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Complex Sentence Processing: A Review of Theoretical Perspectives on the Comprehension of Relative Clauses

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Abstract

A major goal of psycholinguistics is to gain a better understanding of how syntactically complex sentences are processed. Pursuit of this goal has frequently focused on the contrast between object- and subject-extracted relative clauses (RCs). Although a large body of literature demonstrates that comprehension is more difficult for object RCs than for subject RCs, the proposed explanations for this processing asymmetry are diverse and hotly debated. This article reviews theoretical accounts of RC processing in terms of whether they characterize the critical differences in comprehension difficulty as arising from memory processes, interpretive processes, or processes tuned to the frequency with which different types of language are encountered.

Understanding the cognitive mechanisms that enable us to process and comprehend syntactically complex sentences is a central goal of psycholinguistics. The contrast between subject-extracted and object-extracted relative clauses (RCs) has provided an empirically rich test bed for pursuing this goal. In a subject-extracted RC (SRC), as in (1), the head noun phrase (NP) serves as the subject of the RC, whereas in an object-extracted RC (ORC), as in (2), the head NP serves as the object of the RC. According to standard linguistic accounts, both SRCs and ORCs contain a phonologically empty placeholder—or gap—that is co-indexed with the head NP (*the senator* in the examples below). In (1), this gap (denoted by Δ) appears in the subject position of the embedded verb (e.g., *the senator bothered the reporter*), whereas in (2), this gap appears in the object position of the embedded verb (e.g., *the reporter bothered the senator*). In order to understand the sentence, the listener or reader must use information from the filler to interpret the gap, which would otherwise lead to an ungrammatical sentence.

(1) The senator that Δ bothered the reporter caused a big scandal.

(2) The senator that the reporter bothered Δ caused a big scandal.

This contrast is appealing because both sentences contain an extracted element that must be encoded, integrated into the RC, and attached to an NP in the main clause. In addition, both sentences contain exactly the same words and differ only in word order. Despite these similarities, a large body of literature using diverse methods has demonstrated that ORCs impose greater processing difficulty than SRCs (e.g., Caplan et al. 1998; Caramazza and Zurif 1976; Ford 1983; Holmes and O'Regan 1981; Just et al. 1996; King and Just 1991; Wanner and Maratsos 1978).

Three broad classes of explanations have been proposed to explain the asymmetry in processing RCs: (1) those focusing on memory limitations during complex sentence

processing, (2) those focusing on semantic and/or pragmatic interpretation, and (3) those focusing on differences in experience in processing different types of sentence structures. In this paper, we consider complex-sentence processing from each of these three perspectives. Our review focuses specifically on English RCs, as English has been the language used in the majority of RC studies. The processing of RCs has also been studied in a variety of other languages, including: Basque (Carreiras et al. 2010), Chinese (Gibson and Wu forthcoming; Hsiao and Gibson 2003; Kuo and Vasishth 2006; Lin 2008), Dutch (Mak et al. 2002, 2006), French (Cohen and Mehler 1996; Frauenfelder et al. 1980; Holmes and O'Regan 1981), German (Mecklinger et al. 1995; Schriefers et al. 1995), Hungarian (MacWhinney and Pleh 1988), Korean (Kwon et al. 2010; Lee et al. 2007), Japanese (Ueno and Garnsey 2008), and Spanish (Betancort et al. 2009). Although cross-linguistic comparisons in RC processing have become a very active research area that may help answer key questions about RC processing, reviewing that work is beyond the scope of this paper.

Approaches to the ORC-SRC Processing Difference

MEMORY/RESOURCE-BASED MODELS

One class of theories attributes the ORC-SRC processing asymmetry to the cognitive burden imposed by ORC structures. Whereas the extracted element in an SRC (*senator* in 1) can be immediately attached to the embedded verb and integrated into the RC, the extracted element in an ORC (*senator* in 2) must be held in memory across intervening words until it can be integrated. This idea was originally developed and promoted by Miller and Chomsky (1963), who observed that sentences containing multiple embedded syntactic structures can sometimes be nearly impossible to understand, presumably because the reader must keep track of several unattached NPs, which may overload working-memory capacity. Experimental support for this perspective came from Wanner and Maratsos (1978), who had participants read sentences like (1) and (2), but also gave them a list of names to remember at a specific point during the sentence. Results revealed that the ORC-SRC difference (measured in terms of name recall and comprehension of the sentence) was largest when the memory load was imposed during the RC region, compared to any other region of the sentence, suggesting that readers had to devote cognitive resources to maintaining the extracted NP in memory along with the list of names (see also Just and Carpenter 1992; King and Just 1991; cf. Waters and Caplan 1996).

Whereas these early characterizations of the role of memory in complex-sentence processing focused on capacity limitations, more recent approaches have shifted the focus to sentence-internal cues that can influence memory processes. This perspective has been particularly useful in developing the cue-based parsing framework (Lewis and Vasishth 2005; Lewis et al. 2006; Van Dyke and Lewis, 2003), under which difficulty during complex-sentence processing is viewed as arising from difficulties associated with memory encoding, storage, and retrieval. The notion of sentence processing as a cue-based process is very similar to Ericsson and Kintsch's (1995) concept of long-term working memory, which proposes that the role of memory in supporting skilled performance is incompatible with a model that emphasizes the limited capacity of working memory, but instead indicates a highly organized system that allows information to be retrieved from long-term memory rapidly and efficiently. Support for this view comes from experiments that have shown that highly skilled tasks, such as language comprehension, are resumed with

ease following an interruption (e.g., Ericsson and Kintsch 1995; Ledoux and Gordon 2006).

