Tara McAllister
24.951, Language Processing
Final Paper

Toward an Understanding of Working Memory in Parkinson's Disease

1. Introduction

Parkinson's Disease (PD), a neurological disease associated with the degeneration of the dopaminergic nigostriatal pathway, is characterized by a number of physical and cognitive symptoms. The physical manifestations of PD are well-documented, including slowness of movement (bradykinesia), difficulty initiating movement, and resting tremors. However, the cognitive and linguistic aspects of the disease are less thoroughly understood. This paper will focus on the language abilities of Parkinson's patients, particularly those in relatively early stages of the disease prior to the onset of dementia.

It is a standard assumption in the PD literature that patients' language production is "simplified," with a tendency to avoid complicated syntax and especially embedded constructions (Illes et al., 1988). Recalling the physical limitations typical of PD, though, we might guess that patients use short and simple sentences in an attempt to minimize the motor act of speech, which for them is highly effortful. This possibility makes it difficult to draw conclusions about grammatical competence using measures of language production, with the result that most studies of language in PD populations have instead focused on the comprehension abilities demonstrated by these patients. Studies since Lieberman (1990) have mostly held that PD patients, compared to normal populations, demonstrate reduced comprehension of syntactically complex sentences.

Having identified a comprehension deficit in the PD population, we face at least two follow-up tasks: first, to identify which aspects of grammar, if any, pose a particular problem for

PD patients, and subsequently to posit a possible cause for the observed pattern of impairment. Various causes have been proposed for the deficit observed in Parkinson's Disease, ranging from problems of linguistic representation (Natsopoulos et al., 1993) to attention deficits (Grossman et al., 1992) to impairment in the faculty of procedural memory (Ullman et al., 1997) or working memory (Seidl et al., 1995; Kemmerer, 1999; Grossman et al., 1999).

This last proposal, henceforth termed "the working memory hypothesis of Parkinson's disease," has garnered considerable attention. One main reason for this interest lies in a debate external to the clinical literature concerning the architecture of working memory. Studies including King & Just (1991), Just & Carpenter (1992), and Gordon, Hendrick & Levine (2002) have held that a single pool of working memory resources underlies all verbally-mediated operations. However, Waters et al. (1995) and Caplan & Waters (1999) have that working memory is subdivided so that natural language processing is distinct from other verbally-mediated tasks. The relevance of this debate to the question of language impairment in PD derives from the finding that Parkinson's patients as a group demonstrate a general reduction in working memory capacity (Gabrieli et al., 1996). Different theories of working memory make distinct predictions as to how this impairment should affect the language of the PD group. Thus, the participants in the WM debate take a strong interest in the question of whether Parkinson's patients show a reduction in syntactic processing abilities, and if so, whether this impairment can be conclusively attributed to a deficit in working memory capacity.

In this paper, I will again take up the issue of the role of working memory in language processing in PD patients. In Section 2 I will review the debate over the architecture of working memory, also incorporating a discussion of appropriate experimental methodology for investigations of working memory. Section 3 will discuss two studies arguing that Parkinson's

patients do not exhibit any language impairment that can be attributed to working memory deficits (Waters & Caplan, 1997; Caplan & Waters, 1999). In the Section 4, though, I will review three studies that report results compatible with a working memory account of language deficits in PD (Seidl et al., 1995; Kemmerer, 1999; Grossman et al., 1999). However, I will find that no study up to the present has provided a complete and robust answer to our question about the role of working memory in PD patients' language. Therefore, in Section 5 I will propose an experimental design intended to provide a more comprehensive view of this issue. The experiment, which borrows its methodology from a recent study of working memory (Fedorenko et al., 2004), has the potential to further our understanding not only of the specific nature of Parkinson's Disease, but also of more general issues concerning the role of working memory in linguistic processing. Finally, in Section 6 I will briefly overview a different perspective which suggests that language deficits in PD are due to an impairment in the procedural component of long-term memory (Ullman et al. 1997), and I will discuss how this proposal compares to the working memory accounts under consideration here.

2. Investigating Working Memory and Language

Working memory is defined as "a short-duration, limited-capacity memory system capable of simultaneously storing and manipulating information in the service of accomplishing a task" (Caplan & Waters, 1999, p. 77). A generally accepted claim in the memory literature holds that working memory can be subdivided into distinct visuospatial and verbal components (Baddeley, 1986; Shah & Miyake, 1996). However, a debate has arisen as to whether further subdivision of the verbal working memory is necessary. Caplan & Waters (1999) have championed the "separate-sentence-interpretation-resource" (SSIR) theory, claiming that verbal

working memory has one discrete component for natural language processing and another for other verbally-mediated tasks. However, studies such as Just & Carpenter (1992) and Gordon et al. (2002) have argued for the "single-resource" (SR) hypothesis, providing evidence that a single pool underlies both types of processing. More recently, Fedorenko, Gibson & Rohde (2004) have reported strong evidence against the hypothesis of a separate WM pool for sentence processing. While their proposed architecture of working memory is distinct from the single-pool hypotheses mentioned above, advocating a division of WM along parameters of sequentiality and discreteness of the input, the specifics of this proposal will not be investigated in detail in the present paper.

