ERPs to the main-clause verb in both SR and OR sentences showed a greater left anterior negativity than the second verb in sentences that did not contain relative clauses. Although tempted, we will refrain from arguing from this pattern of effects that the insensitivity of the behavioral reaction time data suggests they are more likely to reflect "post-integrative" effects.

C&W also claim that there is no (behavioral) evidence of an interaction between sentence complexity and working memory capacity (WMC), and, because there is no evidence that sentence complexity has larger effects on low-WMC subjects, C&W conclude that RT data from the SR–OR contrast support their proposal for a verbal working memory subsystem specialized for syntactic analysis. Setting aside their interpretation of the behavioral data, we would like to point out that the ERP studies cited above also include notable demonstrations of individual differences in syntactic processing. In both written and spoken English, good comprehenders show large ERP differences between SR and OR sentence types, whereas poorer comprehenders show almost none (see, e.g., King & Kutas 1995; Müller et al. 1997). In good comprehenders, subject relatives elicit a frontal positivity, whereas object relatives show more negative deflections from this pattern. In poor comprehenders, the responses elicited by both the SR and the OR sentences are almost identical to each other and also identical to the response elicited by OR sentences in good comprehenders. It is likely that these good comprehenders would score higher on many (possibly language specific) WMC measures than would poor comprehenders. More sensitive measures thus *do* show the kind of individual differences C&W failed to find. Additionally, however, we find that good and poor comprehenders show ERP differences *even on simple transitive sentences* (Kutas & King 1996), data that are not predicted by any of the existing capacity theories, because these sentence types require far less capacity to process.

Whatever the ultimate subdivisions of verbal working memory turn out to be, we doubt that psycholinguists can afford to ignore the temporal information and processing perspective provided by sentence-level ERP measures. At present, although interesting and provocative, the C&W proposal awaits an exact empirical test.

Accounting for the fine structure of syntactic working memory: Similarity-based interference as a unifying principle

Richard L. Lewis

Department of Computer and Information Science and Center for Cognitive Science, The Ohio State University, Columbus, OH 43210.
rick@cis.ohio-state.edu www.cis.ohio-state.edu/~rick

Abstract: A promising approach to more refined models consistent with the Caplan & Waters hypothesis is based on similarity-based interference, a general principle that applies across working memory domains. This may explain both the fine details of syntactic working memory phenomena and the gross fractionation for which Caplan & Waters have found evidence. Detailed models of syntactic processing that embody similarity-based interference fare well cross-linguistically.

Caplan & Waters (C&W) present a compelling case for specialization within verbal working memory. They conclude their target article by looking ahead to additional specification of the hypothesis based on better developed models of working memory. In this commentary I describe some work that takes up the challenge to develop more refined working memory models. I will first discuss briefly some of the phenomena that must be accounted for by a more detailed theory. I will then argue two theoretical points: first, even though working memory may be quite specialized, there are general principles that apply across all kinds of working memory. Second, one of those general principles, similarity-based interference, may explain both the fine details of syntactic working memory phenomena and the gross fractionation and specialization for which C&W have found evidence (Lewis 1993; 1996b; 1998).

C&W start their discussion of memory demands in sentence comprehension with the notoriously difficult English double center-embedded relative clause (their sentence [1]) and go on to cite a few of the computational models and linguistic metrics that have been developed to account for the problem with such embeddings. What they did not mention is how surprisingly difficult it has been to produce models and metrics that are empirically adequate. Though it is true that there is a "remarkable degree of similarity in the measurements" that some of the models produce (sect. 1), the vast majority of these measurements do not fare well when considered against a broad range of embeddings cross-linguistically. Furthermore, there has been little independent psychological motivation for the proposed memory structures (e.g., stacks, lookahead buffers) and their associated limitations (see Lewis 1996 for a review).

As an example of the kind of empirical hurdle faced by any theory of syntactic working memory, consider a fact established by Cowper (1976) and Gibson (1991) in their seminal work: a metric based on the amount of center-embedding does not account for many difficulty contrasts in English and other languages. Consider sentences (1a) and (1b):

1a. That the food that John ordered tasted good pleased him (Cowper 1976; Gibson 1991).

