AN INVESTIGATION OF SYNTACTIC COMPREHENSION DEFICITS IN PARKINSON'S DISEASE

by

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Chapter 1: Introduction

Many of our cognitive abilities seem to be quite simple because, from a phenomenological point of view, they're effortless, reliable, fast, unconscious, and require no explicit instruction. Some familiar examples include our ability to recognize faces, our ability to reach for a cup of coffee and bring it to our lips, and our ability to recall where we were and what we did last Christmas. The apparent simplicity of these various abilities, however, is deceptive. As is now known, all of them pose fantastically complex computational problems, and the brain contains dedicated, special-purpose information-processing machinery to solve each one. Moreover, the reason these abilities seem to be so simple is precisely because they are supported by this dedicated machinery.

Language comprehension is another instance of a deceptively simple cognitive abi-lity. Someone speaks, the sounds enter our ears, and we understand immediately. We don't normally have to concentrate on the processing itself but rather can think about the message being expressed, how it fits into our belief system, the sincerity of the speaker, how we intend to respond, and so on. In fact, however, language comprehension depends on a vast array of computational mechanisms devoted to solving, often within milliseconds, such problems as the following: converting an acoustic signal to phonetic and phonological representations; matching phonological representations with abstract lexical items stored in long-term memory; accessing the semantic and syntactic information associated with lexical items; assembling hierarchical syntactic constituent structures; inferring the proper semantic roles of nouns in relation to verbs and other predicates; and dealing with more holistic aspects of language such as idiomatic or figurative expres-sions, prosody, and discourse cohesion.

Neuropsychologists have discovered that the underlying complexity of many apparently simple cognitive abilities is revealed most strikingly when brain damage impairs certain aspects of the ability while leaving other aspects intact (Ellis & Young 1988; Shallice 1988; Kosslyn & Koenig 1992; Sacks 1995). This is especially true in the case of language comprehension, because when this ability breaks down, it is usually not an all-or-nothing affair. Instead, different components are affected to different degrees, and sometimes highly selective deficits occur. Sophisticated methodologies are often required, though, to identify the true nature and scope of a disturbance and ascertain its implications for theories about the architecture of the normal system (Caplan 1992).

One kind of comprehension disorder that has been studied a great deal during the past 20 years involves the determination of "who did what to whom." This is one aspect of what is sometimes called syntactic comprehension, since it requires using morphological and word order information to form an integrated representation of the basic meaning of a sentence. For instance, brain-damaged patients have been described who have no difficulty understanding who's chasing whom in a sentence like *It was the boy that chased the girl*, but perform at chance when presented with a sentence like *It was the girl that the boy chased* (Caramazza & Zurif 1976; Caplan & Hildebrandt 1988; Grodzinsky 1990). In some cases, the patterns of preservation and impairment are even more subtle. This is illustrated by a study in which a group of patients performed at chance on sentences like *The man was kicked by the boy,* but performed normally on superficially similar sen-tences like *The man was enraged at the boy* (Grodzinsky et al. 1991). More recently, Hickok and Avrutin (1996; see also Tait et al. 1995 and Frazier & McNamara 1995) conducted a remarkable study about the ability of brain-damaged patients to understand different kinds of questions. The patients had no trouble pointing to the appropriate figure in a picture when presented with questions like *Who chased the girl?* and *Which boy chased the girl?* But when they were presented with questions like *Who did the girl chase?* and *Which boy did the girl chase?*, they performed well on the first type but at chance on the second type. Findings like these are not only impressive in themselves but are valuable for theoretical purposes because they have the potential to reveal the func-tional and neural subdivisions within the syntactic comprehension system. In addition, several researchers have shown that detailed characterizations of the patterns of sparing and loss of ability in patients can lead to the development of effective therapeutic inter-ventions (e.g., Byng 1988; Crerar et al. 1996; Haendiges et al. 1996).

Most of the research that has been conducted on disorders of syntactic comprehension has focused on so-called agrammatic patients who typically have left anterior lesions in the vicinity of Broca's area. For instance, all of the patients mentioned above fall into this clinical category. This concentration of effort on understanding a single population in depth is positive insofar as it has given rise to a large body of intriguing data and has spawned a variety of different explanatory frameworks, many of which are stated in terms of one or another modern grammatical theory. For the current state of the art in this area, see Cahana-Amitay (in press) and the three special 1995 issues of *Brain and Language*, which contain the proceedings from a symposium on agrammatism that was held at the 1994 TENNET conference (Theoretical & Experimental Neuropsychology/Neuropsychologie Expérimentale & Théorique) in Montréal. Such a narrow focus of scientific energy, however, also has its negative side, which in this case is that very little attention has been devoted to the syntactic comprehension abilities of patients with other kinds of brain damage. Only within the past few years have researchers begun to investigate such abilities in patients with closed head injury (Butler-Hintz et al. 1990), patients who have left-hemisphere stroke-induced lesions and fall into a variety of different aphasiological categories (Caplan & Hildebrandt 1988; Dronkers et al., submitted), and patients who have neurodegenerative disorders such as Alzheimer's disease (Kempler et al. 1987; Rochon et al. 1994; Waters et al. 1995), multiple sclerosis (Grossman et al., in press), and Parkinson's disease (Lieberman et al. 1990, 1992; Natsopoulos et al. 1991; Grossman et al. 1992a, 1992b, 1993a, 1993b; Geyer & Grossman 1995; McNamara et al., in press).

The focus of this thesis is on the syntactic comprehension abilities of patients with Parkinson's disease (PD), a disorder that directly affects the basal ganglia and indirectly affects the frontal lobes. Although PD is best known as a movement disorder, about half of such patients also suffer from cognitive deficits similar to those exhibited by patients with lesions in the prefrontal cortex. The handful of studies that have addressed syntactic comprehension in PD patients have been developed from the premise that the types of cortical involvement and general cognitive deficits in PD would be expected to lead to syntactic comprehension deficits as well. Specifically, the prefrontal cortical areas that are rendered dysfunctional in PD patients include areas that have been implicated in syn-tactic comprehension; furthermore, the cognitive deficits found in these patients involve information processing resources such as working memory and attentional control that are also important for syntactic comprehension. Most of the studies have found that roughly half of PD patients do in fact display mild to severe impairments of syntactic comprehension, which is consistent with the proportion of patients who have cognitive deficits. There is some controversy, however, over the precise nature of the functional disturbance that is responsible for this poor performance. Some researchers have proposed that PD patients have a disruption of grammatical structures or operations; others have proposed that the syntactic comprehension deficits are due to an impairment of attentional control; and still others have proposed that these deficits arise from defective short-term memory resources.

The purpose of this thesis is to gain a better understanding of syntactic comprehension deficits in PD. I will specifically test hypotheses about which aspect(s) of comprehension is disrupted: grammatical knowledge, attention, or memory. To accomplish this, the thesis is organized in two main parts. In the first part, which consists of Chapters 2 and 3, I present the background information that is necessary for investigating the syntactic comprehension abilities of PD patients in a principled manner. Chapter 2 is devoted to summarizing the neuropathology and neuropsychology of PD, and Chapter 3 is devoted to setting up a model of the normal syntactic comprehension system at the levels of structure, processing, and neurobiology. Taken together, the material covered in these two chapters leads to the hypothesis that the sentence processing mechanism which is disrupted in PD patients is the resource of attentional control. This hypothesis in turn leads to a number of specific predictions about what types of grammatical constructions should be easy for PD patients to understand and what types should be difficult for them to understand. In the second part of the thesis, which consists of Chapters 4 and 5, the primary goal is to test these predictions. Chapter 4 is devoted to a critical review of the studies that have been done so far on syntactic comprehension deficits in PD, and Chapter 5 is devoted to presenting a series of new studies that I have conducted. Overall, the studies described in this part of the thesis support the general hypothesis that PD patients have an impairment of attentional control. In contrast, I argue that the studies do not support the alternative hypotheses that PD patients have an impairment of grammatical structures or operations, or that they have an impairment of syntactic short-term memory. Finally, I conclude in Chapter 6 by bringing together the main findings of the investiga-tion and suggesting some directions for future research.

This investigation of syntactic comprehension deficits in PD has both theoretical and clinical implications. On the theoretical side, it contributes to the small but growing body of psycholinguistic and neurolinguistic literature exploring the role of attentional control in sentence processing (McNeil et al. 1990; King & Just 1991; Just & Carpenter 1992, 1993; Carpenter et al. 1994, 1995; Miyake et al. 1994, 1995; King & Kutas 1995; Stroms-wold et al. 1996). As I mentioned earlier, the patterns of sparing and loss of sentence processing ability that are exhibited by brain-damaged patients can help us discover the underlying organization of the syntactic comprehension system. What my research suggests is that PD patients constitute a population in which the independence of an attentional component of this system is revealed. Moreover, I show that it is possible to formulate a well-motivated hypothesis about the neural substrates of this attentional component by combining information about the neuropathology of PD with information derived from functional neuroimaging studies of sentence processing in healthy subjects.

With regard to clinical issues, by extending our knowledge of the scope and severity of syntactic comprehension deficits in PD, this investigation brings us a step closer to developing effective methods of treatment for this very large population.

Chapter 2: The Neuropathology and Neuropsychology of Parkinson's Disease

PD is a progressive neurodegenerative disease with a relatively high prevalence, afflicting approximately 1/1,000 individuals uniformly throughout the world (McDowell et al. 1978). Onset is usually between the ages of 50 and 65 years, and the average duration is around 8 years. The cause is unknown, but it may reflect an inherited susceptibilty to certain environmental or endogenous toxins (Jenner et al. 1992). Clinical diagnosis is based upon the presence of two or more of the following motor symptoms:

1. Rhythmic tremor (3-6 beats/sec) involving the hands and lower legs and most prominent at rest.
2. Increase in muscle tone or rigidity that often has a cogwheel- or ratchet-like effect.
3. Slowness in executing movement (bradykinesia) and/or difficulty in initiating movement (akinesia).
4. Stooped, unstable posture with lowered shoulders and flexed elbows and knees.

Additional clinical signs include a "masked" facial expression with a blank stare and reduced rate of eyeblink (hypominia), tiny handwriting (micrographia), impaired articulatory capacities (dysarthria), lowered volume of speech (hypophonia), problems swallowing (dysphagia), oily skin with dry, flaky patches (seborrheic keratitis), dizziness after standing up (orthostatic hypertension), and constipation.

In *An Essay on the Shaking Palsy,* James Parkinson (1817) reported that in this disease "the senses and intellect are uninjured." Half a century later, however, several researchers recognized that this was clearly false (Trousseau 1861; Charcot 1872). Still, very little in the way of sophisticated neuropsychological investigation of PD took place until the beginning of the "L-DOPA era" in the 1970s. Since then, research on cognitive deficits in PD has been steadily accumulating. Overall, this research indicates that PD patients fall into three broad categories (DuBois et al. 1991; Ebmeier et al. 1991; Mayeux et al. 1988, 1992). First, roughly 20% of patients develop global intellectual deterioration severe enough to be considered dementia.[1] Second, another 20% of patients are intellectually not significantly different from age-matched healthy control subjects. Finally, the remaining 60% of patients exhibit a variable "mix" of specific cognitive deficits that are similar to those found in patients who have suffered lesions to the prefrontal cortex.

This chapter has two main goals. The first is to review the underlying neuropathology of PD. PD is one of many disorders that directly affect the basal ganglia and indirectly affect the frontal lobes; other such disorders include Tourette's syndrome, Huntington's disease (HD), progressive supranuclear palsy (PSP), schizophrenia, and obsessive-compulsive or addictive disorders. In section 2.1 I will discuss the anatomy, physiology, neurochemistry, and cortical connections of the basal ganglia as well as the nature of the disturbance that occurs in PD. The second goal of this chapter is to review the major cognitive deficits that are found in PD patients. I will focus on nondemented patients because they are the ones whose syntactic comprehension abilities will be of central concern later in the thesis. Most of the neuropsychological research with this group of patients has concentrated on deficits of executive function that are manifested in several cognitive domainsùspecifically, visuospatial processing, memory, and the regulation of mental "sets." In section 2.2 I will discuss each of these domains of mental impairment.

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[1] According to the widely used "Clinical Dementia Rating Scale" (Hughes et al. 1982), dementia consists of memory loss, temporal and spatial disorientation, impaired judgement and problem-solving ability, and an impaired ability to carry out daily tasks involving social interactions and personal care.

2.1 Neuropathology

2.1.1 The Basal Ganglia[2]

2.1.1.1 Anatomy

The basal ganglia consist of six extensively interconnected subcortical structures: the caudate, the putamen, the ventral striatum, the globus pallidus, the subthalamic nucleus, and the substantia nigra (Figure 1). The *caudate* and *putamen* develop from the same telencephalic structure, and as a consequence they are composed of identical cell types and are fused anteriorly. Together they are referred to as the striatum. Two addi-tional structures located beneath the striatumùnamely, the nucleus accumbens and the olfactory tubercleùare very similar to the striatum in terms of both connections and histological features, and for this reason they are referred to as the *ventral striatum.* The *globus pallidus* (a.k.a. pallidum) is derived from the diencephalon and lies directly medial to the putamen. It is divided into two segments, referred to simply as the internal and external segments. The *subthalamic nucleus* is located under the thalamus at its junction with the midbrain. Finally, the *substantia nigra* is embedded in the midbrain and has two zones, one ventral and the other dorsal. The ventral zone, which is called the pars reticulata, has cell types similar to those in the internal segment of the globus pallidus, and for this reason the two structures are sometimes considered to be a single structure which is arbitrarily divided, much like the caudate and putamen. The dorsal zone, which is called the pars compacta, is comprised of dopaminergic cells that contain neuromelanin, a dark pigment that gives the substantia nigra its nameùliterally "black substance."

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[2] Most of the research that I will review in this section is based on studies of nonhuman primates, typically macaque monkeys.

In highly simplified form, the major features of the connectional architecture of the basal ganglia are as follows (Figure 2). Input is received by the striatum. This input comes from the entire cerebral cortex, including sensory, motor, association, and limbic areas; additional but less significant input comes from the thalamus. Output is sent by the internal pallidum and substantia nigra reticulata (not shown in Figure 2) to several nuclei in the thalamus, which in turn project to the frontal cortex. There are two pathways through the basal ganglia, one direct and the other indirect. The direct pathway goes straight from the striatum to the internal pallidum and substantia nigra reticulata, whereas the indirect pathway goes from the striatum to the internal pallidum and substantia nigra reticulata via the external pallidum and subthalamic nucleus.

Figure 2: Schema of information flow between the cerebral cortex, the thalamus, and several subdivisions of the basal ganglia. "Pallidum" indicates the internal portion of the globus pallidus. (From Houk 1995)

2.1.1.2 Physiology

It is interesting to look at this connectional architecture in a bit more detail (Figure 3). The input structures receive very dense excitatory connections from widespread

Figure 3: Details of basal ganglia architecture (from C t & Crutcher 1994).

areas of the cortexùindeed, each cell receives approximately 10,000 different afferent fibers, a degree of convergence which is second only to that found in the cerebellum (Houk 1995). All of the connections in the two pathways through the basal ganglia are inhibitory except for those extending from the subthalamic nucleus to the output structures. The direct pathway operates in a very straightforward manner: when the cortex activates the input structures, this causes them to suppress the output structures. By contrast, the operation of the indirect pathway is more complicated: when the cortex activates the input structures, this causes them to suppress the external pallidum; this releases the subthalamic nucleus from inhibition; as a result, the subthalamic nucleus activates the output structures. It is apparent, then, that the two pathways are constantly involved in a push-pull tug-of-war for control over the output structures. The effects of these competing forces depend on the following additional features of the architecture: the output structures exert a tonic inhibitory influence on their target nuclei in the thalamus, but the subsequent connections from the thalamus to the frontal cortex are excitatory. Thus, when the direct pathway suppresses the output structures, this disinhibits specific thalamic nuclei, thereby gating or facilitating specific activity patterns in the frontal cortex. Conversely, when the indirect pathway activates the output structures, the thalamus is suppressed, which in turn prevents the thalamus from activating specific cell assemblies in the frontal cortex.