The two perspectives on working memory discussed above, SR and SSIR, differ in their predictions for the relation between language performance and working memory load. What sort of experimental approach will allow us to test for the influence of working memory in language processing? Before we discuss the tasks designed to identify working memory effects, let us consider the theoretical perspective offered by one widely-used model of sentence processing: the Dependency Locality Theory, or DLT (Gibson 1998; 2000). The DLT identifies *storage* and *integration* as two components of working memory implicated in sentence processing. The notion of storage is calculated here by the number of syntactic heads predicted to be necessary to complete the current input as a grammatical sentence (Gibson, 2000). In the discussion to follow, however, we will focus not on storage but on integration, which offers a convenient measure for our investigation of WM in a clinical population. The DLT proposes that the difficulty of integrating a new element into a sentence increases in proportion to the distance between the heads of the two constituents being integrated. One means of measuring this distance relates to decay, where the activation of an attachment site is thought to diminish

over time (Gibson, 2002). It is also possible to measure distance in terms of interference, where the difficulty of integrating a new element is thought to correlate with the degree of similarity between the integrands and any intervening elements; this effect can be attributed to the possibility of source-memory confusion when similar items are held in memory (Gordon et al. 2002). The concepts introduced by the DLT will be important for our understanding of experiments in working memory and language to be discussed below.

Experiments investigating the role of working memory in language processing generally take one of two designs, the individual-differences paradigm and the dual-task paradigm. In the former type of experiment, different subject groups are identified based on their performance on some measure of verbal working memory. Subsequent experimentation seeks to correlate these different degrees of working memory capacity with differing levels of efficiency and/or accuracy in sentence processing (Caplan & Waters, 1999). The dual-task paradigm, on the other hand, asks subjects to carry out sentence processing while simultaneously executing some other task designed to place a load on verbal working memory. One commonly used task calls for subjects to hold in memory a string of digits of variable length (Caplan & Waters, 1999). Another recognized measure asks the subject to keep one or more nouns in memory while processing a sentence, where the memory-nouns can vary in their degree of similarity to the nouns used in the sentence (Gordon et al., 2002).

One final issue that will arise in our discussion of experiments investigating language and working memory is the choice between on-line and off-line measures of language processing. It is widely held that on-line processing provides the more reliable insight into specifically linguistic operations (Grossman et al., 2002). Caplan & Waters point out that off-line processing may involve a range of cognitive functions other than pure linguistic processing, including

planning actions and responses, logical reasoning, and long-term semantic storage (1999). These tasks all involve controlled conscious processing and are therefore thought to place demands on working memory resources. Thus, while an experiment may show a significant off-line effect of WM load on some measure of sentence processing, the possibility of interference from post-interpretive processing prevents us from decisively concluding that the WM task has impeded linguistic processing per se. If we wish to offer conclusive evidence that verbal working memory resources constrain language processing, either in PD patients or in the general population, we should plan to use an on-line measure in our experimentation.

3. Arguing against the Working Memory Hypothesis of Parkinson's Disease

Evidence explicitly contradicting the claim that working memory deficits have an effect on language processing in Parkinson's has been brought forth by Waters & Caplan (1997) and Caplan & Waters (1999). We saw earlier that these authors have argued strongly against the single-pool hypothesis of working memory, maintaining that "part of the working memory system is specialized for interpretive aspects of sentence comprehension, specifically, assigning syntactic structure and using it to determine the meaning of a sentence" (Caplan & Waters, 1999, p. 79). Taking this as their starting hypothesis, Caplan & Waters do not expect to find that the syntactic deficits of Parkinson's disease patients are attributable to a reduction in WM capacity. Indeed, they do report results that dissociate working memory capacity from general language abilities. Here we will briefly consider the design and results of their experiment.

3.1 Waters & Caplan (1997, 1999)

Waters & Caplan (1997) investigated the effects of working memory load on PD patients' processing of sentences that differed either in syntactic complexity or number of propositions. Their experiment has a design of the individual-differences type. Using the Daneman & Carpenter (1980) reading span standard, which calls for the subject to read a series of sentences of increasing length while holding the last word of each sentence in memory, Waters & Caplan found that PD patients had an average WM span of 1.8, as compared to the control group average of 3.4 (1997, p. 65). They then measured the syntactic ability of both patients and controls, using an off-line picture-matching task to assess comprehension of six different sentence types. These types could be grouped either by number of propositions or by syntactic complexity. Waters & Caplan found that the performance of the patient group did not differ significantly from that of the control group on any task. Furthermore, they report that there was no effect of syntactic complexity on sentence comprehension performance as exhibited by either the controls or the PD group. However, they do find a significant effect of number of propositions between sentence types. These findings are not consistent with the working memory hypothesis of PD, which predicts that the working memory deficits of PD patients should translate to an impairment in syntactic abilities relative to control subjects.

