapes language form and comprehension. *Frontiers in Psychology* 4(226). 1–16. DOI: 10.3389/fpsyg.2013.00226.
- MacDonald, Maryellen C., Neal J. Pearlmutter & Mark. S. Seidenberg. 1994. The lexical nature of syntactic ambiguity resolution. *Psychological Review* 101(4). 676–703. DOI: 10.1037/0033-295X.101.4.676.
- Marslen-Wilson, William & Lorraine Tyler. 1987. Against modularity. In Jay L. Garfield (ed.), *Modularity in knowledge representation and natural language processing*, 37–62. Cambridge, MA: MIT Press.
- Martin-Löf, Per. 1984. *Intuitionistic type theory* (Studies in Proof Theory 1). Napoli: Bibliopolis.
- Matsuki, Kazunaga, Tracy Chow, Mary Hare, Christoph Elman Jeffrey L. Scheepers & Ken McRae. 2011. Event-based plausibility immediately influences online language comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 37(4). 913–934. DOI: 10.1037/a0022964.
- McGurk, Harry & John MacDonald. 1976. Hearing lips and seeing voices. *Nature* 264(5588). 746–748. DOI: 10.1038/264746a0.

- McMurray, Bob, Meghan A. Clayards, Michael K. Tanenhaus & Richard Aslin. 2008. Tracking the time course of phonetic cue integration during spoken word recognition. *Psychonomic Bulletin* 15(6). 1064–1071. DOI: 10.3758/PBR.15.6.1064.
- Miyamoto, Edson T & Michiko Nakamura. 2003. Subject/object asymmetries in the processing of relative clauses in Japanese. In Gina Garding & Mimura Tsujimura (eds.), *Proceedings of the 22nd West Coast Conference on Formal Linguistics*, 342–355. San Diego, CA: Cascadilla Proceedings Project.
- Miyao, Yusuke & Jun'ichi Tsujii. 2008. Feature forest models for probabilistic HPSG parsing. *Computational Linguistics* 34(1). 35–80. DOI: 10.1162/coli.2008.34.1.35.
- Momma, Shota & Colin Phillips. 2018. The relationship between parsing and generation. *Annual Review of Linguistics* 4. 233–254. DOI: 10.1146/annurev-linguistics-011817-045719.
- Montague, Richard. 1973. The proper treatment of quantification in ordinary English. In Jaakko Hintikka, Julian Moravcsik & Patrick Suppes (eds.), *Approaches to natural language. Proceedings of the 1970 Stanford Workshop on Grammar and Semantics* (Synthese Library 49), 221–242. Dordrecht: Reidel. DOI: 10.1007/978-94-010-2506-5_10. Reprint as: The proper treatment of quantification in ordinary English. In Richmond H. Thomason (ed.), *Formal philosophy: Selected papers of Richard Montague*, 247–270. New Haven, CT: Yale University Press, 1974.
- Müller, Stefan. 2010. Persian complex predicates and the limits of inheritance-based analyses. *Journal of Linguistics* 46(3). 601–655. DOI: 10.1017/S0022226709990284.
- Müller, Stefan & Stephen Wechsler. 2014. Lexical approaches to argument structure. *Theoretical Linguistics* 40(1–2). 1–76. DOI: 10.1515/tl-2014-0001.
- Phillips, Colin. 2013. On the nature of island constraints I: Language processing and reductionist accounts. In Jon Sprouse & Norbert Hornstein (eds.), *Experimental syntax and island effects*, 64–108. Cambridge, UK: Cambridge University Press. DOI: 10.1017/CBO9781139035309.005.
- Pollard, Carl J. 1999. Strong generative capacity in HPSG. In Gert Webelhuth, Jean-Pierre Koenig & Andreas Kathol (eds.), *Lexical and constructional aspects of linguistic explanation* (Studies in Constraint-Based Lexicalism 1), 281–298. Stanford, CA: CSLI Publications.