Under a cue-based model, a key factor that has been shown to cause comprehension difficulty is memory interference from other words in the sentence. In particular, Bever (1974) observed that comprehension of a double center-embedded structure such as (3) improves substantially when the NPs come from different semantic classes, as in (4), rather than all being of the same category (e.g., role terms).

(3) The senator the banker the salesman knows trusts caused a big scandal.

(4) The senator everyone I know trusts caused a big scandal.

The contrast between (3) and (4) demonstrates that the difficulty in processing a complex sentence depends in large part on the types of NPs that are used; however, two different approaches have emerged to explain how exactly the semantic characteristics of the NPs in a complex sentence influence memory demands.

According to the dependence locality theory (DLT; Gibson 1998, 2000; Grodner and Gibson 2005; Warren and Gibson 2002), ORCs are more difficult to process than SRCs because of the greater distance that the unattached head noun (NP1) must be maintained in memory before it can be integrated with a verb. Critically, the DLT proposes that the integration process will impose greater difficulty on the reader as the number of intervening discourse referents between NP1 and the embedded verb increases. Furthermore, this account draws on the *givenness hierarchy* (Gundel et al. 1993) to explain how the discourse-pragmatic characteristics of the embedded noun (NP2) contribute to the cognitive burden. That is, referents that are more central to the discourse and are presumably already highly accessible (e.g., ''I,'' ''you,'' ''everyone'') are not as cognitively expensive as referents that are peripheral to the discourse and are not readily accessible (e.g., ''the senator,'' ''the banker,'' ''the salesman''). Providing evidence in support of the DLT, Warren and Gibson (2002) showed that the magnitude of the ORC-SRC processing difference is inversely related to the givenness of NP2.

In contrast to the DLT's emphasis on the givenness characteristics of NP2, the similarity-based interference account focuses instead on the relationship between the semantic characteristics of both NP1 and NP2 during RC processing. Under this account, the difficulty in processing an ORC is influenced to a large extent by the degree of similarity between the two NPs. This view proposes that NP1 and NP2 are encoded and stored in memory until the embedded verb cues their retrieval, at which point the reader must assign the correct thematic roles to each NP (i.e., agent and patient roles). The greater the similarity between NP1 and NP2, the more likely they are to become confused in memory, thus making it more difficult for the reader to assign thematic roles correctly. Several experiments have demonstrated support for the notion of similarity-based interference during memory retrieval using methodologies such as self-paced reading (Gordon et al. 2001, 2004; Van Dyke and Lewis, 2003), eye-tracking while reading (Gordon et al. 2006), and a concurrent sentence-reading/memory-load task (Gordon et al. 2002; Van Dyke and McElree 2006). For example, Gordon et al. (2004) showed that the magnitude of the ORC-SRC processing difference was greatly reduced when the role term that had been used as NP2 (e.g., *the reporter*) was replaced by a proper name, indexical pronoun, or quantified expression (see 5 and 6). The reduction in difficulty is seen not only in reading times, but also in comprehension-question accuracies.

(5) The senator that bothered (the reporter/Bob/you/everyone) caused a big scandal.

(6) The senator that (the reporter/Bob/you/everyone) bothered caused a big scandal.

In addition to focusing on the semantic properties of the critical NPs in a sentence, recent work has examined the role of lexical frequency in complex-sentence processing. Johnson, Lowder, and Gordon (2011) have shown that the configuration of high- versus low-frequency NPs in a sentence influences comprehension in much the same way that the frequency configuration of words in a list of to-be-remembered items influences recall (e.g., Merritt et al. 2006). Specifically, work in the memory literature has demonstrated that recall is better for high-frequency words than low-frequency words when words are studied in pure lists (i.e., lists containing only high- or low-frequency words). In contrast, recall is typically better for low-frequency words than high-frequency words after studying a mixed list (i.e., a list containing both high- and low-frequency words). This phenomenon has been explained in terms of the item-order account (DeLosh and McDaniel 1996; McDaniel and Bugg 2008), which proposes that a mixed list of items draws attention to the item-specific properties of the low-frequency words at the expense of processing the high-frequency words. This framework is particularly useful for studying ORCs, given that two NPs must be encoded and stored in memory before either can be integrated into the sentence. Importantly, NP2 must be retrieved before NP1 to comprehend the meaning of the ORC, which makes effective encoding of NP1 critical. Johnson et al. found that the ORC-SRC processing asymmetry was greatly reduced when NP1 was low-frequency and NP2 was high-frequency, compared to the reverse configuration. This pattern is consistent with the predictions of the item-order account and further illustrates the importance of applying findings from the memory literature to research on sentence processing.