However, a number of factors cast doubt on the results reported by Waters & Caplan. Most striking is the observation of an unexpected pattern of performance exhibited by control subjects on Waters & Caplan's measures of syntactic complexity. We reported above that the PD group showed no significant difference in comprehension between complex and simple syntactic constructions. However, the control subjects did show a difference between simple and complex syntax: they exhibited better performance on the sentences that were syntactically *more* complex. This is an unexpected result, quite independent of the position one adopts concerning

the relationship between working memory and language; Caplan & Waters openly acknowledge that "[c]onsiderable research has found evidence that sentences that have more complex syntactic structures are more difficult and time consuming to understand" (1999, p. 79). The unlikely behavior of their control group suggests some problem in the stimulus sets that Waters & Caplan characterize as containing either simple or complex sentences. However, their stimuli are not provided, and moreover, Waters & Caplan never explicitly state the criteria that they used to distinguish between simple and complex conditions. It is thus difficult to draw conclusions from this particular study (although their finding of a significant effect of number of propositions on sentence processing might merit further investigation). In Section 5 below we will revisit the issue of syntactic complexity, and at that time we will suggest a more explicit distinction between simple and complex conditions.

Caplan & Waters also report data from PD populations in a second study, this time using a dual-task experimental paradigm (1999). They repeated the picture-matching task described above, again varying the two factors of syntactic complexity and number of propositions. This time, however, the subjects were given a string of digits to hold in memory during sentence-processing. Caplan & Waters report that even though overall performance was poorer with the inclusion of the digit span, no interaction was observed between memory load and syntactic complexity, although the factor of number of propositions did show a significant interaction. Caplan & Waters again observe that PD patients with severely impaired WM capacity retain effectively normal syntactic comprehension. These two results strongly support their separate-pool hypothesis of language processing.

However, potential problems must be noted for this study as well. The digit span task used by Caplan & Waters has come under criticism from a number of sources, notably Gordon et

al. (2002). As we saw above, these authors argued for a metric of interference that depends crucially on the degree of similarity between the memory-nouns and the nouns used in the sentence (2002). Thus, for example, given a sentence with NPs that denote professions, a proper name held in memory would create less interference than another profession-denoting NP. In Caplan & Waters' experiment, there is a substantial qualitative difference between the digits held in memory and the memory-nouns used in the test sentences. It is altogether possible, therefore, that the interference generated by the memory-nouns in this task simply was not sufficient to create a significant effect of WM load on sentence processing. In this case, the finding that processing exhibited by PD patients does not differ significantly from that seen in normal controls is neither surprising nor damaging to the working memory hypothesis of language in PD.

Finally, it is worth observing that the findings reported in Waters & Caplan (1997) and Caplan & Waters (1999) reflect exclusively off-line measurements of comprehension. Caplan & Waters make note of the fact that an on-line counterpart to their study would be desirable, and they have begun to provide results for on-line processing in DAT (Dementia of Alzheimer's Type) patients (1999). However, parallel data for PD patients are not yet available. The experimental design that I propose in section 5 below will offer an on-line measure of syntactic processing in PD.

4. Arguing in Favor of the Working Memory Hypothesis of Parkinson's Disease

In the previous section we looked at the evidence arguing against a role for working memory in the language deficits of Parkinson's patients. However, many other studies have reported findings that are consistent with the working memory hypothesis of PD. In this section

I will review three such studies: Grossman et al. (1992, 2002), Kemmerer (1999), and Seidl et al. (1995). However, I will also argue that none of these studies has arrived at a conclusive result, leaving a need for further experimentation.

4.1 Grossman et al. (1992, 2002)

An early study of comprehension deficits in PD is offered in Grossman et al. (1992), which argues that Parkinson's patients exhibit a significant impairment relative to normal controls on measures of sentence comprehension. Grossman et al. further demonstrated that the comprehension deficits exhibited by PD patients correlated positively with the increasing syntactic complexity of the sentences. These results contrast with the findings of Waters & Caplan (1997) and Caplan & Waters (1999) described above. However, at this point Grossman et al. do not relate these facts directly to factors of working memory, instead proposing to account for the observed processing difficulties with a rather ill-defined notion of attentional deficit. Despite this slightly lacking analysis, though, the study served as the starting point for many subsequent investigations of impaired syntactic comprehension in Parkinson's and is thus significant in its own right.

In a later study, Grossman et al. further investigate the comprehension abilities of PD patients, comparing their performance to that of normal controls on a large and diverse array of factors (2002). Of these, only one condition revealed significant impairment in PD relative to controls: the comprehension of an object-extracted relative clause construction, provided that the comprehension question probed the subordinate clause of the sentence and not the main clause. Despite the rather haphazard experimental design of the study, this is a result that we would predict under the WM hypothesis for PD: according to the DLT, the longer-distance

dependency created by object extraction imposes greater demands on working memory than subject extraction, and other factors probed by Grossman et al. did not directly relate to syntactic dependency. However, this result does not necessarily suffice to prove that deficient working memory is responsible for the language impairment observed in PD; other factors (including the attentional deficit proposed in Grossman et al. 1992) could still be at stake.