How do the basal ganglia contribute to motor control, cognition, and affect? Although no single, comprehensive theory of basal ganglia function is currently available, research in this area is progressing rapidly and a number of sophisticated hypotheses have been proposed in recent years (Cools et al. 1995; DuBois et al. 1995; Taylor & Saint-Cyr 1995; Partiot et al. 1996; see especially the papers in Houk et al. 1995). Perhaps the most well-established point is that the basal ganglia are crucially involved in regulating the selection of appropriate responses to both exogenous and endogenous stimuli. Cells in the caudate, putamen, and ventral striatum recognize activation patterns in their cortical inputs that represent familar contexts. When such a context is detected, concurrent transmission through the direct and indirect pathways leads to the competitive selection of activation patterns in the output structures, and these activation patterns ultimately serve to facilitate processing routines in the frontal cortex that have been rewarding in similar contexts in the past. Thus the basal ganglia are probably involved in regulating much of our habitual, routine thought and behavior. For instance, the basal ganglia may be in the driver's seat, literally, when we find our-selves in that eerie situation of skillfully negotiating the traffic on a highway while simultaneously daydreaming about something completely different. Another function that has been attributed to the basal ganglia is to coordinate the operations of the posterior, perception-related cortical areas with the operations of the anterior, decision-related cortical areas. On this view, the basal ganglia construct transient working memories that are useful for monitoring the flow of perceptually guided behavior. Finally, the basal ganglia may play a role in the initiation of internally generated movements and ideas. This view is consistent with the akinesia of PD and the hyper-kinesia (i.e., excessive involuntary movements) of HD, as well as with the reports by Tourette's and schizophrenic patients of unwilled, alien thoughts invading their consciousness.

2.1.1.3 Dopaminergic Projection Systems

The basal ganglia contain two dopaminergic projection systems, both of which originate in the pars compacta of the substantia nigra (Figure 4). The first and heaviest of these is the nigrostriatal system, which projects dopaminergic fibers from one part of the compacta to the putamen and caudate. The second is the mesocortical (a.k.a. meso-limbic) system, which projects dopaminergic fibers from another part of the compacta (specifically, the ventral tegmental area, or VTA) to the ventral striatum, amygdala, medial temporal regions, and cortical mantle. The cortical projections are diffuse but

Figure 4: Dopaminergic projection systems. The nigrostriatal system originates in the pars compacta of the substantia nigra and terminates in the striatum. The mesocortical system originates in the ventral tegmental area of the substantia nigra and terminates in the ventral striatum, amygdala, frontal lobe, and some other basal forebrain areas. A third projection system which is shown here but not discussed in the text is the tubero-

infundibular system. It innervates the intermediate lobes of the pituitary and the nearby median eminence. (From Heimer 1983)

nonetheless somewhat region-specificùthey are stronger in the frontal lobes than in the parietal and temporal lobes (Levitt et al. 1984; Lewis et al. 1987), stronger dorsally than laterally and mesially (Williams & Goldman-Rakic 1993), and stronger in the left than the right hemisphere (Glick et al. 1982).

Dopamine is a member of the class of modulatory neurotransmitters called catecholamines (Foote & Morrison 1987; Cooper et al. 1991). There is substantial evidence that it functions as a reinforcement signal that guides both the learning and the maintenance of adaptive behaviors (Wickens & K÷tter 1995). This is illustrated most clearly in the striatum. In order for cells in the striatum to recognize behaviorally relevant contexts in their massive cortical inputs, a training mechanism is required that adjusts synaptic weights in the right directions. Current evidence suggests that the basal ganglia contain their own specialized training mechanism which involves not only unique cellular compartments within the striatum (viz., the striosomal or patch compartments), but also the nigrostriatal dopaminergic projection system (Houk et al. 1995). Physiologically, these dopaminergic fibers serve to reduce the potency of excitatory corticostriatal and thalamostriatal inputs to a moderate degree (Freund et al. 1984; Schultz et al. 1995). This has the effect of enabling only the strongest, most task-relevant inputs to pass through to the impulse-generating mechanism at the cell body; the weakest, most task-irrelevant inputs are filtered out. This has been referred to as a "focussing" effect (Schultz et al. 1995) or an enhancement of the "signal-to-noise ratio" of the cell's inputs (Foote et al. 1975; Robbins & Brown 1990). The contribution of dopamine as a reinforcer of critical inputs is important for learning as well as for maintaining the proper synaptic weights. This is reflected in the fact that dopamine cells always fire with a brief burst discharge that is time-locked to either an event that provides a primary reward or an event that, through learning, has become associated with a subsequent reward (Houk et al. 1995). The overall influence of dopamine on corticostriatal synapses is shown in Figure 5.

Figure 5: The influence of dopamine on striatal information processing (from Schultz et al. 1995). "Suppose that inputs from different cortical origins converge in an ordered manner on single striatal neurons. The different stengths of these inputs reflect the differential activation of cortical neurons by the current behavioral situation . . . (*Top*) In the absence of dopamine, cortical inputs would influence striatal neurons in a poorly contrasted manner. (*Middle*) Dopamine has an immediate focusing effect which non-linearly enhances the strongest inputs occurring at the time of the dopamine signal relative to weaker inputs which are suppressed. (*Bottom*) In a hypothetical learning

mechanism, dopamine facilitates long-term changes at hebbian-modifiable synapses. Arrow width represents the relative synaptic influences on postsynaptic impulse activity, consisting in a combination of presynaptic influence and synaptic strength." (Schultz et al. 1995: 244).

One could say that the basic function of dopaminergic modulation is to ensure that the signals that are allowed to activate striatal cells represent the most behaviorally significant features of the situation that the individual is facing. This in turn enables the basal ganglia to process the cortical input in such a way as to endorse an appropriate response to the situation and feed this recommendation up to the frontal lobes, where it may strongly influence the decision that is ultimately made. Taylor and Saint-Cyr (1995) have suggested that dopamine is especially useful for the learning and main-tenance of adaptive behavior in situations where several optional responses are avail-able. Dopaminergic focussing or, as they put it, "boosting" helps the striatum learn which responses are rewarding and which aren't, so that over time some signals gain greater meaning than others, gradually shaping a "habit pattern" through which perform-ance becomes expert:

> Given the potential of dopamine to modify signal-to-noise ratios within the striatum, the constant application of practice, enhanced by signal boosting, could facilitate reduction of options. In other words, through approximation, the range of choices shrinks, the basal ganglia serving to establish the best "ballpark" of action (Taylor & Saint-Cyr 1991). Ultimately, over time, the optimal response becomes the one with the highest valence and a habit is established. This habit, or set, can be stored as an algorithm, ready to be executed when the stimulus appears. (Taylor & Saint-Cyr 1995: 289-90)

On this view, striatal boosting of the most favorable option serves to augment selective attention, which is under cortical control, thereby facilitating the choice of that option. Although Taylor and Saint-Cyr do not mention it, I should emphasize that selective attention and decision-making in the prefrontal cortex are also influenced by direct dopaminergic reinforcement through the mesocortical projection system (Brozoski et al. 1979; Clark et al. 1987b). If the nigrostriatal system is compromised, the prefrontal cortex is left to reason its way through the available options without striatal boosting, relying solely on the weaker mesocortical innervation for guidance. And if the latter system is also compromised, the prefrontal cortex is completely on its own. As we shall see later in this chapter, both dopaminergic projection systems are damaged in PD, and as a result patients can suffer considerable cognitive deficits.

2.1.1.4 Basal Ganglia-Thalamocortical Circuits

So far I have spoken of the basal ganglia-thalamocortical circuit as if it was unitary. In fact, however, five distinct circuits linking the basal ganglia and the frontal cortex have been identified, and additional ones are likely to exist (Alexander et al. 1986, 1990a, 1990b). All of these circuits have parallel but segregated routes through the basal ganglia and thalamus, and there are even multiple subsets of parallel channels within each circuit. Each of these specialized circuits is named according to its cortical focus (Figure 6).

Two of the circuits are devoted to motor programming. The first is referred to simply as the motor circuit. It includes the following structures: within the cortex, the supplementary (BA[3] 6, medial), premotor (BA 6, lateral), and primary motor (BA 4)

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[3] BA = Brodmann's

areas; within the basal ganglia, the putamen and specific regions of the pallidum, substantia nigra (pars reticulata), and subthalamic nucleus; and within the thalamus, the ventrolateral nucleus. Several lines of researchùcomputational analysis, neural network computer modeling, neuroimaging studies, and lesion studiesùconverge on the view that the three cortical areas participating in the motor circuit contribute to the planning and execution of actions in unique ways that are hierarchically organized (Kosslyn & Koenig 1992). At the top of the hierarchy, the supplementary motor area computes, for a given voluntary movement such as reaching for a glass, the path through space (i.e., the "via points") that one's limb must traverse in order to arrive at the desired position. At the next level, the premotor cortex computes the joint angles (kinematic information) that are necessary for moving one's limb along the trajectory specified by the higher-level area. Finally, the primary motor cortex computes the muscle forces (dynamic information) needed to achieve the appropriate joint angles. Within the basal ganglia, single-cell recording studies have revealed distinct neuronal channels that represent the same three types of information specified in the three cortical areas; in addition, it is well-known that disruption to the basal ganglia impairs motor control, albeit in different ways depending on which structures are affected (Albin et al. 1989).

The second circuit involved in motor programming is called the oculomotor circuit. It includes the following structures: within the cortex, the supplementary and frontal eye fields (BA 8); within the basal ganglia, the body of the caudate nucleus and specific regions of the pallidum, substantia nigra (pars reticulata), and subthalamic nucleus; and within the thalamus, the ventroanterior and mediodorsal nuclei (Figure 6). Studies drawing on lesion analysis as well as single-cell recordings indicate that this circuit is dedicated to the planning and execution of eye movements for visual search (Alexander et al. 1990).

The other three circuits are specified in terms of three gross divisions of the prefrontal cortexùnamely, the dorsolateral, orbital, and anterior cingulate regions. Much less is known about the functional anatomy of these circuits; however, recent investi-gations making use of both deficit-lesion correlations and functional neuroimaging techniques have begun to shed some light on the different roles these circuits play in high-level cognition. The literature on the cortical regions involved in these circuits is very large and is rapidly becoming larger (recent anthologies include Uylings et al. 1990; Levin et al. 1991; Boller & Grafman 1994; Thierry et al. 1994; and Grafman et al. 1995); consequently, the following review is quite selective and limited in coverage.

To begin with the dorsolateral circuit, it includes the following structures: the dorsolateral prefrontal region (BA 46, 9), the dorsal part of the caudate nucleus, specific sectors of the pallidum, substantia nigra, and subthalamic nucleus, and the ventroanterior and mediodorsal nuclei of the thalamus (Figure 6). Cummings (1993, 1995) brings together a great deal of data indicating that damage to either the dorsolateral prefrontal cortex or the dorsal part of the caudate nucleus impairs a broad range of so-called executive functions; moreover, he notes that a few cases have been reported of similar impairments following damage to the pallidum or thalamus. The behavioral syndrome is characterized by depression, together with a reduced ability to "generate hypotheses and flexibly maintain or shift sets as required by changing task demands on such tests as the Wisconsin Card Sort Test [WCST]" (Cummings 1993: 874). In this test, subjects must sort cards according to one criterion (color, form, or number of items depicted) which they must infer solely from the pattern of correct and incorrect responses provided by the examiner. After ten consecutive correct responses, the examiner shifts the sorting principle without warning, forcing subjects to abandon the old principle and infer the new one. In addition to performing poorly on the WCST, patients with damage restricted the dorsolateral circuit exhibit a variety of other executive deficits, including impaired verbal and graphic fluency (i.e., spontaneous word-list and design generation), disrupted organizational strategies for learning tasks, and motor programming distur-bances in tasks that require alternating or sequencing actions in complex ways.

Within the past few years, a large number of neuroimaging studies have provided convergent evidence for the view that the dorsolateral prefrontal cortex is crucial for executive functions. First of all, several studies have shown that this brain region is activated when subjects perform the WCST (PET: Weinberger et al 1986; SPECT: Rezai et al. 1993) as well as when subjects are tested for verbal fluency (PET: Frith et al. 1991a); in both cases the activation is stronger in the left hemisphere than in the right. This brain region is also activated when subjects perform tasks that emphasize completely self-generated or "willed" responses as opposed to purely stimulus-driven responses. For instance, in a PET study Frith et al. (1991b) compared the blood flow maps from two conditions that involved stimulus-driven responses (repeating a spoken word, or lifting a touched finger) with the blood flow maps from two conditions that involved random selection of a response from a repertoire (hearing a letter and gener-ating a word that begins with that letter, or feeling a finger being touched and then lifting one of two fingers). They found activation of the left dorsolateral prefrontal cortex in the condition requiring random word generation and bilateral activation of this region in the condition requiring random finger movements. Another cognitive process that elicits strong activity in the left dorsolateral prefrontal cortex is the controlled manipulation of semantic informationùe.g., generating verbs that are semantically related to nouns (PET: Petersen et al. 1988), monitoring a list of words for items that designate dangerous animals (PET: Petersen et al. 1988), and discriminating between words designating man-made and natural objects (PET: Frith & Grasby 1995). Finally, two very elegant PET studies conducted by Petrides and coworkers have shown that the dorsolateral prefrontal cortex contributes to working memory tasks that require com-paring responses that have already been made to those still remaining to be carried out (Petrides 1995; Petrides et al. 1993a, 1993b). The first study focused on the visual modality (Petrides et al. 1993a). Subjects were presented with sequences of eight abstract figures, and on each trial the sequence was ordered differently. The subjects' task was to select a different stimulus on each trial until all had been selectedùa task that requires keeping track of previous responses. When the blood flow map from this condition was compared to that for a baseline condition (one that involved the same stimuli and motor responses but lacked the working memory component), significant activation in the dorsolateral prefrontal cortex was found, especially in the right hemisphere. The second study focused on the verbal domain but was designed in a manner similar to the first study (Petrides et al. 1993b). In one condition the subjects had to randomly generate numbers from 1 to 10, avoiding repetition of any number until all of them had been produced. In another condition the subjects were presented with random sequences of nine numbers between 1 and 10 and had to identify which number was missing. When the blood flow maps from these conditions were compared to that from a baseline condition (one that simply involved counting forwards from 1 to 10), it was found that, once again, the dorsolateral prefrontal cortex was activated, except this time predominantly in the left hemisphere. Petrides et al. suggest that the major func-tional specialization of the dorsolateral prefrontal cortex is to monitor and manipulate information being held on-line in working memory; in addition, they suggest that this large brain region is subdivided not according to functional differences but rather according to the type of information that is operated on. This general characterization of the functional anatomy of the dorsolateral prefrontal cortex appears to be consistent with the other studies described above; however, it must be acknowledged that the representational and computational details of the processes described by Petrides et al. remain to be clarified. While it is true that considerable progress has been made in understanding executive functions at both cognitive and neural levels of description, it is also true that we have a long way to go before research in this area becomes as sophisticated as, say, research on low-level visual processing. Grafman (1995) expresses the same point by saying, rather sardonically, that current theorizing about executive functions is comparable to Broca's theorizing about linguistic functions.