Memory-based accounts of the ORC-SRC difference face a number of challenges. As discussed above, initial experimental evidence for these accounts came from tasks showing that performance on the two types of sentences was influenced by a memory load of unrelated words (Just and Carpenter 1992; King and Just 1991; Wanner and Maratsos 1978). This dual-task method allows sentence processing to be examined within a general approach to working memory that has been applied to the paper of individual differences (Daneman and Carpenter 1980) and that has been useful in studying memory in relation to cognitive domains other than sentence processing (Baddeley 1986, 2000). However, the strength and consistency of results from this domain-general working-memory approach have been comprehensively critiqued (Caplan and Waters 1999; Waters and Caplan 1996) and continue to be a subject of debate (cf. Evans et al. 2011; Fedorenko et al. 2006). Further, while sentence-processing research using the dual-task memory-load method began within the framework of capacity models, it has also contributed to the conceptual shift in how memory is viewed within sentence processing (Gordon et al. 2002; Van Dyke and McElree 2006), moving from the working-memory approach to the cue-based parsing approach (Lewis and Vasishth 2005; Lewis et al. 2006; McElree 2006; McElree et al. 2003; Van Dyke and Lewis 2003). Like the more traditional working-memory approach, research within this framework emphasizes the continuity between the nature of processes used for memory in general and for sentence processing, but instead of focusing on the capacity limits associated with short-term or working memory, it emphasizes processes of encoding and retrieval as developed in studies of long-term working memory (Ericsson and Kintsch 1995). Both the allure and the challenge of this approach lie in the fact that the organization of language at the lexical, syntactic, semantic, and pragmatic levels provides elaborate ways

of encoding and retrieving information about sentences as they are being processed. The kinds of cues that are seen in general memory studies on unorganized lists of words are rarely dominant in sentence processing (Johnson et al. 2011). As such, the memory component of a cue-based parsing approach is most meaningful when it includes specific hypotheses about which facets of language organization play an important role in memory encoding and retrieval (Lewis et al. 2006).

SEMANTIC/PRAGMATIC MODELS

A second class of explanations includes theories that highlight semantic or pragmatic factors that have been hypothesized to influence processing of RCs. The general notion is that the meaning of a sentence is more straightforward, or is derived in a more straightforward way, when the sentence contains an SRC rather than an ORC. Experimental support for this idea can be seen in the work of King and Just (1991), who showed that the ORC-SRC processing difference was substantially reduced when there was an inherent semantic relationship between the features of the critical NPs and the actions conveyed by the verbs (e.g., *The robber that the fireman rescued stole the jewelry*.) as compared to when NP1 and NP2 were equally or arbitrarily related to the action described by the verbs (e.g., *The robber that the fireman detested watched the program*.). Theoretical explanations of meaning-dependent processing of RCs take a variety of forms, which is not surprising given the diversity of approaches to the meaning of natural language.

One explanatory tactic focuses on pragmatic and discourse factors that contribute to the felicitous use and easy comprehension of sentences with RCs. Corpus analyses have shown that the embedded NP in an ORC tends to be an entity that is already given or familiar in the context of the discourse (Fox and Thompson 1990; Gordon and Hendrick 2005). The purpose of an ORC, under this view, is to introduce a less familiar concept at the beginning of the sentence, ''ground'' it in discourse, and then modify it using the more familiar NP. The embedded NPs in SRCs (when present) do not serve such a grounding function and therefore do not need to be more given than the modified NP. Such discourse effects on the ease of RC processing are captured in a different way by the DLT approach (Warren and Gibson 2002).

A second explanatory tactic focuses on sentence-internal relationships, though some such approaches incorporate discourse-related constructs. Sentences containing an ORC that modifies a subject head have been characterized as having a perspective shift that is not present in sentences containing an SRC (MacWhinney 1977; MacWhinney and Pleh 1988). For example, in a sentence containing an ORC, as in (2), the reader initially takes the perspective of *the senator*, switches in the RC to take the perspective of *the reporter,* and finally switches back at the matrix verb to the perspective of *the senator.* The absence of such perspective switching in sentences with SRCs leads to greater ease in comprehension (MacWhinney 1977; MacWhinney and Pleh 1988). An alternative (or additional) approach to sentence-internal factors that influence the ORC-SRC processing asymmetry focuses on the animacy of the critical NPs (Gennari and MacDonald 2008, 2009; Mak et al. 2002, 2006; Traxler et al. 2002, 2005). These studies have typically found that ORCs with animate NP1s and inanimate NP2s, as in (10), are more difficult to comprehend than SRCs, as in (7) and (9), regardless of their animacy configurations. However, the difficulty in processing ORCs relative to SRCs disappears when NP1 is inanimate and NP2 animate, as in (8).

(7) The article that bothered the reporter caused a big scandal.

(8) The article that the reporter composed caused a big scandal.

(9) The reporter that composed the article caused a big scandal.

(10) The reporter that the article bothered caused a big scandal.

Traxler et al. (2002, 2005) have proposed that this pattern of results supports the idea that readers adopt an active filler strategy during the processing of RCs (for a description of this general approach to syntactic processing, see, e.g., Clifton and Frazier 1989; Frazier and Clifton 1989). That is, upon encountering the complementizer *that*, the reader initially parses the structure as an SRC. This interpretation is found to be incorrect in (8) and (10), and so the reader must engage in a process of reanalysis. Under this view, reanalysis of an animate NP1, as in (10), is more difficult than reanalysis of an inanimate NP1, as in (8), because it is easier to conceive of an inanimate NP being the object of the RC, compared to an animate NP.

Lowder and Gordon (2011) have recently presented evidence demonstrating that the difficulty associated with constructions like *article bothered* in (10) does not contribute to the difficulty associated with processing the RC. In comparing sentences like (11) and (12), they showed that (12) was more difficult to process than (11). Crucially, however, this effect emerged entirely at the embedded verb—not at any other part of the RC, nor at the main verb of the sentence. This pattern suggests that the difficulty associated with processing a sentence like (10) arises not because of broad RC-level effects, but rather because of local difficulty associated with integrating an inanimate NP with a verb.