In an effort to demonstrate that the observed impairment was related to a deficit of working memory, Grossman et al. administered an on-line task intended to minimize the demand on processing resources. The experiment involved a word-recognition procedure, where subjects were presented with a word and were asked to signal once they heard the word in the sentence that followed. The sentence in which the target word appeared was grammatical in some cases, while other cases contained errors of "agreement" (where the quotes here signify that the notion of agreement employed by Grossman et al. goes well beyond the traditional concept of syntactic agreement of phi-features). Grossman et al. found no difference between Parkinson's patients and normal control subjects on the following criterion: when the target word was immediately preceded by an agreement violation, lexical response to the target was slowed to an equal extent in both groups. Because of this comparison, Grossman et al. conclude that language processing in PD patients is normal when resource demands are low.

However, it is not clear that this experiment provides useful information for our investigation of working memory and language in PD. Perhaps the most serious criticism points out that this study does not actually assess the comprehension abilities of PD patients; by measuring their ability to detect agreement violations, it taps only their capacity for grammaticality judgments. Previous clinical investigations have demonstrated that grammaticality judgments are not interchangeable with measures of comprehension; for instance,

studies of Broca's aphasia have demonstrated that the ability to make grammaticality judgments may well be preserved in agrammatic patients who nonetheless have severe comprehension deficits (Mauner et al., 1993). Thus, the on-line study conducted by Grossman et al. does not fill its intended purpose of proving a crucial causative role for working memory factors in comprehension deficits in PD. Taking a more general look at the studies conducted by Grossman et al., we find that no conclusive evidence has been offered to demonstrate a relationship between working memory deficits and language impairment in PD. However, the authors do offer suggestive evidence in their report of an asymmetry between subject- and object-extracted relative clauses, consistent with the WM hypothesis and the DLT. In section 5, I will suggest that this asymmetry could be investigated more fruitfully in a study with tighter experimental design.

4.2 Kemmerer (1999)

Another study that entertains a possible role for working memory in PD language was offered by Kemmerer, who investigated the ability of Parkinson's patients to process raising-to-subject constructions (1999). The experiment presented raised and unraised versions of each sentence, where the raised constituent could originate in either subject or object position (1-2).

(1) a. It seems to Bill that Susan is tall.
   b. Susan seems to Bill __ to be tall.
(2) a. It is easy for Bill to catch Susan.
   b. Susan is easy for Bill to catch __.

As Kemmerer points out, these constructions are highly relevant to the WM hypothesis: in raised constructions, and especially in object raising, the grammatical dependency between the raised constituent and the lexical verb will give rise to increased demands on working memory. These differing demands can be computed quite precisely if we use the Dependency Locality

Theory, although Kemmerer uses more general relative comparisons. In this experimental setup, the working memory hypothesis predicts that PD patients should be significantly impaired relative to controls in comprehending the sentences that involve raising, particularly the sentences featuring raising from object position. Kemmerer reports the following result: for the unraised sentences (1a) and (2a), PD patients show no impairment in comprehension, while their comprehension of both subject and object raising constructions is significantly impaired relative to controls. This finding is consistent with the predictions of the DLT, and it also supports the hypothesized role of a verbal working memory deficit in the language of PD patients.

However, Kemmerer's finding that raising constructions are selectively impaired in PD does not prove that comprehension deficits in PD are caused by working memory factors; an account of these results in terms of a deficit of syntactic representation would be just as plausible. Kemmerer does not actually calculate the comparison that can crucially support or disconfirm the predictions of the DLT—that is, the difference between subject-raised and object-raised constructions. He does provide suggestive evidence indicating that object-raising is impaired relative to subject-raising in PD, reporting that the set of patients who showed impairment on subject-raising constructions was a subset of the patients who showed impairment on object-raising. However, until we can confirm this trend with statistically significant results, no conclusion about WM can be drawn from Kemmerer's findings. It should also be mentioned that even if a contrast between subject- and object-raising could be established, Kemmerer's experiment could not provide truly definitive proof of the working memory hypothesis: while the sentences in (1) are genuine instances of raising, the predicates in (2) are adjectives in "tough"-constructions and are thus distinct from true raising verbs. Given this syntactic difference between conditions, a direct comparison of the two is not guaranteed to reveal only

the effects of working memory. A more suitable contrast is between subject-extracted and object-extracted relative clause constructions, and I will advocate using this comparison in the experimental proposal in Section 5.

4.3 Seidl et al. (1995)

An interesting experimental design was offered by Seidl et al. (1995), who used a dual-task procedure to argue in favor of the working memory hypothesis for language deficits in PD. Seidl et al. recruited two groups, one PD-affected and one normal, to whom they aurally presented sentences of three types: simple (SIM), center-embedded subject relative clause (SUBJ), and center-embedded object relative clause (OBJ). At the same time, a concurrent processing load was imposed using some secondary task, either finger-tapping or a more complex task of verbal or spatial recognition. The experimenter then posed a comprehension question about the sentence just presented, and response latencies and error frequencies across subjects were recorded as the primary data for the experiment. For this experiment, the WM hypothesis would predict that PD patients should show impairment relative to controls on the tasks involving a memory load, and this impairment should become more pronounced as the sentences increase in syntactic complexity.