Moving on now to the orbitofrontal circuit, it includes the following structures: the lateral orbitofrontal cortex (BA 10, 11), the ventral part of the caudate nucleus, specific regions of the pallidum, substantia nigra, and subthalamic nucleus, and the ventro-anterior and mediodorsal nuclei of the thalamus (Figure 6). As with the dorsolateral circuit, evidence about the functions subserved by the orbitofrontal circuit comes from both deficit-lesion correlations and neuroimaging studies. Cummings (1993, 1995) summarizes a wide range of data indicating that damage to either the lateral orbitofrontal cortex or the ventral caudate nucleus produces mania together with irritability, disinhibition, tactless social behavior, and obsessive-compulsive disorder (see also Damasio 1994; Damasio et al. 1990, 1991, 1994, 1995). Patients with lesions to this circuit have difficulty with set-shifting on the WCST. They also tend to perseverate on delayed alternation tasks, which require shifting back and forth between stimuli after brief delay periods. Very few neuroimaging studies have reported task-related activation in the orbitofrontal cortex, perhaps because activity in this rather low-lying region of the brain is sometimes not recorded due to the narrow field of view of current PET cameras (Frith & Grasby 1995). Still, two PET studies have obtained results which are consistent with the picture of lateral orbitofrontal function gleaned from clinical data. First, Alexander et al. (in press) found activation in this region when subjects were required to fixate on an unchanging point for the duration of the scan. Frith and Grasby (1995: 392) comment on this study as follows: "Although this is often used as a 'control' condition, subjects sometimes report that it is quite taxing and requires considerable concentration. It is interesting to note that [lateral orbitofrontal] lesions in man are observed to impair central gaze fixation maintenance (Paus et al. 1991). It is possible then that this area is involved in the suppression of prepotent responses." Second, Jaeger et al. (in press) found activation in the left lateral orbitofrontal cortex when subjects were presented with English verb stems that have irregular past tense forms and had to generate the appropriate past tense form of each one (e.g., *hold - held, swim - swam, see - saw*). They suggest that this activation may reflect the need to suppress inappropriate responses such as overregularizations (e.g., *hold - holded*) or false analogies (e.g., *fling - flang*).

The last basal ganglia-thalamocortical circuit that has been documented is referred to as the anterior cingulate circuit. It includes the following structures: the anterior cingulate cortex (BA 24, 32), the ventral striatum, specific sectors of the pallidum, substantia nigra, and subthalamic nucleus, and the mediodorsal nucleus of the thalamus (Figure 6). According to Cummings (1993, 1995), damage to either the anterior cingulate cortex or the ventral striatum produces apathy, withdrawal, and loss of motivation. Severe lesions of the anterior cingulate and the adjoining areas cause a very strange disorder known as akinetic mutism. Such patients seem to be in what Damasio (1994: 71) calls a state of "suspended animation." They lie peacefully in bed, motionless and speechless, with open eyes but a blank facial expression. They answer questions in monosyllables if at all and display no emotion or concern about their circumstances, even when in pain. In general, they appear not to attend to either external stimuli or internal representations. After one patient had gradually emerged from this state and was asked why she had never been inspired to communicate, she answered quite simply: "I really had nothing to say" (Damasio 1994: 73).

A large number of neuroimaging studies have found activation of the anterior cingulate cortex. In fact, in all of the studies that I mentioned in the discussion of the dorsolateral prefrontal cortex, activation also appeared in the anterior cingulate. This makes sense in light of Posner's (1994) view that this brain region is involved in controlled or focused attention, i.e., attention that serves to amplify processing efficiency within a specific domain of interest, whether it be perceptual, cognitive, emotional, or action-related. Further support for the idea that the anterior cingulate contributes to attention comes from a study conducted by Corbetta et al. (1991). Across three conditions, subjects were shown sequences of two pictures containing objects which could vary along the dimensions of shape, color, and speed of movement. In the first condition, the subjects just passively viewed the stimuli; in the second, they had to detect a change in a single, predetermined dimension; and in the third, they had to detect a change in any of the possible dimensions. In comparison to the baseline condition, the anterior cingulate was not activated in the second condition but was activated in the third condition, which suggests that this brain area comes into play when attentional demands are especially high. Other neuroimaging studies have indicated that the anterior cingulate also contributes to response selection, particularly when the subject must inhibit a routine response and facilitate a nonroutine response; it may be the case, however, that this kind of operation is simply another manifestation of controlled attention (Devinsky et al. 1995; Stuss et al. 1995). For instance, several recent studies have demonstrated that the anterior cingulate is activated when subjects perform the Stroop task (Pardo et al. 1990; Bench et al. 1993; George et al. 1994). Although there are many versions of this task, in the most common one subjects are presented with a succession of color words printed in a color other than the one referred to by the word, and are asked to name the color of the ink as quickly as possible. The task is challenging because the subject must inhibit the strong tendency to read the word. The contribution of the anterior cingulate is apparently very important for this task, because one study found that behavioral performance is positively correlated with activation in this region of the brain (George et al. 1994). It is noteworthy that although response selection is a key function of the dorsolateral prefrontal cortex, no activation was found in this brain area in any of the neuroimaging studies of the Stroop task. It must also be noted, however, that response selection was critical for many of the previously mentioned studies in which activation was found in both the dorsolateral prefrontal cortex and the anterior cingulate cortex. This raises the question of what unique roles these two brain areas play in executing response selection. In considering this question, Frith and Grasby (1995: 392) suggest that the anterior cingulate "is involved when responses are speci-fied, but their selection is not routine. In such cases, close attention to the eliciting stimulus is required. In contrast, [the dorsolateral prefrontal cortex] is involved only when the particular response to be selected is not fully specified." Another question that is worth asking is why the lateral orbitofrontal cortex is not activated when subjects perform the Stroop task; after all, this area is also reputed to be involved in response selection, especially when it is necessary to suppress an automatic behavior. The answer to this question is not clear at the present time, but hopefully future research will shed some light on it.

I have now completed my review of the functional anatomy of the five established basal ganglia-thalamocortical circuits. Before going on to summarize the nature of the neuropathology that occurs in PD, however, there are two final issues that I want to address. First, although the preceding discussion of the three circuits that involve prefrontal cortical sites emphasized the distinctive functional properties of each one, it is important to make explicit the functional properties that they have in common. Based on a thorough survey of the clinical literature, Cummings (1995) has observed that damage to any of these circuits causes, on the one hand, impaired behaviors that are self-generated and, on the other hand, preserved behaviors that are guided by features of the external environment (see also Lhermitte et al. 1986; Lhermitte 1986; and especially Noack 1995). Thus, patients with the dorsolateral syndrome show the following behavioral contrasts: they may achieve set on the WCST but perseverate when required to change set; they have intact recognition memory but impaired recall; they have intact confrontation naming but impaired verbal fluency; they can understand concrete language but have difficulty with abstract or figurative language; and they can execute a stereotyped motor program but cannot reverse the sequence of component actions. Patients with the orbitofrontal syndrome display similar contrasts: although they are able to learn instructions, they respond to the environment on impulse; and although they seem to have at least some degree of personal control, they imitate the actions of others and are tempted to use objects that are within reach (utilization behavior). Finally, extreme envirnomental dependency is exhibited by patients with the anterior cingulate syndrome: they can respond to questions but are otherwise apathetic; they can maintain induced postures but are otherwise catatonic; and last of all, they can repeat words that they hear but otherwise have virtually no spontaneous verbal output (trans-cortical motor aphasia).

Finally, Alexander et al. (1986, 1990a, 1990b) pointed out that additional basal ganglia-thalamocortical circuits are likely to exist, and one candidate is a circuit that has the ventrolateral prefrontal region (BA 45, 47, inferior 46) as its cortical focus. Petrides (1995) argues that this cortical region subserves executive functions that are less complicated than those carried out by the dorsolateral prefrontal cortex. In particular, he claims that this region is devoted to the active selection (i.e., encoding or retrieval) and judgement of information held in short-term or long-term memory stores in the posterior association cortices. This view is supported by lesion studies in nonhuman primates and by two recent PET studies; I will focus on the latter. In the first study, which concerned the visual modality, subjects were scanned under three conditions: passively observing familiar stimuli, passively observing novel stimuli, and making explicit recognition judgements between familiar and novel stimuli (Petrides 1995). When the blood flow maps from the first two conditions were subtracted from that from the third condition, activation was found in the ventrolateral prefrontal cortex (but not, interestingly enough, in the dorsolateral prefrontal cortex). The second study emphasized verbal working memory (Paulesu et al. 1993). In one condition, passive storage of a simple list of words was required but not active articulatory rehearsal; in another condition, rehearsal was also necessary. Inspection of the blood flow maps revealed that the storage com-ponent of verbal working memory is implemented in the left inferior parietal cortex (BA 40) and that the rehearsal component, which involves strategic retrieval of information held in the short-term store, is implemented in the ventrolateral prefrontal cortex (for convergent data from functional neuroimaging research, see Awh et al. 1995, and for convergent data from neuropsychological research, see Vallar & Shallice 1990 and the special issue of *Neuropsychology,* vol. 8, no. 4, 1994).

2.1.2 Disruption in PD

The central pathology in PD is progressive degeneration of the pars compacta of the substantia nigra. This has several deleterious effects. First, disruption of the nigro-striatal dopaminergic projection system causes massive dopamine depletion in the striatum. This loss of dopaminergic innervation follows a gradient such that the putamen is affected more severely than the caudate. Postmortem studies, for instance, have revealed only 5% or less of normal values in the putamen, compared to 15 or 20% in the caudate (Agid et al. 1987). Furthermore, while all patients suffer dopamine depletion in the putamen, only around half of patients exhibit dopamine depletion in the caudate (Martin et al. 1986). As more nigrostriatal dopaminergic neurons die, the surviving neurons become increasingly overactive in order to compensate for the loss (Agid et al. 1973). It is thought that when this compensatory mechanism ceases to be effective and the first parkinsonian symptoms appear, at least 70% of the nigrostriatal system is already damaged (Bernheimer et al. 1973; Riederer & Wuketich 1976; Scherman et al. 1989). The reduced dopamine supply to the putamen and caudate interferes with the information processing capacities of these nuclei, and as a result the multiple circuits linking the basal ganglia and the frontal lobes no longer function normally. Because the putamen participates in circuits with the supplementary, pre-motor, and primary motor cortices, all PD patients develop motor disorders, most notably tremor, rigidity, akinesia, bradykinesia, and gait abnormalities (Delwaide & Gonce 1988). These motor impairments progress in severity and are often measured according to a five-stage scale proposed by Hoehn and Yahr (1967). Moreover, because the caudate participates in circuits with regions of the prefrontal cortex, around half of all patients also develop cognitive disorders similar to those exhibited by patients with lesions in these cortical areas (DuBois et al. 1991; Wolters & Scheltens 1995).

Another consequence of the degeneration of the pars compacta of the substantia nigra is that the mesocortical dopaminergic projection system is disrupted. A significant proportion of dopaminergic neurons in the VTA die, thereby reducing the supply of dopamine to the ventral striatum as well as to cortical and limbic sites; this reduction in dopamine, however, is not as severe as in the striatumùlevels in the ventral striatum, frontal lobes, and hippocampus are approximately 40% of normal, while levels in the cingulate cortex, amygdala, and hypothalamus are closer to 50% of normal (Javoy-Agid & Agid 1980; Scatton et al. 1982; Agid et al. 1987; Shinotoh & Calne 1995). Still, this dopamine depletion is severe enough to contribute to the cognitive deficits of PD patients; in fact, the degree of mesocortical impairment correlates positively with the degree of intellectual impairment (Torack & Morris 1988; German et al. 1989; Rinne et al. 1989).

Although the loss of dopaminergic neurons in the pars compacta of the substantia nigra is the central pathology in PD, it is not the only pathology. There is also mild degeneration of three other modulatory neurotransmitter projection systemsùspeci-fically, the cholinergic, noradrenergic, and serotonergic systems (for reviews see DuBois et al. 1991, 1992). Like the two dopaminergic systems, each of these systems originates in the midbrain and projects rather diffusely to cortical and limbic sites. Reduction of these neurotransmitters may be implicated in the cognitive and affective changes observed in PD patients. For instance, demented patients tend to have more severe damage to the cholinergic system than nondemented patients (Whitehouse et al. 1983; Perry et al. 1985), and depressed patients tend to have more severe damage to the sero-tonergic system than nondepressed patients (Mayeux et al. 1984). Finally, alterations of neurons in the cerebral cortex, especially in the temporal and parietal lobes, have been found in some patients, predominantly in those with dementia (Ruberg & Agid 1987). These alterations consist of senile plaques, neurofibrillary tangles, and Lewy bodies similar to those that occur in Alzheimer's or Cortical Lewy Body Disease.

2.2 Neuropsychology

Given that the neuropathology of PD involves disruption of not only the basal ganglia-thalamocortical circuits but also the direct dopaminergic projection to the prefrontal cortex, it is not surprising that a substantial proportion (around 50%) of patients who are nondemented still suffer from cognitive deficits that are similar to those found in patients with lesions of the prefrontal cortex (for reviews see Brown & Marsden 1990, 1995; Rashkin et al. 1990; Dubois et al. 1991, 1995; Levin et al. 1992; Taylor & Saint-Cyr 1995). In general, the vast neuropsychological research that has been done on PD indicates that such patients have difficulty with the following broad categories of tasks: (1) when the cognitive system does not have a well-learned line of thought or action for the current context and hence must formulate and evaluate hypotheses; (2) where it is necessary to suppress a strong habitual response or resist a temptation; and (3) when attentional control is needed to keep the cognitive system focused on the appropriate stream of information processing. Although it is undoubtedly an oversimplification, these broad categories of tasks seem to map, at least in a rough manner, onto the three basal ganglia-thalamocortical circuits that involve prefrontal cortical sites: the first category corresponds mainly to the dorsolateral circuit; the second category corresponds mainly to the orbitofrontal circuit (although the other two circuits may also contribute); and the third category corresponds mainly to the anterior cingulate circuit. Despite this rough mapping of tasks onto circuits, however, most of the neuropsychological research with nondemented PD patients has concentrated on various cognitive domains independent of anatomical considerations. The cognitive domains that have been investigated most intensively are visuospatial processing, memory, and set regulation. I will review some of the major findings in each of these domains, and then I will conclude by returning to the issue of how the cognitive deficits can be related to the underlying neuropathology.

2.2.1 Visuospatial Processing

Visuospatial processing involves appreciating the relative positions of visually represented objects in space, integrating these objects into a coherent spatial framework, and performing mental operations that actively transform one's internal representation of the visual world, in some cases through imagery. The visuospatial processing abilities of PD patients are controversial because a number of seemingly inconsistent results have been reported. Some researchers have found that PD patients are normal in this domain, others have obtained mixed results, and still others have found that PD patients are impaired on a variety of tasks.

Some of the tasks that do not seem to cause difficulty for PD patients include the following: left-right and above-below discrimination (Brown & Marsden 1986), mentally rotating an object to match it with an item in a sample (Ransmayr et al. 1987; Heitanen et al. 1990), calculating rebound angles (Della Sala 1986), extrapolation of the intersections between a target and a baseline (Della Sala 1986), and judgement of spatial displacement (Stelmach et al. 1989).

By contrast, some of the tasks that do cause trouble for PD patients are as follows. First of all, a large number of studies have shown that PD patients perform poorly at discriminating line orientation (Boller et al. 1984; Goldenberg et al. 1986; Hovestadt et al. 1987; Lavernhe et al. 1989; Wasserstein et al. 1990). Many patients are also impaired at drawing complex figures (DuBois et al. 1991). A third finding is that patients have trouble with visuospatial tasks that require complex planning and sequencing (Ogden et al. 1990). In addition, patients perform poorly on a test where they are shown drawings of angular figures and asked to make a line indicating how each figure could be divided into two parts such that these parts could form a square (Ransmayr et al. 1987). Finally, although patients are able to walk along a given route when there are explicit signposts marking directions, they have difficulty walking along a route when they are forced to generate their own mental map or to use their own body as a constantly changing reference point for movement through space (Bowen et al. 1972). This impairment is captured in an anecdote from a patient: "I used to walk alone in the woods, fog or no fog, but when the symptoms of Parkinson's disease appeared, I noticed that I could not orient myself any more, and in case of fog, I got lost" (Hovestadt et al. 1987).