- Pollard, Carl & Ivan A. Sag. 1987. *Information-based syntax and semantics* (CSLI Lecture Notes 13). Stanford, CA: CSLI Publications.

- Pollard, Carl & Ivan A. Sag. 1994. *Head-Driven Phrase Structure Grammar* (Studies in Contemporary Linguistics 4). Chicago, IL: The University of Chicago Press.
- Real, Florencia & Morten H. Christiansen. 2007. Processing of relative clauses is made easier by frequency of occurrence. *Journal of Memory and Language* 57(1). 1–23. DOI: 10.1016/j.jml.2006.08.014.
- Richter, Frank. 2004a. *A mathematical formalism for linguistic theories with an application in Head-Driven Phrase Structure Grammar*. Universität Tübingen. (Phil. Dissertation (2000)). <http://hdl.handle.net/10900/46230> (10 February, 2021).
- Richter, Frank. 2004b. *Foundations of lexical resource semantics*. Universität Tübingen. (Habilitation).
- Richter, Frank. 2024. Formal background. In Stefan Müller, Anne Abeillé, Robert D. Borsley & Jean-Pierre Koenig (eds.), *Head-Driven Phrase Structure Grammar: The handbook*, 2nd revised edn. (Empirically Oriented Theoretical Morphology and Syntax 9), 93–131. Berlin: Language Science Press. DOI: 10.5281/zenodo.13645007.
- Richter, Frank & Manfred Sailer. 2004. Basic concepts of Lexical Resource Semantics. In Arnold Beckmann & Norbert Preining (eds.), *ESSLLI 2003 – Course material I* (Collegium Logicum 5), 87–143. Wien: Kurt Gödel Society.
- Roland, Douglas, Gail Mauner, Carolyn O’Meara & Hongoak Yun. 2012. Discourse expectations and relative clause processing. *Journal of Memory and Language* 66(3). 479–508. DOI: 10.1016/j.jml.2011.12.004.
- Ross, John Robert. 1967. *Constraints on variables in syntax*. Cambridge, MA: MIT. (Doctoral dissertation). Reproduced by the Indiana University Linguistics Club and later published as *Infinite syntax!* (Language and Being 5). Norwood, NJ: Ablex Publishing Corporation, 1986.
- Sag, Ivan A. 1997. English relative clause constructions. *Journal of Linguistics* 33(2). 431–483. DOI: 10.1017/S002222679700652X.
- Sag, Ivan A. & Thomas Wasow. 2011. Performance-compatible competence grammar. In Robert D. Borsley & Kersti Börjars (eds.), *Non-transformational syntax: Formal and explicit models of grammar: A guide to current models*, 359–377. Oxford: Wiley-Blackwell. DOI: 9781444395037.ch10.
- Sag, Ivan A. & Thomas Wasow. 2015. Flexible processing and the design of grammar. *Journal of Psycholinguistic Research* 44(1). 47–63. DOI: 10.1007/s10936-014-9332-4.
- Sag, Ivan A., Thomas Wasow & Emily M. Bender. 2003. *Syntactic theory: A formal introduction*. 2nd edn. (CSLI Lecture Notes 152). Stanford, CA: CSLI Publications.

- Spevack, Samuel C., J. Benjamin Falandays, Brandon Batzloff & Michael J. Spivey. 2018. Interactivity of language. *Language and Linguistics Compass* 12(7). 1–18. DOI: 10.1111/lnc3.12282.
- Sprouse, Jon, Matt Wagers & Colin Phillips. 2012. A test of the relation between working memory capacity and syntactic island effects. *Language* 88(1). 82–123. DOI: 10.1353/lan.2012.0004.
- Stroop, John Ridley. 1935. Studies of interference in serial verbal reactions. *Journal of Experimental Psychology* 18(6). 643–662. DOI: 10.1037/h0054651.
- Tanenhaus, Michael K., Michael J. Spivey-Knowlton, Kathleen M. Eberhard & Julie C. Sedivy. 1995. Integration of visual and linguistic information in spoken language comprehension. *Science* 268(5217). 1632–1634. DOI: 10.1126/science.7777863.