1b. Der Bauer, der die Kuh, die schlechte Milch gab schlachtete ist krank.
the farmer who the cow which bad milk gave killed is sick.
"The farmer who killed the cow which gave bad milk is sick" (Hawkins 1994).

Though both constructions involve double center-embedding of sentential structures (and sentence [1b] even involves center-embedding of relative clauses), neither causes the comprehension difficulty associated with the classic example cited in the target article.

Although increasing center-embedding certainly increases difficulty, another important observation is that increasing the similarity of the embedded constituents increases difficulty, and making constituents more distinct or dissimilar in some way helps processing. This generalization is an old one; it goes back to Miller and Chomsky's (1963) original self-embedding metric and has been noted several times since (e.g., Bever 1970; Kuno 1974).

Why is this observation significant? Similarity-based interference is a principle that holds true of working memory in general. Starting with the early work of Baddeley (1966) and Conrad (1963), which identified a special system relying on phonological codes and covert rehearsal, evidence has accumulated for a wide range of distinct working memory types subject to selective, type-specific interference. The verbal versus visual-spatial distinction is the best known (Baddeley & Hitch 1974; Logie et al. 1990), but there is also evidence for distinct codes for kinesthetic memory (Williams et al. 1969), odor (Walker & John 1984), and sign language (Poizner et al. 1981), to name a few. The robust result across domains is that, when to-be-remembered items are followed by stimuli that are similar along some dimensions, the original items are more quickly forgotten (Shulman 1970; Waugh & Norman 1965).

Crucially, similarity-based interference operates within major categories as well. The most familiar within-category effect is the phonological similarity effect. Ordered recall of phonologically similar lists of words, consonants, or nonsense trigrams is worse than with dissimilar lists (Baddeley 1966; Conrad 1963; Wickelgren 1965). Related effects show up in immediate memory for American Sign Language (Poizner et al. 1981) and visual orientation (Magnussen et al. 1991).

Building on these results, and the work cited earlier by Gibson (1991), Cowper (1976), and others, I have hypothesized that similarity-based interference as a general principle applies to syntactic working memory as well. Lewis (1993; 1996b) described a

computational model that embodies retroactive, type-specific syntactic interference and accounts for a range of cross-linguistic data concerning difficult center embeddings. The model posited a simple buffer that could maintain no more than two constituents of a particular syntactic type.

The type specificity of the limitation is crucial to the empirical success of the model. To see why, consider again the difficult center embedding discussed in the target article, repeated here as sentence (2a):

2a. The man that the woman that the child hugged kissed laughed.
2b. The man that the woman kissed laughed.

Three noun phrases (NPs) of the same syntactic type (subjects) must be momentarily buffered in order correctly to parse the very difficult sentence (2a), whereas only two such NPs must be buffered to parse the acceptable sentence (2b). But consider now the comprehensible Japanese construction in sentence (3) below:

3. John-wa Bill-ni Mary-ga Sue-ni Bob-o syookai sita to it-ta.
John-TOP Bill-DAT Mary-NOM Sue-DAT Bob-ACC introduced say.
"John said to Bill that Mary introduced Bob to Sue" (Lewis 1993).

Such sentences do not cause the difficulty associated with sentence (2a), despite stacking up five NPs. The crucial difference, of course, is that sentence (3) requires buffering no more than two NPs of any particular syntactic function: at most two subjects, two indirect objects, and a direct object.

What this theory amounts to is adding "syntactic" to the list of immediate memory types that exhibit type-specific interference and decreased performance with increased similarity. Just as there is the well-known phonological similarity effect, there is also a "syntactic similarity effect," and one way this effect manifests itself is difficulty with center embedding. Lewis (1998) extends this theory to combine both retroactive and proactive interference into a measure of working memory load. The new model increases the empirical coverage considerably, and directly yields detailed, moment-by-moment predictions of processing load.

The similarity-based interference hypothesis can be seen as a further specification of the C&W specialization hypothesis. The good news may be that the same principle that yields fractionation at a gross level also seems to work well as a basis for quite detailed models of syntactic processing across languages. Furthermore, it should be clear that we can embrace fractionation and specialization without abandoning more general cognitive principles.