Although these conflicting results about the visuospatial processing abilities of PD patients suggest that the population is quite heterogeneous, several researchers have been able to make at least some degree of sense out of the data. For instance, DuBois et al. (1995) point out that, except for line discrimination, the tasks that elicit poor performance demand mental flexibility and the generation of strategies without guidance from external cues. This is clear in the last example where route-walking with signposts is intact but route-walking without such overt directional markers is impaired. It can also be seen if we compare using mental rotation to match an object against a sampleùa preserved abilityùwith using mental rotation to determine how a figure should be divided so that its parts form a squareùan impaired ability. As Brown and Marsden (1990) point out, in the former task the correct solution is present in the sample array, whereas in the latter task the patient's response is completely self-generated. In sum, it is reasonable to suppose that the majority of visuospatial deficits exhibited by PD patients are not specific to this domain but rather arise from a disruption of more generalized executive or control processes.

2.2.2 Memory

A similar mixture of good and poor performance has been found in the domain of memory. I begin by considering short-term memory (STM). There are numerous content-specific STM systems, but most of the research with PD patients has focused on just two of them: the articulatory loop, which permits rehearsal of verbal information, and the visuospatial scratchpad, which enables temporary storage and manipulation of visuospatial material (Baddeley 1986, 1992). The articulatory loop appears to be intact in PD patients, since they are not deficient at rehearsing sequences of digits such as telephone numbers (Hietanen & Teräväinen 1988; Cooper et al. 1991). The visuospatial scratch-pad also seems to be preserved, since patients are able to retain a representation of a configuration of objects in visual STM during a delay period (Morris et al. 1988; Sullivan & Sagar 1989).

Difficulties emerge, however, when interfering stimuli are introduced into STM tasks. An example is the Peterson and Peterson (1959) paradigm, in which three letters are presented and immediately followed by a distractor task, intended to prevent subjects from focusing exclusively on rehearsing the items to be remembered. PD patients perform significantly worse than control subjects on this test (Tweedy et al. 1982; Huber et al. 1989). Another such case is the Sternberg (1975) paradigm, in which subjects must decide if probe digits correspond to a set of digits being held in verbal STM. PD patients display normal accuracy on this test, but their reaction times are significantly slower than those of control subjects (Wilson et al. 1980; Ransmayr et al. 1986). These results suggest that PD patients are only impaired on STM tasks when they require the strategic use of control processes.

I turn now to long-term memory, which can be divided into implicit and explicit memory (Graf & Schacter 1985; Schacter 1996). There are several forms of implicit memory. One of the most important is motor skills and cognitive routines that have been acquired through multiple exposures and that are not accessible to conscious inspection. Another is lexical priming, in which the occurrence of a word facilitates the response to a semantically or phonologically related word. PD patients have been shown to perform normally on tasks requiring implicit memory (Heindel et al. 1989; Spicer 1994).

Explicit memory consists of declarative knowledge that is available for conscious recollection. It can be measured through both recognition and recall tasks. Recognition tasks are generally passive insofar as subjects need only make a decision about a fixed set of alternatives. A large number of studies have demonstrated that PD patients have normal recognition memory for verbal as well as visuospatial material (Lees & Smith 1983; Boller et al. 1984; Flowers et al. 1984; Weingartner et al. 1984; Taylor et al. 1986; El-Awar et al. 1987). However, recognition performance declines when the task requires the patients to mentally manipulate the material or actively organize a response. For example, in a word-list paradigm Tweedy et al. (1982) asked patients to signal whether a word was a repetition or a synonym of a previously presented one. The patients recognized fewer repetitions than control subjects, but they were most impaired at detecting synonyms.

Recall tasks are inherently more effortful than recognition tasks, since the response must be completely self-generated. PD patients are often impaired at story and paired associate recall, both immediately and after a delay period (Bowen et al. 1976; Halgin et al. 1977; Pirozzolo et al. 1982; Stern et al. 1984; Pillon et al. 1986; El-Awar et al. 1987). Moreover, their performance is especially poor when the material is not semantically organized at presentation, as in word-list acquisition (Tweedy et al. 1982; Villardita et al. 1982; Weingartner et al. 1984; Globus et al. 1985). Many patients are also deficient at recall in the visuospatial domain (Boller et al. 1984; Sullivan et al 1989; Growdon et al. 1990). Finally, it is important to note that performance on recall tasks improves dramatically when explicit cues are provided to trigger efficient access of the appro-priate knowledge (Pillon et al. 1993).

Taken together, these findings concerning long-term memory function in PD patients suggest that the memory stores themselves are intact; the deficit appears to reside in the higher-level control processes that are necessary for actively retrieving and manipulating the information.

2.2.3 Set Regulation

A substantial amount of neuropsychological research on PD has been concerned with a cognitive ability referred to as set regulation. The notion of set that is used in neuropsychology bears many similarities to the notions of schema, frame, and script that are used in cognitive science. Buchwald et al. (1975) define set as "the relatively persisting predisposition to behave in a particular way on the occurrence of a given stimulus," and Flowers and Robertson (1985) define it in a related fashion as "a state of brain activity which predisposes a subject to respond in one way when several alternatives are available." These operational definitions are quite broad, but this breadth is altogether fitting as an initial characterization of the phenomenon, since set effects are in fact a pervasive feature of much adaptive behavior. The information processing systems of humans and other animals must be able to benefit from the redundancies in past experience by using such redundancies to assemble and store stimulus-response strategies, i.e., sets, of varying degrees of hierarchical complexity, and they must also be able to use their inventory of sets in an efficient way by selecting one among a number of competing sets for coping with a given situation. In order to accomplish this selection process, attentional control is sometimes needed to maintain the selected set in the face of interference from alternatives and, when necessary, to shift from an inappropriate set to an appropriate one.

An example should help to make this more concrete. If you are working in your office and the phone rings, this stimulus is directly associated with the response to answer the call. This stimulus-response strategy, or set, is (ceteris paribus) immediately selected as opposed to alternatives, such as ignoring the call or walking out of the room, because it has been reinforced in the past and because it is part of our more general cultural knowledge of the responsibilities of office workers. Such set selection does not require the intervention of attentional control because it is automatic. By contrast, if you are a visitor in someone else's office and the phone rings, this stimulus activates not just the previously described knowledge about the positive consequences of answering phone calls, but also conflicting knowledge about the social rule dictating that a visitor in someone else's office should defer answering the phone. In this case, set selection does require the intervention of attentional control, since the automatic, or default, response of answering the call must be actively inhibited and the alternative response of not answering it must be selected (Grafman 1995).

A large number of studies have demonstrated that PD patients are impaired at shifting from one set to another. A good example is the Wisconsin Card Sorting Test (WCST), which I described earlier in the discussion of the dorsolateral prefrontal cortex. PD patients reliably make numerous perseverative errors on this test, revealing difficulty in "getting out" of one sorting principle and shifting to a new one; it is remarkable that patients may verbalize the correct sorting principle but still perseverate in their behavior (Lees & Smith 1983; Brown & Marsden 1988a, 1988b; Caltagirone et al. 1989a, 1989b). Another example is the Trail Making Test, part B, which requires subjects to connect consecutively numbered and lettered circles, thus continuously shifting from one category (numbers) to another (letters). Again, PD patients are impaired on this test, providing further evidence for a set shifting deficit (Reitan & Boll 1971; Pirozzolo et al. 1982; Hietanen & Ter v inen 1986; Taylor et al. 1986). A third case involves tests of category alternation fluencyùe.g., generating animal names and then shifting to the names of professions, or sorting blocks first by form and then by size. In general, PD patients are disproportionately impaired on the second phase of such tests, when they have to stop thinking in terms of the first category and redirect their attention to the new one (Lees & Smith 1983; Cools et al. 1984; Pillon et al. 1986; Taylor et al. 1986; Goldenberg et al. 1989; Downes et al. 1993).

The hypothesis that PD patients have difficulty shifting between sets was refined by two important studies conducted by Brown and Marsden. In one study (Brown & Marsden 1988a), they required PD patients to shift between two modes of processing a visual stimulus. First, the patients had to make a simple left-right discrimination, and second, they had to mentally rotate the stimulus 180 degrees before making the same left-right discrimination. The patients received alternating blocks of the two tasks, with each block consisting of ten trials; cues indicating how the stimulus was to be processed were given on every trial. The results showed that both PD patients and control subjects had increased reaction times (RTs) and error rates when required to shift, followed by a reduction in RTs and error rates as each block progressed. However, these measures were not significantly greater for the PD patients in the shifting phase compared to the baseline phase. This finding implies that although PD patients are impaired on many tasks that require shifting between different sets, they are not impaired on all such tasks.

In a subsequent study, Brown and Marsden (1988b) sought to determine what distinguishes the shifting tasks that elicit poor performance in PD patients from those that elicit good performance. This study employed a version of the Stroop test. They presented PD patients with sequences of color words printed in noncorresponding colors of inkùeither *red* printed in green ink or *green* printed in red ink. After the presentation of each word, the patients had to push an appropriate button, according to either the meaning or the color of the word. The relevant dimension, meaning or color, remained fixed for ten trials, and then the command to "switch" was given, indicating that the relevant dimension had changed. Twelve switches of this kind were required. In addition, there were two different conditions. In one condition, an explicit cue about the relevant dimension was provided on every trial, and in another condition, a cue was given for just the first trial of the first block, thereby forcing the patients to remember the relevant dimension for the rest of the trials. The results showed that in the first condition, both PD patients and control subjects had increased RTs and error rates when required to switch, followed by a reduction in these measures as each block progressed. The effects were not significantly different for the two groups. By contrast, in the second condition the performance of the two groups diverged: while the control sub-jects had the same pattern of RTs and error rates as they did in the first condition, the PD patients had significantly greater RTs and error rates, especially for the trials immediately following switches. Brown and Marsden interpret this finding as evidence that PD patients are only impaired at shifting between sets when doing so requires internal attentional control. Furthermore, they argue that such a view is consistent with the other studies on set shifting. The shifting tasks that elicit poor performanceùi.e., the WCST, the Trail Making Test, part B, the fluency alternation tests, and the noncued Stroop testùdemand that the patients use internal attentional control to regulate which sets are active and which are inhibited, whereas the tasks that elicit good performanceùi.e., "rotated" left-right discrimination of a visual stimulus (where cues were given on every trial), and the cued Stroop testùprovide external guidance for how the material should be processed and hence do not rely so strongly on high-level control processes.

Several other studies have shown that PD patients are also impaired at maintaining a given set in the face of strong interference from competing ones. For instance, on the WCST, patients make not only perseverative errors but also nonperseverative errors, which indicates difficulty "staying in" a particular sorting principle and avoiding being distracted by others (Bowen et al. 1975; Gotham et al. 1988). Additional evidence for a deficit in maintaining set comes from the performance of PD patients on the Odd Man Out Test, which is similar to the WCST insofar as subjects have to apply a particular sorting principle consistently before switching to a different one. After making the first shift, patients tend to revert to the previous response pattern, suggesting difficulty in keeping their attention focused on the relevant stimulus attribute (Flowers & Robertson 1985). A third example of a set maintenance impairment is the finding that PD patients exhibit abnormally rapid disengagement of visual attention from a target stimulus when measured in Posner's (1980) attentional orienting paradigm (Wright et al. 1990). In some contexts such rapid disengagement may facilitate efficient shifting of attention to a new target and hence have positive implications for cognitive processing, but in other contexts it may reduce the ability to keep attention locked on a specific target and hence have negative implications for cognitive processing (Filoteo et al. 1994). For instance, PD patients have been reported to experience an unusally high rate of spontaneous reversal of perspective when viewing ambiguous visual figures such as the Necker cube (Talland 1962).

To summarize, a considerable body of evidence suggests that PD patients have a deficit in using control processes to regulate the activation levels of sets. Not only do they perform poorly on tasks that require using such processes to shift between different sets; they also have difficulty on tasks that require using such processes to maintain the appropriate sets in the face of interference from alternatives.

2.2.4 Relating the Cognitive Deficits to the Underlying Neuropathology

2.2.4.1 Hypotheses

A number of recurrent themes can be discerned in the preceding review of the patterns of performance that PD patients exhibit in different cognitive domains. On the one hand, patients generally perform well on tasks that are passive, automatic, provide organized stimulus material, provide explicit solutions to choose from, or provide external cues for regulating set. On the other hand, they generally perform poorly on tasks that are active, effortful, require that the patient organize the stimulus material, require the spontaneous generation of a response, or require internal attentional control to regulate set. How can these behavioral contrasts be related to the underlying neuropathology of PD?

At present, no single, well-developed answer to this question is available; however, it is still possible to develop several hypotheses that are based on the information at hand and pitched at a fairly general level of description (for some recent proposals, see Cools et al. 1995; DuBois et al. 1995; Taylor & Saint-Cyr 1995; and Partiot et al. 1996). Recall that PD is essentially a neurochemical disorder that affects the dopamine supply in the brain. As I mentioned in section 2.1.1.3 (pp. 6-8), the primary function of this modulatory neurotransmitter is to serve as a reinforcement signal for the learning and maintenance of adaptive behaviors. In particular, in the striatum and ventral striatum, dopamine increases the signal-to-noise ratio of cortical and thalamic inputs by allowing only the strongest, most task-relevant inputs to get through; in other words, it has a "focusing" or "boosting" effect that enables the target cells to accurately recognize the most behaviorally significant features of the current situation. This in turn enables the basal ganglia to select, by means of competitive processing in the direct and indirect pathways, the most appropriate response to the current situation and then relay this information up to the frontal lobes in the form of a recommendation for thought or action. It is worth adding that the direct dopaminergic innervation of the frontal lobes also contributes to the efficient functioning of these brain areas by facilitating the most task-relevant activation patterns.

There is substantial evidence that the dopaminergic projection systems and the circuits linking the basal ganglia with the prefrontal cortex are more important for tasks that require attentional control and self-generated responses than they are for tasks that provide environmental support (Cummings 1993, 1995). The reason for this may be that when environmental support is available, appropriate responses can be made through more or less direct perceptual-motor linkages without the intervention of the special "biasing" mechanisms of dopamine and the basal ganglia-thalamocortical circuits; however, when environmental support is lacking, these mechanisms are necessary to guide the elaborate decision-making system in the prefrontal cortex toward adaptive behavior. If I may indulge in a convenient metaphor, the dopaminergic projec-tion systems and the basal ganglia-thalamocortical circuits function as a compass that helps the prefrontal cortex navigate through the world of cognitive challenges. This compass is only needed, however, when there aren't clear signposts in the environment that indicate one's position and which direction one should take.

Turning now to PD, when the dopamine supply in the striatum and ventral striatum is significantly reduced, the cells in these nuclei are no longer able to filter out "noisy," irrelevant inputs and hence cannot accurately recognize the most important features of the current situation. As a result, the basal ganglia have difficulty determining the most appropriate strategy for dealing with the situation and cannot send a confident recommendation up to the frontal lobes via the multiple specialized circuits. To use an expression coined by DuBois et al. (1991: 227), the aberrant basal ganglia-thalamocortical signals lead to "cortical demodulation" (as opposed to deafferentation, which occurs when the cortex is completely deprived of subcortical input). Furthermore, because the mesocortical dopaminergic projection system is also moderately compromised, the prefrontal cortex cannot fall back on it for reinforcement and guidance in working out the most adaptive response to the current situation. The overall effect is that the prefrontal cortex is forced to "think through" difficult problems that are nor-mally handled much more quickly and easily by virtue of dopaminergic boosting of the most appropriate course of information processing. To continue with the metaphor introduced earlier, when the compass is damaged, navigation is no longer such a straightforward process; in fact, it can only be accomplished by resorting to more laborious and unreliable ways of determining one's position and the right direction to take to get to one's destination.