- Tanenhaus, Michael K., Michael J. Spivey-Knowlton, Kathleen M. Eberhard & Julie C. Sedivy. 1996. Using eye movements to study spoken language comprehension: Evidence for visually mediated incremental interpretation. In Toshio Inui & James L. McClelland (eds.), *Information integration in perception and communication* (Attention and Performance XVI), 457–478. Cambridge, MA: MIT Press.
- Tanenhaus, Michael K. & John C. Trueswell. 1995. Sentence comprehension. In Joanne L. Miller & Peter D. Eimas (eds.), *Handbook of cognition and perception* (Handbook of Perception and Cognition 11), 217–262. San Diego, CA: Academic Press. DOI: 10.1016/B978-012497770-9.50009-1.
- Traxler, Matthew J., Robin K. Morris & Rachel E. Seely. 2002. Processing subject and object relative clauses: Evidence from eye movements. *Journal of Memory and Language* 47(1). 69–90. DOI: 10.1006/jmla.2001.2836.
- Traxler, Matthew J. & Kristen M. Tooley. 2007. Lexical mediation and context effects in sentence processing. *Brain Research* 1146. 59–74. DOI: 10.1016/j.brainres.2006.10.010.
- Trueswell, John C., Michael K. Tanenhaus & Christopher Kello. 1993. Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 19(3). 528–553. DOI: 10.1037//0278-7393.19.3.528.
- Vasishth, Shravan, Chen Zhong, Qiang Li & Gueilan Guo. 2013. Processing Chinese relative clauses: Evidence for the subject-relative advantage. *PLoS ONE* 8(10). 1–15. DOI: 10.1371/journal.pone.0077006.
- Wanner, Eric & Michael Maratsos. 1978. An ATN approach to comprehension. In Morris Halle, Joan Bresnan & George A. Miller (eds.), *Linguistic theory and psychological reality*, 119–161. Cambridge, MA: MIT Press.

- Wasow, Thomas. 2015. Ambiguity avoidance is overrated. In Susanne Winkler (ed.), *Ambiguity: Language and communication*, 29–47. Berlin: De Gruyter. DOI: 10.1515/9783110403589-003.
- Wasow, Thomas, Florian T. Jaeger & David Orr. 2011. Lexical variation in relativizer frequency. In Horst J. Simon & Heike Wiese (eds.), *Expecting the unexpected: Exceptions in grammar* (Trends in Linguistics: Studies and Monographs 216), 175–195. Berlin: De Gruyter Mouton. DOI: 10.1515/9783110219098.175.
- Wittenberg, Eva, Ray Jackendoff, Gina Kuperberg, Martin Paczynski, Jesse Snedeker & Heike Wiese. 2014. The processing and representation of light verb constructions. In Asaf Bachrach, Isabelle Roy & Linnaea Stockall (eds.), *Structuring the argument: Multidisciplinary research on verb argument structure* (Language Faculty and Beyond 10), 61–80. Amsterdam: John Benjamins Publishing Co. DOI: 10.1075/lfab.10.
- Wittenberg, Eva & Maria Mercedes Piñango. 2011. Processing light verb constructions. *The Mental Lexicon* 6(3). 393–413. DOI: 10.1075/ml.6.3.03wit.
- Yi, Eunkyung, Jean-Pierre Koenig & Douglas Roland. 2019. Semantic similarity to high-frequency verbs affects syntactic frame selection. *Cognitive Linguistics* 30(3). 601–628. DOI: 10.1515/cog-2018-0029.
- Zimmermann, Thomas Ede. 2011. Model-theoretic semantics. In Claudia Maienborn, Klaus von Stechow & Paul Portner (eds.), *Semantics: An international handbook of natural language meaning*, vol. 1 (Handbücher zur Sprach- und Kommunikationswissenschaft / Handbooks of Linguistics and Communication Science (HSK) 33), 762–802. Berlin: Mouton de Gruyter. DOI: 10.1515/9783110226614.946.