Seidl et al. report main effects for group (PD vs. control), secondary task (tapping task vs. span condition), and sentence type (OBJ, SUBJ, SIM); they also identified a significant interaction between sentence type and secondary task. For the tapping task, responses by the PD group to OBJ conditions were significantly slower than responses to the SUBJ condition, which was in turn slower than the SIM condition. This finding is consistent with the predictions of the working memory hypothesis. In the span task, both OBJ and SUBJ were significantly slower

than SIM, although they did not differ significantly from each other. While the lack of contrast between OBJ and SUBJ conditions was not anticipated, it can be understood as an indication that processing resources on the span task were already exhausted under the simpler SUBJ condition. Finally, Seidl et al. report that the frequency of errors increases significantly as sentences increase in syntactic complexity. The authors thus conclude that concurrent processing demands compromise the ability of PD patients to interpret sentences, which leads to slowed response times and frequent errors. Seidl et al. thus report these results as evidence in support of the working memory hypothesis of sentence processing in PD.

However, the conclusions presented by Seidl et al. can be criticized on several grounds. First, the data reported by Seidl et al. are at times inconclusive. Most notably, there was no significant difference in response latency found between the baseline and the span condition for PD patients' processing of OBJ sentences. This suggests that the presence of a concurrent memory load was not important in the processing of this most complex syntactic condition, contrary to our expectations from the WM hypothesis. A possibly related criticism would question some elements of the experimental design used by Seidl et al. The finger-tapping task that they use appears to be insufficiently demanding, since the baseline and tapping conditions do not differ significantly for any syntactic condition in either population. On the other hand, the span condition that Seidl et al. use is more likely to be relevant to language processing, but here the usefulness of their results is compromised: besides a task in which subjects must keep track of a number of words while processing the sentence, another task is presented that requires them to memorize a pattern of dots and identify a displaced dot in a second image. This inclusion of a component of visuospatial recognition, which is not relevant to verbal working memory, is problematic, since Seidl et al. collapse the two span types into a single category in their data-

reporting. Thus, like other experiments we have considered in our discussion so far, this study offers suggestive results to an interesting question, but nontrivial defects in the experimental design once again prevent us from drawing any definite conclusions.

5. Proposed Experimental Design

In the previous sections I reviewed numerous studies of the role of WM in the language of Parkinson's patients, and in each case I argued that the results were compromised by flaws in experimental design or by a failure to investigate the crucial comparisons for our theory. As a result, I conclude that no study up to the present has offered a definitive result concerning the relation between working memory and language processing in PD. Here I will offer my own experimental design in an effort to correct the shortcomings identified in previous research. I propose to use an on-line measure of sentence processing with a concurrent memory load, drawing heavily on the design that Fedorenko, Gibson, & Rohde (2004) used in their Experiment 1 to investigate the role of WM load on sentence processing in normals.

Experiment 1 of Fedorenko et al. offered replication of the results of Gordon et al. (2002), adapting that experiment to the more sensitive measure of on-line reaction time. In the modified experiment, subjects held one or more words in memory while simultaneously performing a self-paced reading task, with phrase-by-phrase presentation, for sentences of varying complexity. Fedorenko et al. measured the reading time associated with each region of the sentence, also recording subjects' accuracy in repeating the memory noun(s) after reading the sentence and their performance on comprehension questions about the sentence. The experiment had a 2 x 2 x 2 design in which the condition of syntactic complexity (subject-extracted or object-extracted relative clause types) was crossed with memory load (easy load of one noun or

hard load of three nouns) and memory-noun type (match or mismatch with respect to sentence nouns, where all nouns were either professions or proper names).

In the critical region of the sentence where the relative clause was presented, Fedorenko et al. report main effects in reading time for memory-noun type (such that match conditions were read more slowly than mismatch conditions) and syntactic complexity (such that the syntactically more complex object-extracted relative clause condition was read more slowly than the subject-extracted condition). The crucial result, however, was a significant interaction between syntactic complexity and memory-noun type, where the difference in reading time between subject- and object-extracted relative clause types was greater in the more WM-intensive match condition. This interaction provides a strong indication that the sentence-processing task and the concurrent verbally-mediated task are competing for a single pool of processing resources.

Let us now consider how this design might be used to investigate the role of working memory in syntactic processing in Parkinson's disease. It would clearly be desirable to replicate Fedorenko et al.'s Experiment 1 but test both Parkinson's patients and normal controls, thereby adding a new factor of group (PD versus normal). In such an experiment, what result should we look for to confirm or disconfirm the working memory hypothesis for PD?