From this perspective, then, it is possible to make some sense of the general finding that PD patients have the most trouble with tasks that are not environmentally supported but rather depend on internal attentional control and self-generated responses. For instance, to take a case that fits nicely with the navigation metaphor, the fact that patients perform poorly on route-walking tasks when there aren't any explicit cues available may be explained in terms of insufficient facilitation of visuospatial working memory by the relevant basal ganglia-thalamocortical circuits (probably the dorsolateral circuit is most important hereùsee Goldman-Rakic 1987, 1995) and by the mesocortical dopaminergic system. Similarly, good performance on recognition tasks may occur because the stimulus primes the appropriate response, whereas poor performance on recall tasks may be due to a lack of basal ganglia-thalamic and mesocortical-dopa-minergic enhancement of cell assemblies in the prefrontal cortex that are involved in actively retrieving information stored in long-term memory (the right ventrolateral prefrontal cortex and its putative circuit with the basal ganglia may be especially impor-tant hereùsee Kapur et al. 1995 and Schacter et al. 1996). Finally, problems with set shifting and set maintenance, especially when there aren't any explicit cues available, could derive from the noisiness of signal processing in the striatum and ventral striatum and the resultant loss of precision in how the direct and indirect basal ganglia pathways operate to determine which response strategy, or set, is recommended to the prefrontal cortex (as I mentioned earlierùsee p. 20ùthe anterior cingulate, dorsolateral, and orbitofrontal cortices are probably all involved in set regulation).

2.2.4.2 Further Evidence about the Role of Dopamine

Support for the importance of dopamine in attentional control and working memory comes from experimental studies involving both animals and humans. First of all, studies with rats, cats, and monkeys have shown that the integrity of dopaminergic projections is critical for the attentional control that underlies the selection of appro-priate responses to stimuli. Disruption of these projections causes spatial neglect, diminished orienting capacity, stereotypic behavior, abnormal search and exploratory behavior, and impaired switching of attentional focus (Clark et al. 1987a). With regard to working memory, Fuster (1980), Goldman-Rakic (1987), and others have found cells in the dorsolateral prefrontal cortex of the rhesus monkey that are specific to a particular visuospatial stimulus-response set and that remain active during a brief delay period between presentation of the stimulus and execution of the response. Not only does ablation of this cortical area destroy the animal's ability to carry out such delayed response tasks (Diamond & Goldman-Rakic 1989), but so does pharmacological blocking of the dopamine receptors in this cortical area (Brozoski et al. 1979). It is notable that although nondemented PD patients are not impaired at simple visuospatial delayed response tasks, demented PD patients are (Freedman & Oscar-Berman 1986). Apparently the reduction of prefrontal cortical dopamine in nondemented patients isn't severe enough to cause significant difficulty with this kind of task (Brown & Marsden 1990).

In humans, evidence about the functions of the dopaminergic projection systems has come not only from research on PD but also from research on schizophrenia. One of the most enduring biological accounts of schizophrenia (Carlsson 1988) maintains that the positive symptoms (e.g. hallucinations and delusions) are due to dopamine overactivity in the basal ganglia and prefrontal cortex, whereas the negative symptoms (e.g., flatten-ing of affect, various cognitive deficits, impaired social functioning, etc.) are due to dopamine underactivity in these brain regions . Prominent among the cognitive distur-bances observed in schizophrenic patients are, first, problems with a variety of tests that measure the ability to select one "train of thought" or behavioral response in the face of multiple competing ones, and second, poor performance on tests that are sensitive to working memory (Cohen & Servan-Schreiber 1992).

Additional evidence for the view that dopamine is important for both attentional control and working memory comes from recent studies that investigated the effects of dopamine agonists and antagonists on the cognitive abilities of normal human subjects. Looking first at attentional control, Clark et al. (1987b) assessed the performance of subjects on a target detection task that involved monitoring a list of words for predetermined items. One group was given a placebo while another group was given droperidol, an antipsychotic drug that temporarily blocks dopamine receptors in the brain. The results showed that the drug decreased the accuracy and reduced the speed of word detection. In addition, when the subjects were not being tested, they were withdrawn and unwilling to attend to external eventsùa state resembling the akinetic mutism that follows damage to the most anterior sector of the cingulate gyrus (see º2.1.1.4, pp. 13-14). The researchers interpreted these findings as suggesting that dopamine blockade disrupts the allocation of attentional resources and reduces responsiveness to the environment.

Turning now to working memory, two studies have demonstrated that a significant improvement in performance on tests of this capacity may occur when normal subjects are given drugs that increase dopamine levels in the brain (Luciana et al. 1992; Kimberg et al. 1994). Moreover, the study by Kimberg et al. (1994) showed that improvement is dependent on the subject's baseline capacity. While subjects with a low baseline capa-city displayed improvement under conditions of dopamine supplementation, subjects with a high baseline capacity worsened under such conditions. The same pattern has been observed in single-cell studies of dopamine metabolism in the dorsolateral prefrontal cortex of rhesus monkeys as the animals performed tasks requiring working memory (Williams et al. 1995). Also, these findings are consistent with the "hyper-dopaminergic" model of the positive symptoms of schizophrenia (Carlsson 1988; Hoffman et al. 1995).

2.2.4.3 Effects of Medication

The preceding discussion of pharmacological studies with normal subjects leads naturally to the question of how levodopa treatment affects the cognitive abilities of PD patients. Of the handful of studies that have addressed this question, perhaps the most interesting is the one conducted by Gotham et al. (1988). These researchers assessed the performance of PD patients on four tests that are known to be sensitive to prefrontal cortical dysfunction: (1) the WCST; (2) two measures of verbal fluency, one with a single category and another with alternation between two categories; (3) a self-ordered pointing task in which 12 cards were presented in sequence, each bearing 12 different abstract figures randomly arranged, and the patient's task was to point to a different figure on each card; and (4) a conditional associative learning task which involved learning to match abstract figures with particular colors. The patients were tested with these materials under two conditionsùfirst while "on" levodopa medication, and then while "off" it.

The results were as follows. Performance on the WCST was significantly impaired regardless of whether the patients were on or off their medication. Performance on the verbal fluency test varied depending on both the version of the test and the patients' medication status. Thus, the patients had normal verbal fluency with a single category in both on and off conditions; however, their verbal fluency with alternating categories was good while on levodopa but poor while off it. For the remaining two testsùself-ordered pointing and conditional associative learningùan unexpected pattern was found. The patients showed largely normal performance while off levodopa, but they were significantly impaired while on it.

These findings indicate that the effect of levodopa treatment on cognitive abilities supported by the prefrontal cortex is quite variable: sometimes it has no positive effect at all, sometimes it has a normalizing effect, and sometimes it has an adverse effect.
Such variablility also emerges when other studies are compared with one another. Thus, while some studies report an improvement in frontal lobe function when PD patients are on levodopa medication (Perry et al. 1985; Mohr et al. 1987; Taylor et al. 1987; Jahanshahi et al. 1992), other studies have not found a positive change (Girotti et al. 1986; Pullman et al. 1990). Gotham et al.'s (1988) discovery that levodopa can have adverse effects is not completely new (see, e.g., Parkes et al. 1972), and it can be explained by considering the neuropathology of PD. As I mentioned in section 2.1.2 (p. 18), dopamine depletion is always more severe in the putamen than in the caudate, ventral stria-

tum, and prefrontal cortex, and in some patients the degree of dopamine depletion in the latter structures is negligible. Given this background, Gotham et al. (1988: 316) suggest that "levodopa doses necessary to remedy the dopamine lack in the putamen may 'over-dose' any area where dopamine regions are relatively intact . . ." Gotham et al. conclude their article by pointing out that studies of cognitive function in PD patients are required which use neuroimaging techniques to initially classify patients according to their levels of dopamine in various brain areas.

2.3 Summary

The basal ganglia are a set of subcortical nuclei that receive massive input from throughout the cortex and project output to the frontal lobes via a number of distinct circuits: the motor circuit, which is involved in bodily movements; the oculomotor circuit, which is involved in eye movements; the dorsolateral prefrontal circuit, which is involved in executive processes; the lateral orbitofrontal circuit, which is involved in impulse control; and the anterior cingulate circuit, which is involved in selective attention (there may also be a ventrolateral prefrontal circuit involved in executive processes). The role of the basal ganglia in these circuits appears to be to identify the most task-relevant features of the current situation and use this information to bias the appropriate prefrontal areas toward the most adaptive decision-making routines. The basal ganglia also contain two dopaminergic projection systems: the nigrostriatal system, which projects to the putamen and caudate; and the mesocortical system, which projects to the ventral striatum, the frontal lobes, and several limbic structures. Dopa-mine serves to increase the signal-to-noise ratio of the inputs to a given cell. This has a "focusing" or "boosting" effect that enables the cell to be influenced by the most perti-nent inputs while filtering out the less important ones, thereby increasing the efficiency of information processing.

PD is a progressive neurodegenerative disease which primarily involves deterior-ation of the dopaminergic projection systems of the basal ganglia. The nigrostriatal system is affected most strongly, causing severe dysfunction in the putamen in 100% of patients and less severe dysfunction in the caudate in around 50% of patients. The dopamine reduction in the putamen and caudate prevents these structures from processing their cortical and thalamic input in the normal fashion, and this in turn leads to "demodulation" of the areas in the frontal lobe with which these structures interact. Since the putamen participates in the motor circuit, all patients develop the motor disorders that are the most salient characteristics of PD; and since the caudate partici-pates in the dorsolateral and orbitofrontal circuits (and perhaps also a ventrolateral circuit), about half of patients develop cognitive disorders as well. The mesocortical dopaminergic projection system is also affected, albeit less severely than the nigro-striatal system. This leads to moderate dopamine depletion in the ventral striatum, which is involved in the anterior cingulate circuit, as well as directly in the frontal lobes. Hence, the degeneration of this dopaminergic system contributes to the cognitive deficits found in PD patients.

Neuropsychologically, around 50% of nondemented PD patients display cognitive deficits that are similar to those exhibited by patients who have suffered lesions to the prefrontal cortex. In a variety of mental domains, including visuospatial processing, memory, and set regulation, they perform well on tasks that provide explicit cues for response selection, but perform poorly on tasks that require them to rely entirely on internal attentional and working memory resources in order to formulate and select the appropriate response. More generally, they appear to depend far more than healthy age-matched subjects on environmental guidance for the control of thought and behavior. As a consequence, they have difficulty concentrating and flexibly shifting among different trains of thought.

Chapter 3: A Framework for Investigating Syntactic Comprehension Deficits in Parkinson's Disease

In order to investigate syntactic comprehension deficits in PD, or for that matter in any clinical population or individual brain-damaged patient, a detailed theory of the normal syntactic comprehension system is necessary, since it provides the essential frame of reference for identifying and specifying disorders. For this reason, the goal of this chapter is to delineate the architecture of the normal syntactic comprehension system at three different levels of analysis: structure, processing, and neurobiology.

Any approach to describing the organization of the normal syntactic comprehension system must begin by adopting one or another grammatical theory. At present, however, this is by no means a simple decision, since the theoretical marketplace is jammed with a panoply of alternatives to choose fromùmore than one can count on both hands, in fact. Although there is no simple procedure for selecting one theory over the others, there are several criteria that can be used to narrow down the search. First of all, one should prefer theories that can provide natural descriptions of grammatical phenomena in not only the language of interestùin my case, Englishùbut also in typologically diverse languages throughout the world. The motivation for this criterion is that the general design of the syntactic comprehension system is presumably compatible with all human languages, and therefore the basic structures that one incorporates into one's model of the system should also be compatible with all human languages. Another criterion is that one should prefer theories that strive for so-called psychological reality. Such theories attempt to accommodate evidence about how grammatical knowledge is acquired in childhood, how it is employed in on-line language processing, and how it is implemented in the brain. Taken together, these criteria are quite restrictive and elim-inate from consideration a number of grammatical theories (e.g., Generalized Phrase Structure

Grammar, Head-Driven Phrase Structure Grammar, Relational Grammar, Word Grammar, and Systemic Functional Grammar); however, they still leave a range of candidate theories in the running (e.g., Government-Binding theory, Lexical-Func-tional Grammar, Cognitive Grammar, and Role and Reference Grammar).

In recent years, the vast majority of researchers who have investigated normal and disordered syntactic comprehension have adopted some version of Government-Binding theory (GB), most likely because of the longstanding hegemony of the Chomskyan paradigm in linguistics. Many of the psycholinguistic and neurolinguistic studies of syntactic comprehension that have been anchored in GB are very impressive. For instance, the differences between three types of empty category posited by the theoryùspecifically, WH-trace, NP-trace, and PROùhave been supported by studies of the sentence processing abilities of normal subjects (Bever & McElree 1988; Fodor 1989; Nicol & Swinney 1989) as well as by studies of the patterns of sparing and loss of ability exhibited by brain-damaged patients (Caplan & Hildebrandt 1988; Grodzinsky 1989; Grodzinsky et al. 1989).

Despite the virtues of the GB-based approach to investigating normal and disordered syntactic comprehension, I have chosen not to take such an approach for the following reasons. With regard to the studies just cited which provide psycholinguistic and neurolinguistic support for the inventory of empty categories posited by GB, it is worth noting that other researchers have argued that these categories are not really necessary to account for the data (Kemmerer 1994a, 1994b; Pickering & Barry 1991; Pickering 1993; Fodor 1995; Sag & Fodor 1995). In addition, although GB is clearly concerned about achieving universal validity, it is nonetheless strongly biased toward the design features of English and other Indo-European languages and hence cannot describe in a natural, economical way the characteristics of head-marking languages, nonconfigurational languages, languages that lack traditional grammatical relations like subject, and a variety of other typological phenomena (Van Valin 1987, 1993). Finally, because GB is highly "syntactocentric," it is unable to account adequately for a variety of phenomena that involve close interactions between syntax, semantics, and pragmaticsùe.g., extrac-tion restrictions, grammatical categories, pronominal anaphora, voice alternations, split intransitivity, etc. (Croft 1991; Givon 1995; Huang 1994; Kuno 1987; Lakoff 1987; Langacker 1987, 1991; Van Valin 1990, 1994; Kuno & Takami 1993).

Instead of grounding my investigation in GB, then, I will use an alternative theory that appears to do a better job of satisfying the criteria mentioned earlierùnamely, Role and Reference Grammar (RRG) (Foley & Van Valin 1984; Van Valin 1993; Van Valin & LaPolla, in press). Unlike GB and many other generative theories, RRG started out by considering not just English but also languages as typologically diverse as Dyirbal (Australia), Tagalog (Philippines), and Lakhota (Native American); moreover, it has continued to draw heavily on a wide range of crosslinguistic data during its development. Besides being committed to achieving genuine universality, RRG has the additional goal of capturing the interaction of syntax, semantics, and pragmatics. The theory views language as a complex form of social behavior that evolved as a solution to the adaptive problem of communicating an open-ended number of detailed propositions about the world (especially the social worldùcf. Dunbar 1993). As a result, it regards syntactic structures and rules as motivated to a large extent by semantic and pragmatic factors. Finally, RRG is concerned about psychological reality. So far, however, very little research along these lines has been conducted. Some efforts have been made to account for certain aspects of language acquisition in terms of RRG (Bowerman 1990; Braine 1992; Rispoli 1991a, 1991b, 1994; Van Valin 1991, 1994). But no work has been done to date on developing a processing model for RRG, and only one attempt has been made to characterize within RRG various types of neurolinguistic data, such as the selective deficits in syntactic comprehension exhibited by brain-damaged patients (Kemmerer 1994a). Still, the emphasis in RRG on discovering what properties of grammatical systems are universal and what properties are language-specific may give it an advantage over alternative theories with respect to the goal of achieving psychological reality, since universal validity is a natural requirement for psychological reality. Indeed, this is the main reason why I have chosen to work within this particular theory.

