memory problems should at least be extended or discussed in a different context. In particular, the question arises of whether sentence comprehension deficits in aphasic or central nervous system (CNS) dysfunction patients are solely a consequence of a specific working memory resource deficit and/or a computational deficit. In other words, can there be an independent resource deficit without some interference from a computational deficit at the "post-interpretive" processing level? We will present data from an aphasic patient with verbal working memory deficits to broaden this discussion.

Patient H. G., a 45-year-old male, suffered an ischemic stroke in 1996. T2-weighted images in the axial plane taken about half a year after the stroke revealed an extended lesion in the left temporoparietal region and a small lesion in the left posterior frontal area. The temporoparietal lesion encloses (1) the left Heschl gyrus, (2) the posterior part of the superior temporal gyrus, (3) the supramarginal gyrus, and (4) the occipital gyri. The frontal lesion involves the middle portion of the praecentral gyrus and the posterior part of the frontal gyrus (F2p). The inferior frontal gyrus (F3) is spared. The functional deficit due to the frontal lesion could be twofold: (1) an articulatory deficit due to the lesion in the praecentral gyrus or (2) a verbal working memory deficit due to the lesion in the posterior F2 area. The lesioned supramarginal gyrus in the temporoparietal region should crucially affect the phonological short-term memory (STM; see Warrington 1975), with intact rehearsal processes (see unaffected F3 region). In terms of the functional–neuroanatomical correlates, H. G. should show the classical picture of an aphasic patient with an STM deficit and potentially a syntactic processing deficit during sentence comprehension.

In a first step, we tested H. G. for deficits in the articulatory rehearsal and phonological storage system. Results indicate no STM deficit in H. G. Tests for verbal working memory capacities such as verbal word span (span: 2–3) and an adapted aphasic reading span task (span: 1) as well as digit spans (forward and backward), however, indicate a severe verbal working memory deficit in H. G. Next, H. G. was tested with several sentence-comprehension paradigms engaging syntactic complexities (word category violations, subject–object relative clauses, subordinate clause violations). Furthermore, a combination of syntactic complexity with increasing propositional content was applied. We used both sentence picture-matching tasks and auditory and visual comprehension tasks in the two test batteries. Results indicate that H. G. did not show a significant deficit in sentence comprehension at the "interpretive" or "post-interpretive" level of processing. Thus, if working memory impairments exclusively influence "post-interpretive" processing, as proposed by C&W (sects. 3.3 and 3.4), H. G.'s data provide evidence against this hypothesis. Most strikingly, he did not show any effect of increasing propositional content. One example of this effect is that he scored 100% on a German version of the Token Test (DeRenzi & Vignolo 1962; Martin & Feher 1992) and in a judgment task with increasing propositional content.

To ensure that the "untimed" accuracy measures of sentence comprehension were not due to a ceiling effect, we proceeded to test H. G. in a combined syntactic and semantic judgment paradigm utilizing event-related potentials (ERPs). We assumed that if the verbal working memory deficit of H. G. has any effect on sentence comprehension it should be visible in the on-line measurements of ERP components specific to syntactic and semantic processes (see also Friederici et al., in press). Even though this judgment paradigm did not use the most complex syntactic structures nor a dual-task manipulation with additional load, H. G. displayed an interesting picture. Whereas the performance data were in the normal range, H. G. showed that on-line computation of syntactic structure and semantic integration was influenced by the input parameters. The evaluation of syntactic violations (word category errors) and semantic violations (selectional restriction errors) and correct sentences in connected speech did not elicit any of the expected ERP components in H. G. A similar picture emerged in the visual modality with a fast presentation rate (SOA: 500 msec). In a long SOA (1100 msec) visual manipulation, the N400 (onset: 350 msec) was elicited to semantic violations and a delayed P600 (onset: 1,000 msec) was elicited to syntactic violations. These results, although by no means exhaustive in the discussion of resource-capacity models, give evidence that reduced verbal working memory capacities might go hand in hand with a temporal deficit.

## In-line measures of syntactic processing using event-related brain potentials

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**Abstract:** Scalp-recorded event-related potential (ERP) measures of reading and listening have been proved more sensitive to the time course of syntactic processing than the chronometric and behavioral data described by Caplan & Waters. ERP studies using sentences containing relative clauses indicate that there are individual differences in syntactic processing that appear at the earliest theoretically relevant time points and are attributable to working memory operations.

Leaving aside a discussion of Caplan & Water's (C&W's) specific proposal that there are two distinct verbal working memory systems, we note that C&W base much of their argument on chronometric and behavioral data from the processing of sentences containing subject-relative (SR) and object-relative (OR) clauses. The focus on the contrast between SR and OR clauses is clear; arguments concerning limitations in working memory capacity permeate the experimental literature on this topic. The decision to focus on reaction time measures, however, is less clear to us. Although a host of measures show consistent chronometric differences between the two sentences, these effects are generally observed substantially *after* the point in the sentence where they would be expected owing to a difference in working memory storage demands per se. In the following examples,

OR: The reporter who *the senator* harshly attacked admitted the error.
SR: The reporter who harshly attacked the senator admitted the error.

the noun phrase "the senator" in the OR sentence marks the beginning of the differential working memory load between the two sentence types. However, RT differences are not seen until the end of the relative clause or even later, on the main clause verb. Thus, one might question the sensitivity of the chronometric measures on which C&W base their arguments, at least if monotonic increases in memory load lead to monotonic increases in processing time, as many assume.

There is, however, one measure of brain processing that shows differential activity for OR versus SR sentences starting precisely where one would expect from the usual working memory arguments, namely, event-related potentials (ERPs). While C&W miscite who found out what and when, they do note that the processing of OR sentences is associated with a greater negativity than the processing of SR sentences. This electrophysiological pattern has been observed repeatedly during word-by-word reading in English (King & Kutas 1995) and German (Mecklinger et al. 1995; Münte et al. 1997) as well as in connected speech (Müller et al. 1997). This ERP difference between subject and object relatives is large and is more pronounced over anterior electrode sites; with visual materials, it is also left-lateralized. (Indeed, it is this topographic characteristic of the data that C&W highlighted when referring to ERP results in their section on the anatomical locus of verbal working memory processes.) But, to emphasize the point, the electrophysiological data show a much earlier point of divergence. Moreover, King and Kutas (1995) found that the

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

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**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 line psycholinguistic processing and one or more resource pools that may be used for other verbally-mediated tasks. How fine a fractionation of resource systems will be needed to account for capacity limitations in language processing and other verbally mediated cognitive functions is not known at this point (Waters & Caplan 1996c).

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**Letters "a" and "r" appearing before authors' initials refer to target article and response, respectively.**


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