(11) The reporter that the senator bothered caused a big scandal.

(12) The reporter that the article bothered caused a big scandal.

Furthermore, Lowder and Gordon showed that the difficulty associated with integrating an inanimate NP with a verb (e.g., *The article bothered the reporter*) is reduced when the two constituents appear in separate clauses (e.g., *The article that bothered the reporter…*). This pattern of results demonstrates that subject-verb integration is difficult for inanimate compared to animate NPs, but that this effect is reduced when there is a structural separation between them.

Meaning-based accounts of the ORC-SRC difference face a variety of challenges. Studies falling under this perspective have shown that the magnitude of the ORC-SRC difference depends on factors such as inherent associations between the meanings of the critical NPs and the embedded verb (King and Just 1991) and the thematic roles of the critical NPs (Traxler et al. 2002, 2005). While these studies clearly demonstrate that sentence meaning can moderate RC processing effects, a wealth of other studies have demonstrated the ORC-SRC difference in sentences where the meanings are arbitrary, the thematic roles are consistent across type of RC, and where the relationships between the different NPs and the verbs have been counterbalanced across conditions (e.g., King and Just 1991; Johnson et al. 2011).

Meaning-based accounts also face central questions in determining the boundaries between sentence-level semantic factors and discourse-level pragmatic factors. For example, rather than compare performance on ORCs and SRCs, Gennari and MacDonald (2008) compare performance on ORCs containing active verbs (e.g., *The journalist that the article bothered…*) with RCs containing passivized verbs derived from the corresponding ORC

(e.g., *The journalist that was bothered by the article…*), claiming that the passive RC construction provides "a semantically-similar control condition to the structure of interest" (p. 165). This characterization is accurate at the level of the truth-conditional semantics of the sentence, but at a broader level the meaning of the two types of sentences is not equivalent given the pragmatic implications and discourse functions of passives (e.g., Gordon and Chan 1995). Moreover, ORCs and SRCs play different roles in discourse, and the types of NPs (e.g., pronouns) that are associated with reductions in the ORC-SRC processing difference have distinct characteristics in terms of information accessibility associated with discourse structure, which raises questions about the extent of the semantic similarity between the active and passive sentences.

FREQUENCY-BASED MODELS

A final class of explanations includes theories that highlight the role of experience in explaining complexity effects on sentence processing. The general notion is that people have an easier time understanding sentence structures that they have encountered more frequently as compared to those that they have encountered less frequently; corpus studies show that SRCs occur more frequently in English than ORCs (Gordon and Hendrick 2005; Keenan 1975; Roland et al. 2007), giving this idea some appeal in accounting for the ORC-SRC difference in ease of processing.

Empirical findings presented in support of frequency-based models of language comprehension have come from studies that correlate ease of processing to different measures of experience. For example, the frequency of different types of pronouns within ORCs and SRCs (as given by corpus counts) has been related to the magnitude of processing differences between ORCs and SRCs (Reali and Christiansen 2007), in particular providing some evidence that with certain types of pronouns ORCs are processed more quickly than SRCs. Experimental (i.e., non-correlational) evidence for the importance of experience in RC processing comes from the finding that participants who received extensive practice reading ORCs over multiple sessions later demonstrated significantly faster processing of these structures, compared to a group of participants who received the same amount of practice reading other types of complex sentence structures (Wells et al. 2009).

The role of language experience in RC processing has been incorporated into a variety of theoretical accounts which provide quite distinct perspectives on language processing. *Simple recurrent networks*, as formulated by Elman (1991), have been used to demonstrate that the highly frequent noun-verb-noun sequence yielded by canonical subject-verb-object English sentences facilitates processing of the similar noun-verb-noun-verb sequence in SRC sentences as compared to the less similar noun-noun-verb-verb sequence of ORC sentences; this pattern occurs even when frequency of SRCs and ORCs is the same but diminished as the network receives greater training on the artificial language corpus (MacDonald and Christiansen 2002). Other more syntactically-oriented accounts have focused on how the difference in overall frequency of the two types of RCs creates a greater reduction of uncertainty about upcoming input for SRCs as compared to ORCs (Hale 2001; Levy 2008). Recent work has attempted to integrate the concept of statistical reduction of uncertainty with findings on how the semantic characteristics of head nouns affect the magnitude of the ORC-SRC difference in ease of processing (Gennari and MacDonald 2008, 2009).

Like memory- and meaning-based accounts, frequency-based accounts face a number of challenges. While corpus studies show that SRCs are generally more frequent than ORCs, a large portion of the SRCs analyzed in corpus studies contain an intransitive

embedded verb (e.g., *The toaster that broke…*). In contrast, the embedded verb of an ORC must always be transitive. If SRCs with intransitive embedded verbs are removed from corpus counts, the robust difference in frequency between SRCs and ORCs is greatly reduced, with at least one corpus of spoken language (Switchboard) actually showing a higher incidence of ORCs from transitive verbs than SRCs from transitive verbs (Gordon and Hendrick 2005). This raises the "grain problem," which pertains to the need to specify the level (or levels) of language at which frequency operates (Gordon et al. 2004; Mitchell et al. 1995). All the psycholinguistic studies that we know of contrast ORCs with transitive verbs to SRCs with transitive verbs. If overall frequency of the type of RC is the critical variable in ease of processing (that is, the grain is very large), then the dependence of relative frequency on verb transitivity is immaterial. However, studies of the frequency-performance relation in the ORC-SRC difference have also focused on very fine grains such as the type of pronoun embedded in an RC (Reali and Christiansen 2007). One solution to the grain problem is to argue that frequency at any level of language analysis contributes to ease of processing. However, such an approach must address experiments that have found that substantial differences in the frequencies of distinct classes of NPs observed in ORCs and SRCs are unrelated to the magnitude of the ORC-SRC difference in ease of comprehension (Gordon et al. 2004).