As I mentioned earlier, the purpose of this chapter is to characterize the normal syntactic comprehension system at three different levels of analysis: structure, processing, and neurobiology.[1] Each of these levels of analysis is addressed in a separate section of the chapter. Thus, in section 3.1 I discuss the nature of the computational problem that the syntactic comprehension system must solve. More precisely, I describe the kind of syntactic and semantic structures that occur in various linguistic constructions, as well as the way in which the syntactic structure is linked to the semantic structure. In section 3.2 I shift to the second level, which is concerned with the processing operations and resources that are dedicated to assembling syntactic and semantic structures and linking the former to the latter. Finally, in section 3.3 I move to the third level, which focuses on the brain areas in which the syntactic comprehension system is physically realized.

3.1 Structure

In this first section, I review the RRG approach to dealing with the two fundamental aspects of grammatical structure: hierarchical structure and relational structure. Hierarchical structure involves the part-whole organization of phrases, clauses, and sentences, whereas relational structure involves the syntactic, semantic, and pragmatic relations that obtain between syntactic elements. My review will focus on those aspects of the theory

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[1] These three levels correspond to the levels of computation, algorithm, and implementation that were originally proposed by Marr (1982) and that have been adopted by many cognitive neuroscientists since then (Kosslyn & Koenig 1992). See Kosslyn (1994) for an especially useful discussion and application of a revised version of Marr's metatheory.

that are most relevant to analyzing the types of English constructions that I will be concerned with in the rest of the thesis. The information presented below is drawn mainly from Van Valin (1993); further details can be found there as well as in Foley and Van Valin (1984) and Van Valin and LaPolla (in press).

3.1.1 Architecture of RRG

3.1.1.1 Hierarchical Structure

Hierarchical structure in RRG is not based on the X-bar schema familiar to most syntacticians but is instead more semantically based. The general organization of simple sentences, which is called the Layered Structure of the Clause (LSC), is shown below in Figure 7.

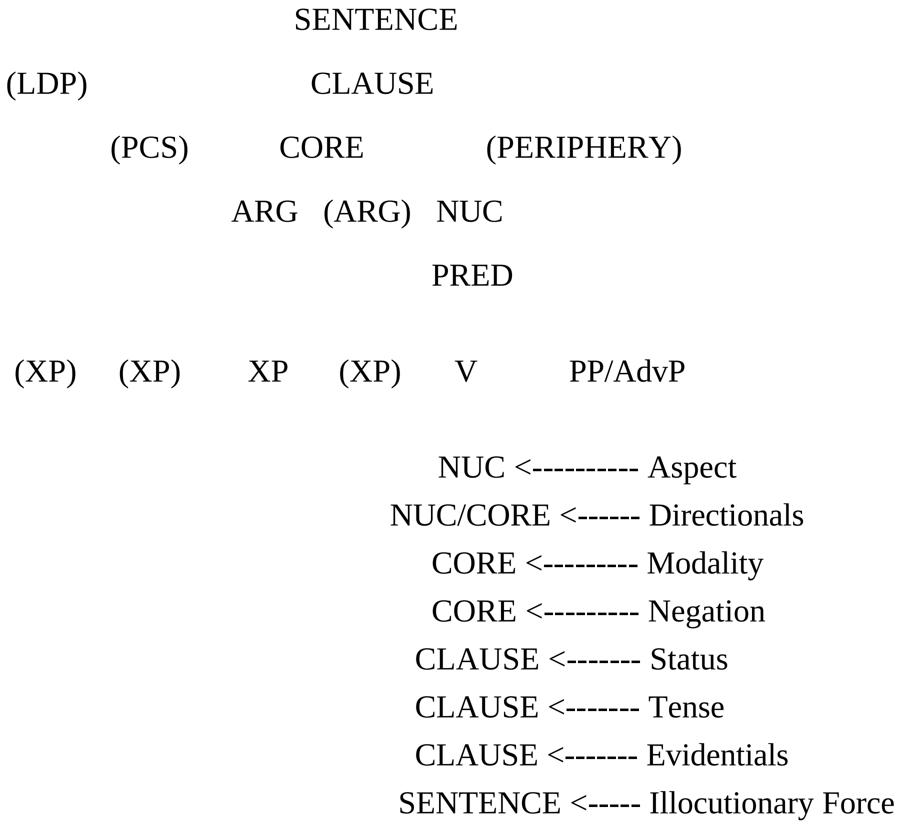

Figure 7: LSC with constituent and operator projections

Consider first the top half of the diagram. The most basic distinction expressed here is between core and periphery. A core consists of a nucleus (NUC) for the predicate, which is usually a verb, and argument positions (ARG) for the arguments of the predi-cate. Core arguments are typically those which are specified in the semantic represen-tation of the predicate, and they may be syntactically realized as either direct or oblique: a direct core argument appears without an adposition (e.g., *Sam dropped the bag*), whereas an oblique core argument appears with an adposition (e.g., *Sam put the ball in the bag*). An optional periphery is attached to the core; this is for adjuncts, i.e., expres-sions that are not specified in the semantic representation of the verb and are not sensi-tive to the major syntactic rules of the language, e.g., locative and temporal "setting" expressions such as *at the park* or *last night.*

Three points about the notions of core and periphery deserve to be mentioned before going on to describe the rest of the scheme. First, these notions are universally valid because every language distinguishes, on the one hand, between a predicate and its arguments and, on the other hand, between elements which are arguments of the predicate and those which are not. Second, the elements making up the core and periphery may occur in any linear order whatsoever, since the languages of the world run from one extreme of fixed word order (e.g., English) to the opposite extreme of nonconfigurationality (e.g., Warlpiri [Australian]). Third, the basic syntactic units are strongly motivated by basic semantic units, as shown below:

Semantic Unit(s)	Syntactic Unit
Predicate	Nucleus
Argument in semantic representation of predicate	Core argument
Predicate + Arguments	Core
Non-arguments	Periphery

It is important to recognize, however, that the units in the LSC are in fact syntactic in nature, since they do not always correspond directly to their semantic analogues. For instance, although NPs are normally associated both syntactically and semantically with a single core, there are complex sentences in which an NP is syntactically associated with one core but semantically associated with a different core (e.g., in *Bill seems to like chocolate*, the NP *Bill* is a syntactic argument of *seem* but a semantic argument of *like*). Thus, the notion of core argument is essentially syntactic.

Returning now to the top half of Figure 7, the units that dominate the coreùnamely, clause and sentenceùare universal, but the units that branch off from the clause and sentence nodesùnamely, PCS and LDPùare not. PCS stands for pre-core slot, which is a special position for WH-phrases and topicalized phrases (e.g., *What did you put on the table? This book you put on the table*). Arguments that are specified in the semantic representation of a predicate can appear in the PCS. LDP stands for left-detached position, which is reserved for phrases that are set off from the rest of the sentence by a pause or intonation break (e.g., *After the picnic, we went to the zoo*). Finally, the XPs in the figure denote any type of phrase that can appear below the immediately dominant unit; generally they are noun phrases (NPs). An example of an English sentence containing all the elements of the top half of Figure 7 is shown below in Figure 8.

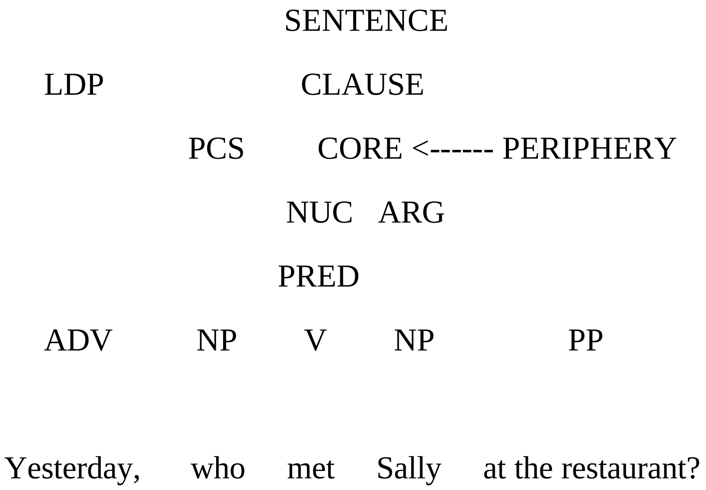

Figure 8: Constituent structure of English sentence

The bottom half of Figure 7 expresses a variety of categories which are collectively referred to as operators. They are qualitatively different from predicates and arguments insofar as they function as modifiers of the various hierarchical units of sentences. Languages code operators with auxiliary verbs, verbal affixes, and verbal clitics. As shown in the figure, each of the major layers of a simple sentenceùnucleus, core, and clauseùis modified by one or more operators. The verb is the "anchoring point" for operators, which makes sense, given that they are traditionally considered verbal categories. Operators are not relevant to the central issues of this thesis, so I will not describe them in detail here.

According to RRG, complex sentences consist of combinations of clauses, cores, and nuclei. The normal linkage pattern is for units at the same level to be combined, i.e., clauses with clauses, cores with cores, and nuclei with nuclei. Each of these combinations may be accomplished in three different ways: coordination, where the syntactic units are simply added together and neither unit depends on the other, either structurally or for certain operators; subordination, where one syntactic unit is structurally dependent on the other; and cosubordination, where one syntactic unit depends on the other for certain operators but is not embedded in it. Since there are three levels of combination and three types of combin-ation for each level, it is theoretically possible for a language to have nine distinct patterns for complex sentences: clausal coordination, subordination, and cosubordination; core coordination, subordination, and cosubordination; and nuclear coordination, subordination, and cosubordination. Some languages have all nine patterns (e.g., Korean), but most do not (e.g., English has seven, and Nootka [Native American] has six) (Van Valin & LaPolla, in press). It is important to note that each of these abstract patterns can be instantiated in a language with several different grammatical constructions. For instance, in English both complement clauses (e.g., *Harry persuaded Sally* *that he was sincere*) and adverbial clauses (e.g., *Harry visited Sally* *after he finished work*) are cases of clausal subordination.

Many syntacticians have observed that the hierarchical structure of NPs is similar to the hierarchical structure of clauses. Within RRG the basic organization of NPs is expressed as in Figure 9:

NP
(LDP) CORE$_N$ <--------------------(PERIPHERY)
NUC$_N$ (ARG) (ARG)
REF

(NP) N (PP) (PP) (PP/AdvP)

NUC$_N$ <------ Aspect
NUC$_N$ <------ Quality
CORE$_N$ <----- Quantity
CORE$_N$ <----- Negation

NP <--------- Locality

Figure 9: Constituent and Operator Projections of NP

As before, consider first the top half of the diagram. Since nouns have a referential function, they are dominated by the node REF; this is analogous to the PRED node that dominates verbs and that indicates their predicating function. In addition, nouns are similar to verbs in that both can take arguments and hence can serve as the nucleus of a core (e.g., *the destruction of the city by the enemy*). Two further commonalities between NPs and clauses are, first, that both have a periphery in which adjunct "setting" expressions can appear (e.g., *the concert in Central Park*) and, second, that both have a left-detached position in which optional material can appear (e.g., *Mark's book*). Yet another feature that makes NPs similar to clauses is that, as the bottom half of Figure 9 shows, NPs are modified by a distinctive set of operators. However, since these operators are not relevant to the issues that I will be dealing with later, I will not discuss them in any detail. Finally, it is worth noting that complex NPs can be formed by combining syntactic units at all three levels of NP structureùNP, core$_N$, and nucleus$_N$ùand these combinations can be of all three of the types described earlierùcoordination, subordination, and cosubordination.

3.1.1.2 Semantic Relations

From the perspective of RRG, three different kinds of relational structure are important for grammatical phenomena: semantic relations, syntactic relations, and pragmatic relations. I will only be concerned with the first two, however, since the third is not central to the major topics of this thesis. Semantic relations are the focus of this subsection, and syntactic relations are the focus of the next.

The RRG approach to semantic relations is based on the following four-way classification of verbs originally proposed by Vendler (1967):[2]

States: *be shattered, be cool, be dead, be tall, be sick, know, have, believe, love*
Activities: *march, walk, roll* (intransitive versions); *swim, think, rain, read, eat*
Achievements: *shatter, cool* (intransitive versions); *die, learn, receive, realize*
Accomplishments: *shatter, cool* (transitive versions); *kill, teach, give, convince*

Although Vendler arrived at these fundamental distinctions by investigating only English verbs, subsequent research has shown that they are crosslinguistically valid; in fact, some languages code the different verb classes with explicit morphological markers (e.g., Tepehua [Totonacan, Mexico], Qiang [Tibeto-Berman], and Russian). Dowty (1979) developed a set of syntactic and semantic tests for determining which class a verb belongs to; these tests are discussed in detail by Van Valin (1993), so I will not review them here. Dowty (1979) also proposed a formal representational system for expressing the logical structure (LS) of each verb class, and this system is adopted by RRG:

Verb Class	Logical Structure (LS)
State	**predicate** (x) or (x,y)
Activity (+/- agentive)	**do** (x, [**predicate** (x) or (x,y)])
Achievement	BECOME **predicate** (x) or (x,y)
Accomplishment	å CAUSE #, where å is normally an activity predicate and # an achievement predicate

In this scheme, states and activities are both considered primitive, but activities contain the generalized activity predicate **do**. In addition, activities vary as to whether the action is controlled by the entity or not; when the action is necessarily agentive (rather than

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[2] What follows is the "old" version of the RRG approach to semantic relations (Van Valin 1993); a more refined version is presented in Van Valin and LaPolla (in press). I have chosen to stick with the original version for the simple reason that it is adequate for the purposes of this thesis.

agentivity merely being an implicature), this is signaled by the operator DO, which has scope over the entire LS. Achievements are derived from states and are semantically inchoative, so they are represented as a state modified by a BECOME operator. Finally, accomplishments involve causation, typically between an activity and an achievement, so they are represented with a CAUSE operator linking two variables. Examples of some English verbs with their LS are shown below:

States:

a. *The watch is broken.* **broken** (the watch)
b. *The soup is cool.* **cool** (the soup)
c. *Sam saw the painting.* **see** (Sam, the painting)

Activities:

a. *The ball rolled.* **do** (the ball, [**roll** (the ball)])
b. *The door squeaks.* **do** (the door, [**squeak** (the door)])
c. *The man read the magazine.* DO (the man, [**do** (the man, [**read** (the man, the magazine)])])

Achievements:

a. *The watch broke.* BECOME **broken** (the watch)
b. *The soup cooled.* BECOME **cool** (the soup)
c. *Sam noticed the painting.* BECOME **see** (Sam, the painting)

Accomplishments:

a. *The baby broke the watch (accidentally).* [**do** (the baby, °)] CAUSE [BECOME **broken** (the watch)]
b. *The breeze cooled the soup.* [**do** (the breeze, [**blow-on** (the breeze, the soup)])] CAUSE [BECOME **cool** (the soup)]

c. *Mary showed the painting to Sam.* [DO (Mary, [**do** (Mary, °)])] CAUSE [BECOME **see** (Sam, the painting)]