We can begin by excluding a few possibilities that would *not* constitute a strong result. First, we note that several studies (including Seidl et al. 1995, Caplan & Waters 1999) have looked for an interaction between syntactic complexity and working memory load in PD patients. However, if we follow Fedorenko et al. and hold that syntactic processing can be affected by concurrent WM load in normal subjects, the presence of a comparable interaction in the PD group does not shed light on the specific role that working memory plays in the disordered processing of Parkinson's patients. (It would, however, offer replication of Fedorenko et al.'s

result). Secondly, we have seen several other studies investigating the issue of whether syntactic processing in Parkinson's patients is generally slowed or impaired relative to processing in normals (Waters & Caplan 1997, Kemmerer 1999, Grossman et al 2002). However, a result simply finding such a slowdown does not necessarily implicate working memory as a causative factor. We might attempt to establish a correlation between the degree of impairment in working memory exhibited by PD patients and the level of impairment they show in syntactic processing. However, patients with a more severely decayed WM capacity are liable to be more impaired across the board, and the possibility of concomitant deficits in attention, syntactic representation, or other factors makes it difficult to ascertain the precise relationship between working memory and language.

To investigate our hypothesis in a rigorous fashion, then, we need to look for a more complicated interaction; specifically, we need to ask whether a working memory load affects language processing in PD more strongly than it does in normal subjects. The basic goal of our experiment, then, is to determine whether the factor of group significantly influences the interaction between working memory and syntactic complexity. This condition would manifest itself in a three-way interaction between group, syntactic complexity, and a measure of working memory load (presumably the memory-noun type condition found to interact with syntactic complexity in Fedorenko et al.'s Experiment 1). To confirm the working memory hypothesis of language processing in Parkinson's, then, we would first look for results replicating the findings of Fedorenko et al. We would additionally need to find at least two more effects: a main effect of group, such that processing in the PD group is slower than in the control group; and the three-way interaction of group, syntactic complexity, and memory-noun type, such that the effect of the working memory task on syntactic processing is greater in the PD group than in normal

subjects. This result is not predicted by a theory that attributes language deficits in Parkinson's disease to any factor other than working memory impairment. It is also inconsistent with the claim that verbal working memory is divided into separate pools for natural language processing and for other verbally-mediated tasks. Thus, if we were to replicate Fedorenko et al.'s Experiment 1 for both normal and PD groups, and if we did indeed find the three-way interaction described here, the working memory hypothesis of Parkinson's disease would be strongly confirmed, while the separate sentence interpretation resource theory of processing would be substantially disconfirmed.

6. A Different Perspective: Ullman et al. (1997)

Having investigated several perspectives on the role of working memory in the language of Parkinson's patients, we can finish with a brief discussion of a proposal that seeks neither to support nor to refute the working memory hypothesis of PD. Ullman et al. (1997) propose that certain language deficits in PD can be attributed to an impairment in long-term memory. More specifically, Ullman et al. investigated the role of memory in the language abilities of two groups, Alzheimer's Disease and Parkinson's Disease patients, and concluded that the language deficits of these two groups can be attributed to impairment in declarative long-term memory and procedural long-term memory, respectively. Here we will consider their proposal and their experiments in more detail.

We can begin by stating the assumptions that underlie Ullman et al.'s hypothesis. First, they make standard assumptions regarding the location of damage in the two disorders they study: neural damage is thought to be localized in the temporal/parietal cortex in AD, while PD is associated with damage to the basal ganglia. They also adopt research that locates different

cognitive and linguistic functions in these regions. Ullman et al. assume a basic division of long-term memory into declarative and procedural components, where the former stores factual and event-related knowledge, while the latter processes skills in the motor, cognitive, and perceptual domains. In this model, it is widely assumed that declarative memory is subserved by temporal and parietal regions of the cortex, while the basal ganglia are regarded as the seat of procedural memory. Finally, Ullman et al. adopt the "Words and Rules" (WR) scheme for dividing language, which holds that the aspects of language related to lexical knowledge and word retrieval are crucially dependent on declarative memory, while linguistic rules and operations are the province of procedural memory. This division is thought to extend to a distinction between regular and irregular past verbal inflection: the former involves productive, rule-based generation of forms and thus belongs in the domain of procedural memory, while the latter calls for storage of arbitrary forms and thus relates to declarative memory (Pinker & Ullman, 2002).

Taking all of these assumptions into account, Ullman et al. make the following prediction: we expect a double dissociation in the performance of AD and PD patients on tasks of past tense formation, where AD patients should perform better on regular than irregular verbs, and vice versa for PD patients. We might also expect to see overregularization of verbs in AD but not in PD. Below, I will review the experimental procedure used by Ullman et al.; since our focus here is basically exclusive to Parkinson's disease, I will be more detailed in my discussion of the portions of the experiment that relate to language in PD.