LOCUS (OR LOCI) OF THE EFFECT

The three accounts of RC processing are similar to one another in that they aim to capture moment-by-moment steps involved in sentence comprehension and use this information to develop their theoretical perspectives. As such, the timing of RC effects (or their locus with respect to specific words) has been and continues to be the subject of considerable attention in psycholinguistics. A variety of online methods have been used to address this question, including eye-tracking during reading (Holmes and O'Regan 1981), continuous judgment tasks (Ford 1983), and self-paced reading (King and Just 1991). For a time something of a consensus emerged from these methods (at least as implied by the types of analyses reported by different researchers) that the greater difficulty associated with ORCs as compared to SRCs emerged at the last constituent of the embedded RC (a verb in the case of an ORC and a noun in the case of an SRC) and continued at the matrix verb (for eye-tracking see Gordon et al. 2006; Holmes and O'Regan 1981; Traxler et al. 2002, 2005; for self-paced reading see Gordon et al. 2001, 2004; King and Just 1991; Wells et al. 2009; for continuous judgment tasks see Ford 1983). This locus of effects was broadly considered to be consistent with memory-based approaches to the ORC-SRC difference as it occurs when the memory load of holding and retrieving NP1 and interpreting NP2 could affect ease of processing.

Two recent papers, one using eye-tracking (Staub 2010) and the other a continuous judgment task (Forster et al. 2009) have challenged this characterization by providing evidence that differences in ease of processing can be detected earlier in the sentence, at the constituent immediately following the complementizer. These results have supported the contention that at least part of the greater processing difficulty associated with ORCs occurs because they are less frequent than SRCs, causing increased processing load when the RC is first encountered as proposed by expectancy-based models of sentence comprehension in which processing load depends on the degree to which incoming language fits with probabilistic expectations derived from the initial part of a sentence (Hale 2001; Levy 2008). Acceptance of this conclusion still faces methodological and interpretive challenges. Examination of ease of processing for ORCs and SRCs under this

approach requires that processing times be compared for the same words at different sentence positions (e.g., the embedded verb is the first word of the RC in an SRC, but is the last word of the RC in an ORC), which could account for some differences (see Johnson et al. 2011 for a detailed discussion). Even if this methodological hurdle is overcome, the link between locus of the difference in difficulty and the underlying process is not straightforward. For example, effects found early in RCs could be explained by memory accounts as being due to greater effort being devoted to encoding in situations where a memory load is encountered (Johnson et al. 2011) and do not necessitate an interpretive process based on expectation. Similarly, effects found late in an RC do not require a memory-based explanation and could be due to the ease with which later parts of the RC and main clause are integrated semantically with earlier parts of the sentence.

Comparison of Approaches to RC Modeling

The three classes of explanations discussed above do not necessarily provide mutually exclusive accounts of the greater difficulty associated with the understanding of ORCs as compared to SRCs. In principle each could explain some aspects of the processing of the contrast between ORCs and SRCs and cannot be ruled out by a single inconsistent or unexpected finding. This point is perhaps best illustrated by considering the meaning-based approach to RC processing. As discussed above, several studies have shown that the magnitude or even the presence of the ORC-SRC processing asymmetry can be influenced by the meanings of the nouns or noun-verb pairings in the stimulus sentences that are compared. Thus, it is clear that meaning can play an important role in the processing of relative clauses. However, many other studies have shown that ORCs are more difficult to process than SRCs when meanings of the nouns or noun-verb pairings are balanced across the two types of RC sentences, demonstrating that other factors contribute to the widely attested difference in the ease of processing the two types of RCs.

Here we briefly sketch how memory, meaning, and frequency might operate within a processing system and might each at times constrain the processing of complex sentences such as those containing ORCs; we recognize that development of a full model faces many challenges and choices. This sketch develops from our idea that the broad conceptual differences between memory-based and meaning-based accounts have been reduced by the theoretical shift in memory-based accounts (discussed above) from a focus on memory capacity to a focus on how memory encoding, storage, and retrieval operate within a system of cue-based processing. Cue-based processing accounts specify that comprehension depends on the ease with which language information can be encoded into and retrieved from memory. Further, it seems reasonable to believe that these encoding and retrieval processes will be easier for those sentences or parts of sentences for which it is easier to derive a meaningful interpretation (whether at the semantic, pragmatic, or syntactic level). This makes it difficult to distinguish cases of difficulty in sentence processing due to memory from those due to meaning, which in turn suggests that memory-based and meaning-based accounts are fully compatible and often make the same predictions. It might further be argued that it is easier to encode and retrieve frequent language patterns than less frequent ones, thereby providing a path to integrate frequency-based sentence complexity effects within this same general approach.