Semantic relations can be thought of as the roles that arguments play in the LSs of verbsùe.g., in the LS "**see** (Sam, the painting)," Sam plays the role of perceiver and the painting plays the role of target of visual perception. Since states and activities are the two primitive verb classes, all types of semantic relations are defined with reference to argument positions in the LSs of these verb classes. The following continuum of semantic relations, which is by no means exhaustive, is from Van Valin and LaPolla (in press):

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Single arg of DO	1st arg of **do** (x, ...	1st arg of **pred** (x,y)	2nd arg of **pred** (x,y)	Single arg of state **pred** (x)
agent	mover	location	theme	patient
	effector	domain	entity	
	emitter	perceiver	stimulus	
	user	cognizer	content	
	consumer	wanter	desire	
	creator	judger	judgement	
	speaker	possessor	possessed	
	observer	experiencer	sensation	
	performer	emoter	target	
		attributant	attribute	
			implement	
			consumed	
			creation	
			spoken	
			locus	
			performance	

Three semantic relations which are not listed above but which are important for many grammatical phenomena are recipient, goal, and source. They are defined as follows:

recipient: first argument in LS configuration "... BECOME **have** (x,y)"
goal: first argument in LS configuration "... BECOME **be-located-at** (x,y)"
source: first argument in LS configuration "... BECOME NOT **have**/**be-located-at** (x,y)"

In addition to these specific semantic relations, RRG also posits two broader semantic relationsùnamely, actor and undergoerùwhich are generalizations across classes of argument positions in LSs. These semantic relations are refered to as macroroles, since each of them subsumes a number of specific semantic relations. For instance, the actor macrorole subsumes such narrower relations as agent and mover, and the undergoer macrorole subsumes such narrower relations as patient and theme. In short, the more agent-like an argument is, the more it qualifies as an actor, and the more patient-like an argument is, the more it qualifies as an undergoer. This is expressed in the actor-undergoer hierarchy shown below:

ACTOR UNDERGOER

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Single arg of DO	1st arg of **do** (x, ...	1st arg of **pred** (x,y)	2nd arg of **pred** (x,y)	Single arg of state **pred** (x)

['----->' = increasing markedness of realization of argument as macrorole]

The motivation for positing these two macroroles is that each one captures a grouping of specific semantic relations which are treated alike for grammatical purposesùe.g., actors are typically realized as subjects of transitive clauses while undergoers are typically realized as objects of transitive clauses; undergoers can be realized as subjects in passive constructions; etc. Macroroles are important for determining the syntactic transitivity of verbs, i.e., the number of direct core arguments that a verb takes. Verbs that have two macroroles are transitive and hence take two direct core arguments (e.g. *toss*, *push*). Verbs that have one macrorole are intransitive and hence take only one direct core argument (e.g., *run, be sick*). For these verbs, the nature of the macrorole is based on whether or not the verb has an activity predicate in its LS: if it does, the macrorole is actor (e.g., *run*); if it doesn't, the macrorole is undergoer (e.g., *be sick*). Finally, verbs that have no macrorole at all are atransitive (e.g., *rain, seem*). Since these verbs are exceptional, they are marked in the lexicon with the feature [MR0], which means zero macrorole. This feature has significant gramma-tical consequences, since it implies that none of the arguments in the LS of the verb can be syntactically realized as a direct core argument. Because English requires that all sentences contain a subject, atransitive verbs occur with the "dummy" subject *it* (e.g., *It is raining, It seems that Jeff is happy*). Alternatively, sentences with *seem* or *appear* can be structured in such a way that an argument which is semantically associated with the verb in the dependent core is syntactically realized as subject of the verb in the matrix core (e.g., *Jeff seems/appears to be happy*).

3.1.1.3 Syntactic Relations

With regard to the second major kind of relational structureùi.e., syntactic relationsùRRG departs from traditional grammatical theory. Up to now I have referred to the common notion of syntactic subject, but this has been solely for expository purposes. RRG rejects the universality of subjects and replaces this notion with the notion of pivot. In all languages there are restrictions on which arguments can be involved in particular constructionsùe.g., verb agreement, reflexivization, relativization, control, raising, etc. The argument that plays a privileged role in a given construction is called the pivot of the construction. In some languages the role that the pivot plays is defined semantically in terms of macrorolesùe.g., in Acehnese (Austronesian, Sumatra) the omitted argu-ment in a control construction is always an actor, and the argument associated with the predicate in a resultative construction is always an undergoer. In most languages, however, the role that the pivot plays in a particular construction is defined in purely syntactic terms; in other words, the distinction between actor and undergoer is neutral-ized for syntactic purposes.

Consider, for instance, the English raising sentences below:

a. Susan$_i$ seems ____$_i$ to be dancing.
b. Susan$_i$ seems ____$_i$ to be happy.
c. Susan$_i$ seems ____$_i$ to be winning the race.
d. *Susan$_i$ seems the man to have pushed ____$_i$.
e. Susan$_i$ seems ____$_i$ to have been pushed by the man.

In purely syntactic terms, the initial NP in the matrix core of all these sentences is coreferential with a missing argument in the embedded core, as notated by coindexation. There is a restriction, however, on what the missing argument can be. This restriction cannot be stated semantically in terms of macroroles, because in (a) and (c) the missing argument is an actor whereas in (b) and (e) it is an undergoer. The restriction can, however, be stated syntactically in terms of the positions of arguments in the embedded core, as the contrast between (d) and (e) indicates: in both sentences the missing argument is an undergoer, but in (d) the "gap" occurs in core-final position whereas in (e) it occurs in core-initial position. Thus, the pivot relationship for the English raising construction can be described as follows: the initial NP of the matrix core must correspond to the initial position of the embedded core.

It is worth noting that most languages have the same pivot for most constructions, and for this reason languages can be classified as either syntactically accusative (e.g., English) or syntactically ergative (e.g., Dyirbal): in syntactically accusative languages the default choice for pivot of a transitive clause is the actor, but in syntactically ergative languages the default choice for pivot of a transitive clause is the undergoer. These defaults can be overridden in certain marked constructionsùe.g., in syntactically accusative languages the passive construction selects the undergoer as pivot, and this is signalled by special verb morphology; similarly, in syntactically ergative languages the antipassive construction selects the actor as pivot, and this too is signaled by special verb morphology.

A final point about syntactic relations is that grammatical phenomena that have traditionally been accounted for with reference to the notions of direct and indirect object are accounted for in RRG in terms of the notion of direct core argument. Since this point is not crucial for the issues that I will concentrate on later, I will not elaborate it further.

3.1.1.4 Linking

Before turning to the RRG approach to analyzing specific English construction types, there is one more feature of the general architecture of RRG that I must mentionùnamely, the theory of linking between syntax and semantics. This theory is shown below in Figure 10. According to this scheme, linking can be accomplished in two directions: from syntax to semantics, and from semantics to syntax. The former direction pertains to language comprehension and the latter to language production. Naturally, because the focus of this thesis is on comprehension, I will only be concerned with linking from syntax to semantics. This type of linking takes place in two stages: first, syntactic relations are linked to macroroles according to the pivot hierarchy; and second, macroroles are linked to argument positions in the LSs of specific verb classes according to the actor-undergoer hierarchy. Linking in simple as well as complex sentences is governed by a general principle called the Completeness Constraint, which states that every argument position in a verb's LS must be linked to an NP in the sen-tence containing the verb, and every NP in a sentence must be linked to an argument position in an LS.

SYNTACTIC RELATIONS: Pivot Direct Core Arguments Oblique Core Arguments

Pivot Hierarchy:
Actor > Undergoer (e.g., English)
Undergoer > Actor (e.g., Dyirbal)

SEMANTIC MACROROLES: Actor Undergoer

ACTOR UNDERGOER

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Single arg of DO	1st arg of **do** (x, ...)	1st arg of **pred** (x,y)	2nd arg of **pred** (x,y)	Single arg of state **pred** (x)

[increasing markedness of realization of argument as macrorole]

Transitivity = No. of Macroroles
Transitive = 2
Intransitive = 1
Atransitive = 0

Argument Positions in **LOGICAL STRUCTURE**

Verb Class	Logical Structure
State	**predicate** (x) or (x,y)
Activity (+/- agentive)	**do** (x, [**predicate** (x) or (x,y)])
Achievement	BECOME **predicate** (x) or (x,y)
Accomplishment	å CAUSE #, where å is normally an activity predicate and # an achievement predicate

Figure 10: System for Linking Syntactic and Semantic Representations

3.1.2 RRG Analyses of English Construction Types

The English construction types that I will be most concerned with in this thesis are shown in (1):

(1) a. transitive active: *Harry saw Sally.*
    b. passive:
        i. foregrounding: *Sally was seen.*
        ii. backgrounding: *Sally was seen by Harry.*
    c. relative clause:[3]
        i. subject-subject relative: *The man that saw Sally knows me.*
        ii. subject-object relative: *The man that Sally saw knows me.*
        iii. object-subject relative: *I know the man that saw Sally.*
        iv. object-object relative: *I know the man that Sally saw.*
    d. cleft:

---

[3] Since RRG does not posit syntactic relations equivalent to the traditional notions of subject and object, the names for these constructionsù"subject-subject relative," "subject-object relative," etc.ùare technically inappropriate. I continue to use these names, however, because they are so familiar and because there aren't any replacement names in RRG. The same holds for the names of the cleft constructionsù"subject cleft" and "object cleft"ùand the raising constructionsù"subject-to-subject raising" and "object-to-subject raising."

        i. subject cleft: *It was the man that saw Sally*.
        ii. object cleft: *It was the man that Sally saw*.
    e. raising-to-subject:
        i. subject-to-subject raising:
            a. canonical: *It seems to Harry that Sally is tall.*
            b. noncanonical: *Sally seems to Harry to be tall.*
        ii. object-to-subject raising:
            a. canonical: *It's easy for Harry to see Sally.*
            b. noncanonical: *Sally is easy for Harry to see.*
    f. undergoer control:[4]
        i. active matrix core: *Harry persuaded Sally to be nice.*
        ii. passive matrix core: *Sally was persuaded by Harry to be nice.*

    g. intransitive:
        i. actor-intransitive: *Harry left.*
        ii. undergoer-intransitive: *Harry drowned.*

3.1.2.1 Transitive Active

Consider first the transitive active construction exemplified in (1a). This construction is quite straightforward and is represented below in Figure 11:[5]

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[4] Although it would seem natural to include the actor control construction as wellùe.g., *Harry promised Sally to be nice*ùI will not deal with this construction because there is only one verbùnamely, *promise*ùwhich occurs very frequently in this construction, and even when this verb is used, a *that* complement clause (e.g., *Harry promised Sally that he would be nice*) seems to be preferable to an infinitival comple-ment clause.

[5] In this and the following figures, I will suppress the nodes inside NPs (cf. Figure 3) unless there is a complex NP which requires that they be expressed. This is strictly to avoid needlessly cluttered

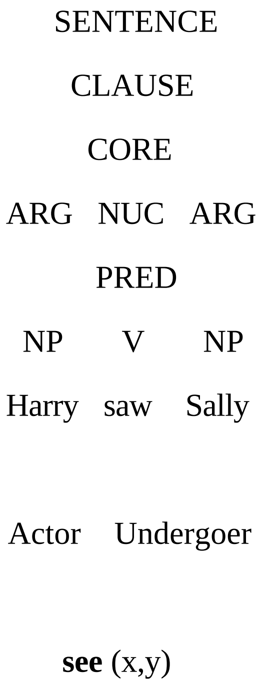


Figure 11: Representation of Transitive Active Construction

The clause consists of a single core, which in turn contains a nucleus for the verb and argument positions for the pivot NP *Harry* and for the direct core NP *Sally*. The predicate **see** has a state LS with two argument positions, one for a perceiver and another for a perceptual target. The linking between the NPs in the constituent structure and the argument positions in the LS is mediated by macroroles and takes place in two steps. First, NPs are linked to macroroles, and since the verb is in the active voice this linking follows the default pattern: the pivot NP *Harry* is linked to the actor macrorole, and the direct core NP *Sally* is linked to the undergoer macrorole. Second, macroroles are linked to argument positions in the LS of the predicate according to the actor-undergoer hierarchy: the actor macrorole is linked to the first argument position, and the undergoer macrorole is linked to the second argument position. Thus, the transitive active construction has a perfectly canonical linking pattern.

3.1.2.2 Passive

By contrast, the distinguishing feature of passive constructions in general is that they involve a noncanonical linking pattern which is signaled by special morphological markers. Two different types of passive construction are exemplified in (1b); since the construction in (b-ii) is identical to the one in (b-i) except for the addition of a *by*-phrase, only (b-ii) is illustrated below in Figure 12:

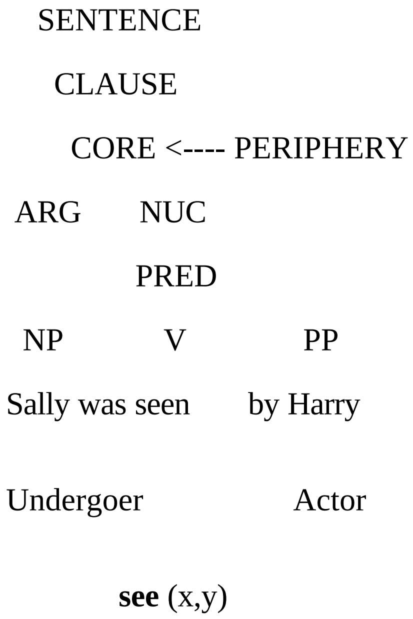


Figure 12: Representation of Backgrounding Passive Construction

The clause consists of a single core, which in turn contains a nucleus for the verb and an argument position for the pivot NP *Sally*. In addition, the core has an attached periphery for the PP *by Harry*. As in the transitive active sentence above, the predicate **see** contains a perceiver argument and a perceptual target argument, and the linking between NPs and argument positions in the LS is mediated by macroroles. Unlike in the transitive active construction, however, here the first stage of the linking processùi.e., between

NPs and macrorolesùdoes not follow the default pattern, since the verb is in the passive voice. The passive morphology signals explicitly that the pivot NP *Sally* is not linked to the actor macrorole but is instead linked to the undergoer macrorole. Furthermore, the preposition *by* in the periphery signals explicitly that the oblique NP *Harry* is linked to the actor macrorole. The second stage of the linking processùi.e., between macroroles and argument positions in the LSùis the same as in the transitive active sentence: the actor macrorole is linked to the first argument position, and the undergoer macrorole is linked to the second argument position. The construction in (b-i) is unique in that it lacks a *by*-phrase; it is called a foregrounding passive because its sole function is to promote the undergoer to pivot status. On the other hand, the distinctive feature of the construction in (b-ii) is that it includes a *by*-phrase; it is called a back-grounding passive because, in addition to promoting the undergoer to pivot status, it demotes the actor to oblique status.

3.1.2.3 Relative Clauses and Clefts

Consider now the relative clause and cleft constructions exemplified in (1c) and (1d). RRG treats relatives and clefts as being similar in some respects and different in other respects. The major difference is pragmatic in nature. On the one hand, cleft constructions involve marked narrow focus in the following sense. Narrow focus typically falls on the final argument of a core, so that in the sentence *The man saw Sally* narrow focus falls on *Sally* by default. In order to give narrow focus to *the man*, it is necessary for this NP to be realized as a core-final argument. This in turn requires that the rest of the proposition be realized in a peripheral clause and that the pivot of the matrix core be filled in by the dummy NP *it*, yielding the subject cleft sentence *It was the man that saw Sally*. By using this grammatical construction, the speaker presupposes that someone saw Sally and asserts that this individual was the man. On the other hand, the speaker of a sentence with a relative clause like *The man that saw Sally knows me* presumably assumes that the simple NP *the man* does not provide the addressee with sufficient information to identify the man in question, so the restricting clause *that saw Sally* is added to indicate precisely which man is being referred to. Thus, with regard to pragmatics, the speaker presupposes that the man saw Sally and asserts that this man knows me.