Adopting the hypothesis that language deficits in Parkinson's reflect impaired procedural memory stemming from damage to the basal ganglia, Ullman et al. predict that other functions regulated by this structure ought to be affected in parallel. Since motor functions are also controlled by the basal ganglia, Ullman et al. anticipate a correlation between a patient's degree

of hypokinesia (difficulty in motor activity) and his degree of grammatical impairment. However, given the WR theory of past tense formation, they expect this correlation to be present only for regular, productive verbs, and not for irregulars. Ullman et al. conduct a second experiment to test a related hypothesis: taking the five most severely hypokinetic patients, they investigated the relative performance of these patients on regular, novel, and irregular verbs. Here the WR theory predicts that the first two verb types would be significantly more impaired than the last. Finally, recall that Ullman et al. also investigated the language of Alzheimer's patients. To do so, they performed two experiments nearly identical in protocol to the experiments described above, with the exception that the degree of difficulty in word-naming (anomia) was used as a metric of severity in place of hypokinesia.

Ullman et al. report results that mostly support their original hypotheses. For the first experiment on PD patients, they maintain that "right-side hypokinesia…correlated significantly with difficulties producing regular verbs, and with difficulties producing novel verbs, but not with difficulties producing irregular verbs" (1997, p. 272). On the second experiment, the difference between regular and irregular verbs within the PD group did not attain significance (p = .059), contrary to the expectation of the WR theory. However, the difference between irregular verbs and novel verbs was significant, with the strongly rule-dependent novel verbs showing substantial impairment. The authors also report a significant interaction between the Regular/Irregular Verb and the PD/Control condition. In the experiments involving AD patients, meanwhile, Ullman et al. find nearly complementary results: the degree of anomia correlated significantly with difficulty in irregular past formation, while the correlation between anomia and regular past formation did not reach significance. Thus, the results reported by Ullman et al. seem to support their hypothesized double dissociation. In PD, regular past formation is

impaired, while irregular past formation appears to be relatively spared; in AD, the opposite pattern of impairment is observed.

What implications does Ullman et al.'s analysis have for the working memory hypothesis of PD that we discussed above? For the most part, the two models are orthogonal to one another; it is quite possible that both a working memory deficit and an impairment of long-term procedural memory could be present in Parkinson's patients. However, it is worth noting that the procedural impairment model alone cannot account for all features of language in PD, since many of the properties of language comprehension reported in the experiments discussed above do not find an explanation in Ullman et al.'s theory. For instance, the contrast between subject-extraction and object-extraction constructions reported by Seidl et al. (1995) cannot be explained by a deficit in procedural memory because both cases equally involve the application of a single movement operation. It is only by incorporating some measure of distance, like that offered by a DLT-based working memory account, that we can understand this contrast.

Let us now consider the flip side of this question: is it possible for the working memory hypothesis of PD language to explain the deficits that Ullman et al. attribute to procedural memory impairment? While I cannot present a well-developed theory of such a role for working memory here, I will offer a quick overview of evidence from other clinical populations suggesting that working memory may play a larger role than previously thought. The pattern of impaired production of regular past-tense inflection together with relatively preserved irregular inflection has been observed in language-disordered populations other than PD. These include Specific Language Impairment, or SLI (Clahsen & Almazan, 1998) and autism spectrum disorder (Roberts, Rice & Tager-Flusberg, 2004). From the point of view of research regarding language in Parkinson's disease, it is interesting to note that a deficit in working memory has

also been posited for SLI (Gathercole & Baddeley, 1990; Montgomery, 2000) and for autism (Bennetto, Pennington, & Rogers, 1996). Crucially, though, these three groups do not all agree with regard to the status of procedural memory. Deficits of procedural memory have been posited for both PD and SLI, although there is not a general consensus on this issue. For autistic populations, however, it has been held that procedural memory represents an area of relative strength. In fact, the tendency of autistic patients to engage in repetitive activity or to perseverate in a particular response has been attributed to a highly functioning, perhaps hyperactive faculty of procedural memory (Kemper & Bauman, 1998). The evidence from other clinical populations thus suggests that a disparity between regular and irregular verbs in past tense formation does not necessarily indicate a deficit in procedural memory; we should consider other possible causes as well. Given the fact that all three populations exhibiting this particular disparity agree for the presence of a working memory deficit, we might investigate this impairment as one potential causative factor. Of course, this line of reasoning is highly speculative, and much testing will be needed before we can make any definitive statements. On the whole, though, I maintain that while it is quite possible that impairments in procedural memory are part of the clinical profile of PD, as proposed by Ullman et al., further experimentation is needed before we can decisively attribute the language problems of this population to such a deficit.

7. Conclusions

In this paper, I addressed the question of whether apparent deficits in comprehension exhibited by patients with Parkinson's disease could be attributed to a reduction in their verbal working memory capacity. While a number of experiments have been conducted to argue both

for and against this account, it was shown above that none of these studies could provide a result that unequivocally supports or refutes the working memory hypothesis. This failure to arrive at a decisive finding can be attributed to several causes. For instance, we observed a general tendency among these experiments to use off-line measures of comprehension, even though on-line measures are known to be more reliable. Furthermore, in most cases we could identify potential confounding factors that compete with the experimental hypothesis to offer a possible explanation for the reported results.