Of course such an account needs to be specified in much more detail, and important empirical questions would remain about the division of labor between memory-based, meaning-based, and frequency-based components of the model. For example, the ORC

with an embedded pronoun (*we*) in (13) is almost certainly easier to understand than the matched ORC with an embedded definite description (*the authors*) in (14).

(13) The review that we began is almost done.

(14) The review that the authors began is almost done.

Based on the general memory constraints in a cue-based processing approach it could be argued that it is easier to retrieve NP1 from memory when NP2 is a pronoun rather than a description because pronouns impose less memory load than descriptions (Gibson 1998) or because a pronoun and a description are less similar than two descriptions (Gordon et al. 2001). The meaning-based and frequency-based constraints of a cue-based processing model would argue that it is easier to interpret the sequence of words as an ORC terminated by a gap that requires retrieval of NP1 when NP2 is a pronoun rather than a description. This could occur because the functional meaning of an RC is to ground the head in a specific discourse situation or model, a process that is achieved very effectively through pronouns (Fox and Thompson 1990). It might also occur because NP2 in an ORC is frequently a pronoun, which could facilitate recognition of the structure and the need to retrieve NP1. Determining the degree to which each of these accounts is correct for this particular contrast is an interesting and important question, but its resolution would still leave room for constraints on RC processing that arise from meaning, memory, and frequency.

While this sketch leaves much room for development, its characterization of sentence processing does make commitments that differ from those found in the broad class of expectancy models, where processing difficulty results from the degree of match between expected and actual language input (Hale 2001; Levy 2008; MacDonald and Christiansen 2002; Wells et al. 2009). Expectancy models differ critically from cue-based processing models in that the difficulty in understanding different types of RC sentences derives from the ability to accurately predict upcoming information rather than from the difficulties associated with retrieving the head NP from memory. The only role for memory within expectancy-based models of human language processing would be in the learning and storage of information based on exposure to language; no working memory (whether short-term or long-term) is needed (MacDonald and Christiansen 2002). The model that we sketch makes the alternative commitment, shared by many other researchers, that retrieving information from (long-term) working memory is a critical constraint on language comprehension, one that is seen in the difference in ease of understanding object- and subject-extracted relative clauses.

Short Biographies

Peter C. Gordon obtained his Ph.D. from the University of Michigan in 1984. He is now Professor of Psychology and Director of the Program in Cognitive Science at the University of North Carolina at Chapel Hill. He has strong interest in widespread areas of language, but research in his lab currently focuses on the relationship between language processing and memory, using both behavioral and neural methods.

Matthew Lowder is a Ph.D. student in the Department of Psychology at the University of North Carolina at Chapel Hill where he studies online sentence processing, focusing especially on the roles of syntax and semantics. He holds a BA in Psychology from Wake Forest University and an MA in Psychology from the College of William and Mary.

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Works Cited

Baddeley, Alan D. 1986. Working memory. New York, NY: Oxford University Press.

——. 2000. The episodic buffer: a new component of working memory? Trends in Cognitive Sciences 4. 417–23.

Betancort, Moisés, Manuel Carreiras, and Patrick Sturt. 2009. The processing of subject and object relative clauses in Spanish: an eye-tracking study. Quarterly Journal of Experimental Psychology 62. 1915–29.

Bever, Thomas G. 1974. The ascent of the specious, or there's a lot we don't know about mirrors. Explaining linguistic phenomena, ed. by David Cohen, 173–200. Washington, DC: Hemisphere Publishing Company.

Caplan, David, Nathaniel Alpert, and Gloria Waters. 1998. Effects of syntactic structure and propositional number on patterns of regional cerebral blood flow. Journal of Cognitive Neuroscience 10. 541–52.

——, and Gloria S. Waters. 1999. Verbal working memory and sentence comprehension. Brain and Behavioral Sciences 22. 77–126.

Caramazza, Alfonso, and Edgar B. Zurif. 1976. Dissociation of algorithmic and heuristic processes in sentence comprehension: evidence from aphasia. Brain and Language 3. 572–82.

Carreiras, Manuel, Jon Andoni Duñabeitia, Marta Vergara, Irene de la Cruz-Pavía, and Itziar Laka. 2010. Subject relative clauses are not universally easier to process: evidence from Basque. Cognition 115. 79–92.

Clifton, Charles E., Jr, and Lyn Frazier. 1989. Comprehending sentences with long-distance dependencies. Linguistic structure in language processing, ed. by Gregory N. Carlson and Michael K. Tanenhaus, 273–317. Dordrecht: Kluwer.

Cohen, Laurent, and Jacques Mehler. 1996. Click monitoring revisited: an on-line study of sentence comprehension. Memory & Cognition 24. 94–102.

Daneman, Meredyth, and Patricia A. Carpenter. 1980. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior 19. 450–66.

DeLosh, Edward L., and Mark A. McDaniel. 1996. The role of order information in free recall: application to the word-frequency effect. Journal of Experimental Psychology: Learning, Memory, and Cognition 22. 1136–46.

Elman, Jeffrey L. 1991. Distributed representations, simple recurrent networks, and grammatical structure. Machine Learning 7. 195–224.

Ericsson, K. Anders, and Walter Kintsch. 1995. Long-term working memory. Psychological Review 102. 211–45.

Evans, William S., David Caplan, and Gloria Waters. 2011. Effects of concurrent arithmetical and syntactic complexity on self-paced reaction times and eye fixations. Psychonomic Bulletin & Review 18. 1203–11.

