Working Memory and Sentence Processing

Experiments that investigate the effects of working memory (WM) on sentence comprehension utilize three basic approaches. The first is to divide subjects into high and low WM groups often using a version of the Daneman and Carpenter task to compare group differences in syntactic complexity. The second approach, called the dual-task approach, uses the logic that performance on sentence comprehension will be reduced with a secondary task if both tasks rely on the same WM resources. The secondary task often manipulates load, or the number of items held in memory, while comprehending sentences. A third approach to investigating the effects of WM on sentence processing is to use patient populations. Patients with selective impairments in either working memory or syntactic comprehension provide evidence that these two systems can work independently of each other.

All sentence comprehension models agree that performance is modulated by the amount of resources available and the efficiency of the resources. Comprehension difficulty is either the result of decreased resource capacity or inefficient resource use. Various models of sentence comprehension have been proposed in order to account for individual differences in sentence comprehension. Just and Carpenter (1992) propose a capacity-constrained theory in which memory (capacity) and computational operations (efficiency) necessary for sentence processing are shared by a single WM system leading to trade-offs between storage and processing. Thus they would predict (WM group x sentence complexity) and (WM load x sentence complexity) interactions. Caplan and Waters (1999) propose that sentence processing is mediated by 2 separate WM systems. The first is used for online, interpretive processing while the second processes offline, postinterpretive information. Their theory predicts that WM (offline tasks) and sentence complexity (online tasks) interactions should *not* occur. They have claimed that the lack of significant interactions between WM and syntactic complexity in published data supports their theory. They also present data on patient populations. Some DAT and PD patients with working memory deficits have intact sentence processing, and some aphasic patients with syntactic deficits have preserved working memory. MacDonald and Christiansen (2002) propose that processing abilities emerge from an individual's experience with language (capacity) and their phonological representations (efficiency). All of these models agree that WM resources can affect sentence processing, but they disagree as to how.

Fedorenko, Gibson, and Rohde (2004) use the dual-task approach and provide evidence for an interaction with online sentence processing complexity. As mentioned previously, this interaction is what has been lacking in the literature to disprove Caplan and Waters' theory. Experiment 2 found adding numbers presented with each segment of a self-paced reading task produced an interaction between the math complexity and the sentence complexity. Subject and object extracted RC were differentially affected by the complexity of math addends in the critical region of the sentence. Fedorenko et al. claim

to have ruled out increased attentional costs in the harder math condition as the source for the interaction using results from experiment 3. In this experiment, spatial pie segments were added with each segment of the same self-paced sentences used in experiment 2. Critically, no interaction was found between syntactic complexity and spatial addition complexity in any region of the sentence. The lack of interaction was used to argue against the attentional account of the interaction found in experiment 2. The authors concluded that syntactic operations and math operations utilize the same pool of WM resources, and syntactic operations and spatial operations do not share the same WM resources. They propose another theory of WM and sentence processing in which WM is divided into four different resource pools along two dimensions: 1) sequentiality of the input, 2) discreteness of the input.

Discreteness and sequentiality are first introduced in the discussion section of this paper and specific definitions of these concepts are lacking. Examples of discrete informational units provided are words and numbers in arithmetic. The complexity of computation for each of these units is affected by distance in a sentence or number line, respectively. Spatial areas are considered non-discrete as intervening elements do not exist and cannot interfere with the integration or computation. Exact calculations can occur with discrete units while only approximate calculations can occur with nondiscrete units. The difference between sequential and non-sequential information is less clear. The authors state, "visuo-spatial processing often involves non-sequential input, such that you are getting the information all at once." How this relates to the serial presentation of spatial areas with segments of the sentences is unclear. The authors seem to be implicating that individual calculations are required in adding numbers but not in adding spatial areas. For example, "3+5" may be added up to "8". The number "8" is held in memory and then added to the third number and so forth. Spatial information may not require these individual steps, and numerous visual areas may be held in memory and summed without intervening information held in memory.

The different results in experiment 2 and 3 are claimed to be due to discreteness and sequentiality, and these concepts provide two explanations for why an interaction occurred in experiment 2 but not experiment 3. It seems that one fundamental difference between discrete and nondiscrete items is in phonological rehearsal. Discrete items, such as words or numbers, can be rehearsed while non-discrete spatial areas cannot be rehearsed. MacDonald and Christiansen (2002) provide evidence that phonological activation is important for written and spoken sentences, particularly for more complex items. If more rehearsal is required for more complex items (math complexity and sentence complexity), then a shared phonological rehearsal system could be the locus of the interaction found. Thus, discreteness may be a synonym for phonological rehearsal.

In order to address the issue of sequentiality, understanding the strategy subjects used to complete the dual tasks in experiment 2 and 3 is important. Since this was not reported, we can only speculate. The concept of "sequentiality" introduced by the authors seems to imply that subjects might process the math task by calculating an intermediate sum after each number was presented while the visual task was completed by adding up all the areas at the end of the sentence. This would cause the math task to interrupt

sentence processing more than the visuo-spatial task leading to increased attentional costs during sentence processing in experiment 2. The interaction found in experiment 2 may be due to increased attentional costs. Caplan and Waters (1999) report that experiments in which memory load interrupts sentence comprehension often show an interaction between the complexity of the secondary task and syntactic complexity due to increased attentional demands, but experiments in which memory load does not interrupt sentence comprehension have not shown interactions. Understanding the strategy that subjects used to accomplish the dual task in experiment 2 and 3 would help distinguish whether sequentiality is truly an issue.

Patient populations may provide further evidence as to how sentence comprehension, working memory, and mathematical computation interact. Aphasic patients with poor syntactic skills can have preserved math and memory abilities. DAT patients with poor working memory can present with good sentence comprehension and math skills. Acalculia (a deficit in math) can occur independent of any sentence comprehension or memory skills and dyscalculia can occur in children with good verbal skills and memory. Patient case studies, therefore, may provide evidence that these three systems can be independently lesioned.

Gordon, Hendrik, and Levine (2002) used cleft subject and cleft object sentences containing either two descriptive nouns (e.g., the dancer) or two names (e.g., John). Three descriptions or three names were presented before the sentences and were held in memory during the self-paced sentence presentation. In the "matched" condition, the nouns in the memory load and in the sentences were of the same type (both descriptions or both names) and in the "unmatched" condition the nouns were of opposite type. They found an interaction between match type and syntactic complexity such that the matched condition impaired the cleft objects to a greater extent presumably due to interference of similar information. This interaction was only significant for the comprehension question which is an offline measure but the same trend was found in online reading time measurements though nonsignificant. Fedorenko et al modified this task in experiment 1 and found the critical interaction between match type and syntactic complexity in online measures. This provides the most convincing evidence against the theory proposed by Caplan and Waters (1999) as no interaction between offline verbal storage and online sentence processing is predicted in their theory. Clearly, these results implicated a shared pool of resources between item recall and sentence processing that monitors or is activated by similar inputs. Whether this means that working memory and online sentence processing share the same resources, or whether they share some overlapping resources for higher-level monitoring/integration is a new question for psycholinguistics.