Further fractionations of verbal working memory

Randi C. Martin

Psychology Department, Rice University, Houston, TX 77251.
rmartin@rice.edu **www.ruf.rice.edu/~psyc/faculty/martin.html**

Abstract: Although the working memory capacity involved in syntactic processing may be separate from the capacity involved in word list recall, other aspects of initial sentence interpretation appear to depend on some of the same capacities tapped by span tasks. Specifically, there appears to a capacity for lexical–semantic retention involved in both sentence comprehension and span measures.

Caplan & Waters (C&W) have presented a convincing case concerning the independence of the working memory resources involved in syntactic processing and those that are tapped by various span measures such as reading span or digit span. They have amassed a large body of data showing that across different materials, experimental procedures and subject populations critical interactions are not obtained between the effects of syntactic complexity and extraneous memory load and between syntactic complexity and individuals' working memory capacity.

A less well justified claim put forward by C&W is that sentence comprehension can be divided into interpretive and post-interpretive processes and that all interpretive processes depend on capacities separate from those tapped by standard span measures. In order to make this claim they have to argue that an effect on comprehension of number of propositions (which does interact with extraneous load) occurs because the number of propositions effect is due to post-interpretive processes. However, their definition of interpretive processes includes "assigning thematic roles, focus, and other aspects of propositional and discourse-level semantics." According to this definition, it is not clear why greater post-interpretive capacity rather than greater interpretive capacity is involved in deciding the sensibility of sentences with two propositions (e.g., "The famous author wrote the play that watched the audience") versus one proposition ("It was the play that watched the audience"). If the capacities involved could be said to fall under interpretive processes, then C&W would be forced to conclude that, even within what might be termed interpretive processes, there are separable capacities devoted to the maintenance of different types of information, for example, syntactic structure versus propositions.

In several publications, we have argued that there are separable components involved in the maintenance of phonological, lexical–semantic, and syntactic information during sentence processing, and at least the phonological and lexical–semantic components play a role in short-term memory for word lists (Martin & Romani 1994; Martin et al. 1994; Martin 1995). Brain-damaged patients who have a disruption of the semantic component, but not those who have a disruption of the phonological component, have difficulty understanding sentences in which the integration of meanings of words is delayed because the meanings of a number of words must be held in an unintegrated fashion until some key word is processed (Martin & Romani 1994). For example, for sentences in which there are a number of adjectives preceding a noun ("the rusty old red pail"), the meaning of the adjectives cannot be precisely determined nor can their meaning be integrated with the noun until the noun is processed. Similarly, when a number of nouns precede a verb ("flowers, trees, and shrubs grew . . ."), the thematic role that the nouns play with respect to the verb cannot be determined until the verb is processed. These patients' difficulty in understanding such sentences is not an effect of the number of propositions, insofar as these patients could understand sentences with the same number of propositions when immediate integration was possible, such as when the adjectives followed the noun ("the pail was old, red, and rusty") or the nouns followed the verb ("the gardener grew flowers, trees, and shrubs"). It would be difficult to claim that comprehension of the sentences involving the maintenance of several unintegrated word meanings depends on "post-interpretive" processes. The ability to hold individual word meanings until they can be integrated with other words' meanings to form propositions would seem to be a fundamental ability involved in initial sentence interpretation. It should be noted that the same patients who had difficulty with the delayed integration sentences did not have difficulty making grammaticality judgments for sentences in which several words intervened between the two words signaling a grammatical error. Thus, the capacity affected was specific to maintaining lexical–semantic information and not syntactic information.

In discussing the separation between the working memory involved in post-interpretive processes and that involved in interpretive processes, C&W point to lesion localization and functional neuroimaging data. As they indicate, there is much evidence implicating the dominant perisylvian cortex in fundamental aspects of language processing. They further claim that neuroimaging studies of working memory have not implicated these areas. However, contrary to this claim, several neuroimaging studies of working memory have found activation in Broca's area and in the inferior parietal region (Brodmann's area 40; see Fiez et al. 1996 for an overview). Activation in these areas has generally been attributed to phonological retention and rehearsal. If these working memory studies used more meaningful word materials rather than