Fedorenko, Evelina, Edward Gibson, and Douglas Rohde. 2006. The nature of working memory capacity in sentence comprehension: evidence against domain-specific working memory resources. Journal of Memory and Language 54. 541–53.

Ford, Marilyn. 1983. A method for obtaining measures of local parsing complexity throughout sentences. Journal of Verbal Learning and Verbal Behavior 22. 203–18.

Forster, Kenneth I., Christine Guerrera, and Lisa Elliot. 2009. The maze task: measuring forced incremental sentence processing time. Behavior Research Methods 41. 163–71.

Fox, Barbara A., and Sandra A. Thompson. 1990. A discourse explanation of the grammar of relative clauses in English conversation. Language 66. 297–316.

Frauenfelder, U., J. Segui, and J. Mehler. 1980. Monitoring around the relative clause. Journal of Verbal Learning and Verbal Behavior 19. 328–37.

Frazier, Lyn, and Charles Clifton Jr. 1989. Successive cyclicity in the grammar and the parser. Language and Cognitive Processes 4. 93–126.

Gennari, Silvia P., and Maryellen C. MacDonald. 2008. Semantic indeterminacy in object relative clauses. Journal of Memory and Language 58. 161–87.

——, and Maryellen C. MacDonald. 2009. Linking production and comprehension processes: the case of relative clauses. Cognition 111. 1–23.

Gibson, Edward. 1998. Linguistic complexity: locality of syntactic dependencies. Cognition 68. 1–76.

——. 2000. The dependency locality theory: a distance-based theory of linguistic complexity. Image, language, brain: papers from the first Mind Articulation Project Symposium, ed. by Alec Marantz, Yasushi Miyashita and Wayne O'Neil, 95–126. Cambridge, MA: MIT Press.

——, and H.-H. Iris Wu. forthcoming. Processing Chinese relative clauses in context. Language and Cognitive Processes. doi: http://dx.doi.org/10.1080/01690965.2010.536656.

Gordon, Peter C., and Davina Chan. 1995. Pronouns, passives, and discourse coherence. Journal of Memory and Language 34. 216–31.

——, and Randall Hendrick. 2005. Relativization, ergativity, and corpus frequency. Linguistic Inquiry 36. 456–63.

——, ——, and Marcus Johnson. 2001. Memory interference during language processing. Journal of Experimental Psychology: Learning, Memory, and Cognition 27. 1411–23.
——, Randall Hendrick, and Marcus Johnson. 2004. Effects of noun phrase type on sentence complexity. Journal of Memory and Language 51. 97–114.
——, Randall Hendrick, Marcus Johnson, and Yoonhyoung Lee. 2006. Similarity- based interference during language comprehension: evidence from eye tracking during reading. Journal of Experimental Psychology: Learning, Memory, and Cognition 32. 1304–21.
——, ——, and William H. Levine. 2002. Memory-load interference in syntactic processing. Psychological Science 13. 425–30.
Grodner, Daniel, and Edward Gibson. 2005. Consequences of the serial nature of linguistic input for sentential complexity. Cognitive Science 29. 261–91.
Gundel, Jeanette K., Nancy Hedberg, and Ron Zacarski. 1993. Cognitive status and the form of referring expressions in discourse. Language 69. 274–307.
Hale, John. 2001. A probabilistic Earley parser as a psycholinguistic model. Proceedings of the Second Meeting of the North American Chapter of the Association for Computational Linguistics. 159–66.
Holmes, V. M., and J. K. O'Regan. 1981. Eye fixation patterns during the reading of relative- clause sentences. Journal of Verbal Learning and Verbal Behavior 20. 417–430.
Hsiao, Franny, and Edward Gibson. 2003. Processing relative clauses in Chinese. Cognition 90. 3–27.
Johnson, Marcus L., Matthew W. Lowder, and Peter C. Gordon. 2011. The sentence- composition effect: processing of complex sentences depends on the configuration of common noun phrases versus unusual noun phrases. Journal of Experimental Psychology: General 140. 707–24.
Just, Marcel A., and Patricia A. Carpenter. 1992. A capacity theory of comprehension: individual differences in working memory. Psychological Review 99. 122–49.
——, ——, Timothy A. Keller, William F. Eddy, and Keith R. Thulborn. 1996. Brain activation modulated by sentence comprehension. Science 274. 114–6.
Keenan, Edward L. 1975. Variation in universal grammar. Analyzing variation in language, ed. by Ralph W. Fasold and Roger W. Shuy, 138–48. Washington, DC: Georgetown University Press.
King, Jonathan, and Marcel A. Just. 1991. Individual differences in syntactic processing: the role of working memory. Journal of Memory and Language 30. 580–602.
Kuo, Kuelian, and Shravan Vasishth. 2006. Processing relative clauses: evidence from Chinese. Potsdam: University of Potsdam. MS.
Kwon, Nayoung, Yoonhyoung Lee, Peter C. Gordon, Robert Kluender, and Maria Polinsky. 2010. Cognitive and linguistic factors affecting subject/object asymmetry: an eye- tracking study of prenominal relative clauses in Korean. Language 86. 546–82.
Ledoux, Kerry, and Peter C. Gordon. 2006. Interruption-similarity effects during discourse processing. Memory 14. 789–803.
Lee, Yoonhyoung, Hanjung Lee, and Peter C. Gordon. 2007. Linguistic complexity and information structure in Korean: evidence from eye-tracking during reading. Cognition 104. 495–534.
Levy, Roger. 2008. Expectation-based syntactic comprehension. Cognition 106. 1126–77.
Lewis, Richard L., and Shravan Vasishth. 2005. An activation-based model of sentence processing as skilled memory retrieval. Cognitive Science 29. 375–419.
——, ——, and Julie A. Van Dyke. 2006. Computational principles of working memory in sentence comprehension. Trends in Cognitive Sciences 10. 447–54.
Lin, Chien-Jer Charles. 2008. The processing foundation of head-final relative clauses. Language and Linguistics 9. 813–38.
Lowder, Matthew W., and Peter C. Gordon. 2011. The pistol that injured the cowboy: difficulty with inanimate subject-verb integration is reduced by structural separation. Chapel Hill, NC: University of North Carolina. MS.
MacDonald, Maryellen C., and Morten H. Christiansen. 2002. Reassessing working memory: comment on Just and Carpenter (1992) and Waters and Caplan (1996). Psychological Review 109. 35–54.
MacWhinney, Brian. 1977. Starting points. Language 53. 152–68.
——, and Csaba Pleh. 1988. The processing of restrictive relative clauses in Hungarian. Cognition 29. 95–141.
Mak, Willem M., Wietske Vonk, and Herbert Schriefers. 2002. The influence of animacy on relative clause processing. Journal of Memory and Language 47. 50–68.
——. 2006. Animacy in processing relative clauses: the hikers that rocks crush. Journal of Memory and Language 54. 466–90.
McDaniel, Mark A., and Julie M. Bugg. 2008. Instability in memory phenomena: a common puzzle and a unifying explanation. Psychonomic Bulletin & Review 15. 237–55.
McElree, Brian. 2006. Accessing recent events. The psychology of learning and motivation: advances in research and theory, vol. 46, ed. by Brian H. Ross, 155–200. San Diego, CA: Academic Press.
——, Stephani Foraker, and Lisbeth Dyer. 2003. Memory structures that subserve sentence comprehension. Journal of Memory and Language 48. 67–91.