In an effort to correct these deficiencies, I borrowed the experimental design of Fedorenko et al. (2004), which was effective in revealing an on-line interaction between working memory load and syntactic complexity in normal processing. When the same task is presented to both a PD group and a control group, if a significant three-way interaction between group, syntactic complexity, and WM load (memory-noun type) is observed, we have reason to believe that the comprehension deficits observed in Parkinson's disease are attributable to an impairment in working memory resources specific to this group. Besides the implications that such a result would have for our understanding of Parkinson's disease, this finding would also offer significant evidence in the debate over the role of working memory in general language processing. Specifically, the finding of a three-way interaction would be inconsistent with the claim that natural language processing makes use of a pool of verbal working memory independent of the resources accessed by other verbally-mediated tasks. Thus, when we investigate the role of working memory in the linguistic deficits associated with Parkinson's disease, we are in a position not only to further our clinical knowledge of this disorder, but also to weigh in on our understanding of the general relationship between language and working memory across populations.

Works Cited

Baddeley, A. (1986). *Working Memory.* New York: Oxford University Press.

Bennetto, L., Pennington, B., & Rogers, S. (1996). Intact and impaired memory functions in autism. *Child Development, 67*, 1816-1835.

Caplan, D., & Waters, G. (1999). Verbal working memory and sentence comprehension. *Brain & Behavioral Sciences, 22,* 77-126.

Clahsen, H., & Almazan, M. (1998). Syntax and morphology in Williams syndrome. *Cognition, 68,* 167-198.

Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450-466.

Fedorenko, E., Gibson, E., & Rohde, D. (2004). Shared processing resources for l language and math. Manuscript submitted for publication, Department of Brain and Cognitive Sciences, MIT.

Gabrieli, J., Singh, J., Stebbins, G., & Goetz, C. (1996). Reduced working memory span in Parkinson's disease: Evidence for the role of a frontostriatal system in working and strategic memory. *Neuropsychology,* 10, 322-332.

Gathercole, S., & Baddeley, A. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29,* 336-360.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition, 68,* 1-76.

Gibson, E. (2000). The dependency locality theory: A distance-based theory of linguistic complexity. In Miyashita, Y., Marantz, A., & O'Neil, W. (Eds.), *Image, Language, Brain.* Cambridge, MA: MIT Press.

Gordon, P., Hendrick, R., & Levine, W. (2002). Memory-load interfereince in syntactic processing. *Psychological Science, 13*, 425-430.

Grossman, M., Carvell, S., Stern, M., Gollomp, S., & Hurtig, H. Sentence comprehension in Parkinson's disease: The role of attention and memory. *Brain and Language, 42,* 347-384.

Illes, J., Metter, E., Hanson, W., & Iritani, S. (1988). Language Production in Parkinson's Disease: Acoustic and Linguistic Considerations. *Brain and Language*, *33*, 146-160.

Just, M., & Carpenter, P. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*, 122-149.

Kemmerer, D. (1999). Impaired comprehension of raising-to-subject constructions in Parkinson's disease. *Brain and Language, 66,* 311-328.

Kemper, T., & Bauman, M. (1998). Neuropathology of Infantile Autism. *Journal of Neuropathology and Experimental Neurology, 57,* 645-652.

King, J., & Just, M. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30,* 580-602.

Lieberman, P., Friedman, J., & Feldman, L. (1990). Syntax comprehension in Parkinson's disease. *Journal of Nervous and Mental Disease, 178,* 360-366.

Mauner, G., Fromkin, V., & Cornell, T. (1993). Comprehension and Acceptability Judgments in Agrammatism: Disruptions in the Syntax of Referential Dependency. *Brain and Language, 45,* 340-370.

Montgomery, J. (2000). Verbal Working Memory and Sentence Comprehension in Children With Specific Language Impairment. *Journal of Speech, Language, and Hearing Research, 43,* 293-308.

Natsopoulos, D., Grouios, G., Bostantzopoulou, S., Mentenopoulos, G., Katsarou, Z., & Logothetis, J. (1993). Algorithmic and heuristic strategies in comprehension of complement clauses by patients with Parkinson's disease. *Neuropsychologia, 31,* 951-964.

Pinker, S., & Ullman, M. (2002). The past and future of the past tense. *Trends in Cognitive Sciences, 6,* 456-462.

Seidl, A., Onishi, K., White, H., D'Esposito, M., & Grossman, M. (1995). Resource limitations and grammatical complexity in the sentence comprehension of patients with Parkinson's disease. *Brain and Language, 51,* 106-108.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125,* 4-27,

Ullman, M., Corkin, S., Coppola, M., Hickok, G., Growden, J., Koroshetz, W., & Pinker, S. (1997). A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of Cognitive Neuroscience, 9,* 266-276.

Waters, G., Caplan, D., Rochon, E. (1995). Processing capacity and sentence comprehension in patients with Alzheimer's disease. *Cognitive Neuropsychology, 12,* 1-30.

Waters, G., & Caplan, D. (1997). The role of working memory in sentence processing: Evidence from Parkinson's Disease. *Brain and Language, 60,* 64-66.