Mecklinger, A., H. Schriefers, K. Steinhauer, and A. D. Friederici. 1995. Processing relative clauses varying on syntactic and semantic dimensions: an analysis with event-related potentials. Memory & Cognition 23. 477–94.
Merritt, Paul S., Edward L. DeLosh, and Mark A. McDaniel. 2006. Effects of word frequency on individual-item and serial order retention: tests of the order-encoding view. Memory & Cognition 34. 1615–27.
Miller, George A., and Noam Chomsky. 1963. Finitary models of language users. Handbook of mathematical psychology, vol. II, ed. by R. Duncan Luce, Robert R. Bush and Eugene Galanter, 269–321. New York, NY: Wiley.
Mitchell, Don C., Fernando Cuetos, Martin M. B. Corley, and Marc Brysbaert. 1995. Exposure- based models of human parsing: evidence for the use of coarse-grained (nonlexical) statistical records. Journal of Psycholinguistic Research 24. 469–88.
Reali, Florencia, and Morten H. Christiansen. 2007. Processing of relative clauses is made easier by frequency of occurrence. Journal of Memory and Language 57. 1–23.
Roland, Douglas, Frederic Dick, and Jeffrey L. Elman. 2007. Frequency of basic English grammatical structures: a corpus analysis. Journal of Memory and Language 57. 348–79.
Schriefers, Herbert, Angela D. Friederici, and Katja Kühn. 1995. The processing of locally ambiguous relative clauses in German. Journal of Memory and Language 34. 499–520.
Staub, Adrian. 2010. Eye movements and processing difficulty in object relative clauses. Cognition 116. 71–86.
Traxler, Matthew J., Robin K. Morris, and Rachel E. Seely. 2002. Processing subject and object relative clauses: evidence from eye movements. Journal of Memory and Language 47. 69–90.
——, Rihana S. Williams, Shelley A. Blozis, and Robin K. Morris. 2005. Working memory, animacy, and verb class in the processing of relative clauses. Journal of Memory and Language 53. 204–24.
Ueno, Mieko, and Susan M. Garnsey. 2008. An ERP study of the processing of subject and object relative clauses in Japanese. Language and Cognitive Processes 23. 646–88.
Van Dyke, Julie A., and Richard L. Lewis. 2003. Distinguishing effects of structure and decay on attachment and repair: a cue-based parsing account of recovery from misanalyzed ambiguities. Journal of Memory and Language 49. 285–316.
——, and ——. 2006. Retrieval interference in sentence comprehension. Journal of Memory and Language 55. 157–66.
Wanner, Eric., and Michael Maratsos. 1978. An ATN approach to comprehension. Linguistic theory and psychological reality, ed. by Morris Halle, Joan Bresnan and George Miller, 119–61. Cambridge, MA:MIT Press.
Warren, Tessa, and Edward Gibson. 2002. The influence of referential processing on sentence complexity. Cognition 85. 79–112.
Waters, Gloria S., and David Caplan. 1996. The capacity theory of sentence comprehension: critique of Just and Carpenter (1992). Psychological Review 103. 761–72.
Wells, Justine B., Morten H. Christiansen, David S. Race, Daniel J. Acheson, and Maryellen C. MacDonald. 2009. Experience and sentence processing: statistical learning and relative clause comprehension. Cognitive Psychology 58. 250–71.