Relative clause and cleft constructions are similar in that they contain the same kind of complex NP. This can easily be seen in the sentences in (1c) and (1d), which are reproduced below for convenience:

relative clause:
  i. subject-subject relative: *[The man that saw Sally] knows me.*
  ii. subject-object relative: *[The man that Sally saw] knows me.*
  iii. object-subject relative: *I know [the man that saw Sally.]*
  iv. object-object relative: *I know [the man that Sally saw.]*

cleft:
  i. subject cleft: *It was [the man that saw Sally.]*
  ii. object cleft: *It was [the man that Sally saw.]*

As the bracketings make clear, the subject-subject relative in (1c-i), object-subject relative in (1c-iii) and subject cleft in (1d-i) have in common the complex NP *the man that saw Sally,* and the subject-object relative in (1c-ii), object-object relative in (1c-iv), and object cleft in (1d-ii) have in common the complex NP *the man that Sally saw.* The constituent structures and LSs of these two complex NPs are shown below in Figure 13:

NP NP

CORE$_N$ <-----------PERIPHERY CORE$_N$ <-----------PERIPHERY

NUC$_N$ CMPL---> CLAUSE NUC$_N$ CMPL---> CLAUSE

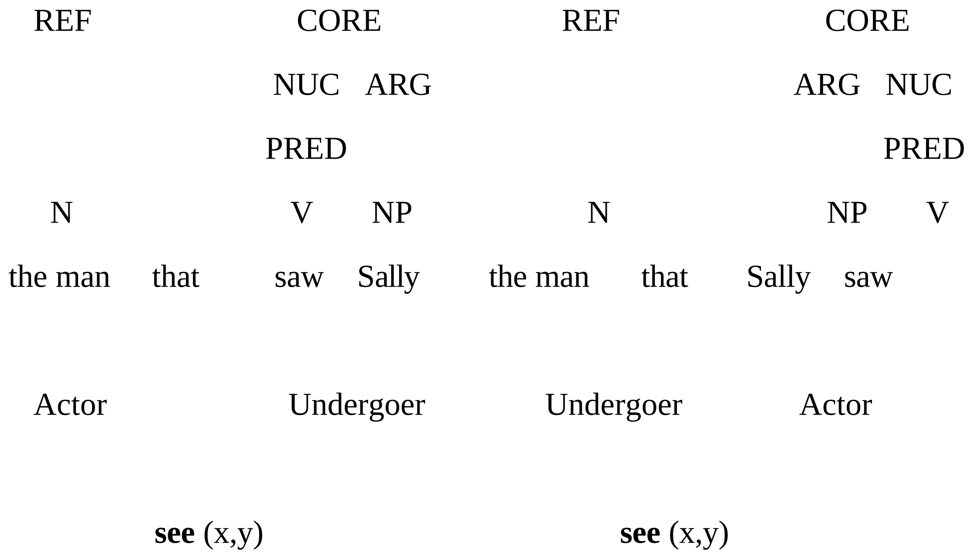


Figure 13: Representation of Complex NPs of Relative Clause and Cleft Constructions

Each of the trees in Figure 13 has the following two parts: first, the head NP *the man*, and second, a periphery which is attached to the CORE$_N$ of the head NP and which contains an embedded clause that modifies it. The embedded clause itself consists of a core with a nucleus and a single argument position. As before, the LS of **see** has two argument positions, and linking is mediated by macroroles. Within the embedded clause, linking follows the typical pattern, since the verb is in the active voice: in the left-hand figure the core-final NP is linked to the undergoer macrorole, which in turn is linked to the second argument position in the LS; and in the right-hand figure the core-initial NP is linked to the actor macrorole, which in turn is linked to the first argument position in the LS. In each complex NP, this leaves the head NP *the man* unlinked to an argument position in the LS, and an argument position in the LS unlinked to an NP. In order to prevent a violation of the Completeness Constraint, these two elements are linked together. Thus, in the left-hand figure the head NP is linked to the actor macro-role, which in turn is linked to the first argument position in the LS; and in the right-hand figure the head NP is linked to the undergoer macrorole, which in turn is linked to the second argument position in the LS. In the left-hand complex NP the ordering of arguments in relation to the verb is like the ordering in the transitive active constructionùi.e., actor - predicate - undergoerùand for this reason the complex NP has a canonical linking pattern. By contrast, in the right-hand complex NP the ordering of arguments in relation to the verb is atypicalùi.e., undergoer - actor - predicateùand for this reason the complex NP has a noncanonical linking pattern.

Before moving on to the next set of constructions, a few remarks are in order about the larger syntactic contexts in which these two types of complex NP can occur. In the relative clause and cleft constructions exemplified in (1c) and (1d), the complex NP is a constituent of the matrix clause: in the subject-subject relative (1c-i) and subject-object relative (1c-ii), the head of the complex NP functions as the pivot of the matrix clause; and in the object-subject relative (1c-iii), object-object relative (1c-iv), and both clefts, the head of the complex NP functions as the direct core argument of the matrix clause. Thus, in all of these constructions the head of the complex NP is linked not only to an argument position in the LS of the predicate in the peripheral clause, but also to an argument position in the LS of the predicate in the matrix clause. The following examples should make this clear: in the sentence *The man that saw Sally knows me,* the NP *the man* is actor of both *saw* and *knows;* in the sentence *The man that Sally saw knows me,* the NP *the man* is undergoer of *saw* but actor of *knows;* in the sentence *I know the man that saw Sally,* the NP *the man* is undergoer of *know* and actor of *saw;* finally, in the sentence *I know the man that Sally saw,* the NP *the man* is undergoer of both *know* and *saw.*

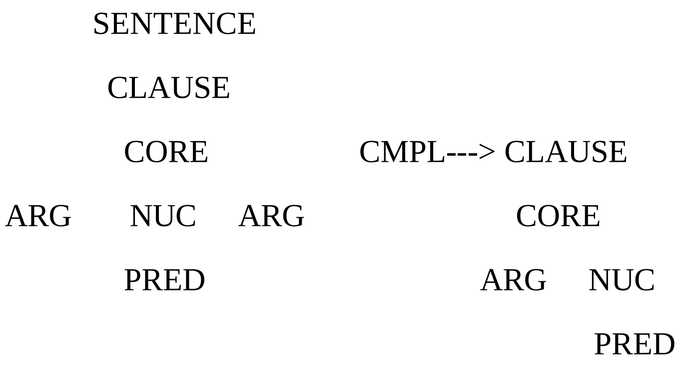
3.1.2.4 Raising-to-Subject

I shift now to the raising-to-subject constructions in (1e); the representative sentences are reproduced below for ease of reference:

raising-to-subject:

- i. subject-to-subject raising (SS):
  - a. canonical: *It seems to Harry that Sally is tall.*
  - b. noncanonical: *Sally seems to Harry to be tall.*
- ii. object-to-subject raising (OS):
  - a. canonical: *It's easy for Harry to see Sally.*
  - b. noncanonical: *Sally is easy for Harry to see.*

I will describe the structure and linking pattern of each of these constructions individually, starting with the canonical SS construction, which is shown in Figure 14. The matrix clause has two components: first, it has a core which consists of a nucleus and two argument positions; and second, it has an embedded clause which consists of a core with a nucleus and a single argument position. As I mentioned briefly in the discussion of semantic relations in section 3.1.1.2, the predicate **seem** is marked with the feature [0MR]. This feature indicates that neither of the predicate's two semantic argumentsùan experiencer and a propositionùhas macrorole status, which in turn indicates that neither of these arguments can be syntactically realized as pivot (cf. **Harry seems that Sally is nice*, **That Sally is nice seems to Harry*). Thus, the pivot position in the canonical SS construction is occupied by the dummy NP *it*. The predicate's experiencer argument is then realized as the oblique core NP *Harry* (object of the preposition *to*), and the predicate's proposition argument is realized as an embedded clause. Because



NP V PP NP V

It seems to Harry that Sally is nice

Undergoer

seem (x, [**be nice** (y)]) [0MR]

Figure 14: Representation of Canonical SS Raising Construction

seem does not have any macroroles, the linking between the oblique core NP and the experiencer argument is unmediated. However, the proposition **be nice** (y), which fills the proposition slot in the LS of **seem**, does allow its single argument to have macrorole status. Hence the linking between the NP in the embedded clause and the single argument position in the predicate **be nice** is accomplished in a straightforward manner via the undergoer macrorole.

The noncanonical SS construction is represented in Figure 15. The clause contains two coresùa matrix core which itself consists of a nucleus and two argument positions, and an embedded core which has just a nucleus. As with the canonical SS raising construction, the fact that **seem** carries the feature [0MR] means that neither of its two semantic arguments can be realized as pivot. Thus, as before, the experiencer argument is realized as an oblique core NP (object of *to*), and the linking is not mediated by a

SENTENCE

CLAUSE

CORE CMPL---> CORE

ARG NUC ARG NUC

PRED PRED

NP V PP V

Sally seems to Harry to be nice

Undergoer

seem (x, [**be nice** (y)]) [0MR]

Figure 15: Representation of Noncanonical SS Raising Construction

macrorole. The difference between the canonical and noncanonical constructions lies in how the pivot is treated. Here the position is not filled by the dummy NP *it* but rather by an argument of the predicate within the proposition slot of **seem**. If this predicate contains only a single argument, as with **be nice**, then this argument is realized as the pivot; but if the predicate contains two or more arguments, the one that is realized as the pivot is the one that would normally be realized in the preverbal position of the embedded core (cf. *Karen*$_i$ *seems* ____$_i$ *to like Jeff* vs. **Karen*$_i$ *seems Jeff to like* ____$_i$). In the sentence represented in Figure 15, the linking between the pivot NP *Sally* and the argument of **be nice** is mediated by the undergoer macrorole, since this predicate is not marked by the feature [0MR]. In summary, the distinguishing characteristic of the non-canonical SS raising construction is that a semantic argument that would normally be realized as an NP in the initial position of the embedded core is instead realized as the pivot NP of the matrix core; the argument metaphorically "raises up" to this higher syntactic position, and as a result the embedded core lacks an NP position for it.

Now consider the canonical and noncanonical OS constructions. The canonical construction is shown in Figure 16:

SENTENCE

CLAUSE

CORE CMPL-----> CORE

ARG NUC ARG NUC ARG

PRED PRED

NP V NP V NP

It is easy for Harry to see Sally

Actor Undergoer

be easy (**see** [x,y])

Figure 16: Representation of Canonical OS Raising Construction

The clause in this construction has two coresùa matrix core with a nucleus and one argument position, and an embedded core with a nucleus and two argument positions. The predicate **be easy** takes a proposition argument which is instantiated here by **see** (x,y). Since **be easy** is not marked with the feature [0MR], it is possible for the proposition to be realized as a complex pivot (e.g., *For Harry to see Sally is easy*). But in the OS construction in Figure 16, an alternative linking pattern is used where the proposition is realized as an embedded core and the pivot position is filled by the dummy NP *it*. Because the predicate in the embedded core is in the active voice, the linking between NPs and argument positions in the predicate's LS is accomplished in the standard fashion via macroroles. Thus, the core-initial NP *Harry* is linked to the actor macrorole, which in turn is linked to the predicate's first position; and the core-final NP *Sally* is linked to the undergoer macrorole, which in turn is linked to the predicate's second position.

The noncanonical OS construction is represented in Figure 17:

SENTENCE

CLAUSE				
CORE		CMPL---> CORE		
ARG	NUC		ARG	NUC
	PRED			PRED
NP	V		NP	V
Sally	is easy	for	Harry	to see
	Undergoer		Actor	

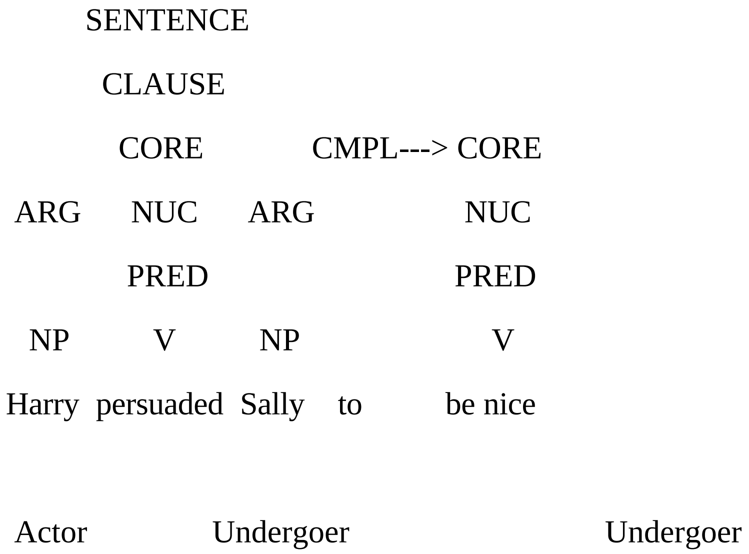
be easy (**see** [x,y])

Figure 17: Representation of Noncanonical OS Raising Construction

The clause contains two cores, both of which have a nucleus and a single argument position. The matrix predicate is **be easy**, and its proposition argument is instantiated by **see** (x,y), just as in the sentence shown in Figure 16. The difference between that sentence and the one shown in Figure 17 is that here the proposition **see** (x,y) does not map completely into the embedded core. The proposition's first argument and predicate do in fact correspond to the initial NP and verb of the embedded core; in addition, because the verb is in the active voice, the linking between the semantic argument and the NP position is mediated by the actor macrorole. However, the second argument of the proposition is not realized as the final NP of the embedded core but is instead realized as the pivot NP of the matrix core and is linked to this position via the undergoer macrorole. The argument metaphorically "raises up" to this higher syntactic position, just like the first argument of the proposition in the noncanonical SS construction. Indeed, the noncanonical SS and OS constructions are quite similar, the only significant difference having to do with which argument of the proposition "raises up" to the pivot positionùthe first argument in the SS construction, and the second argument in the OS construc-tion.

3.1.2.5 Undergoer Control

The next construction that I will consider is the undergoer control construction, which is exemplified by the sentence *Harry persuaded Sally to be nice.* This construction is shown in Figure 18:



persuade': [**do** (x, [**say** (x,y)])] CAUSE [BECOME **be nice** (z)]

Figure 18: Representation of Undergoer Control Construction

The clause contains two coresùa matrix core which has a nucleus and two argument positions, and an embedded core which has just a nucleus. The LS of **persuade** has three argument positions: one for the persuader, another for the person being persuaded, and a third for the proposition expressing what the second person is persuaded to do; in the sentence represented above, this third argument position is filled by the proposition **be**

nice (z). Since the matrix verb is in the active voice, the linking between the NPs in the matrix core and the first two argument positions in the LS of **persuade** is accom-plished in a standard manner: the pivot NP *Harry* is linked to the actor macrorole, which in turn is linked to the first argument position in the LS; and the direct core NP *Sally* is linked to the undergoer macrorole, which in turn is linked to the second argu-ment position in the LS. This leaves the single argument position of **be nice** unlinked to an NP. The solution to this problem is that one of the two NPs in the matrix core is linked not only to an argument position in the LS of the matrix verb, but also to the single argument position in the LS of the embedded verb. Which macrorole serves this functionùa function referred to as "control"ùis determined by the semantic properties of the matrix verb. This is captured in the RRG "theory of control," which states that causative change-of-state verbs and directive speech-act verbs (i.e., jussives) have undergoer control, and all other verbs have actor control. Note that, according to this theory, it is the macrorole that is relevant to control, not its specific syntactic realization in the matrix core. This is shown by the fact that if the sentence represented in Figure 18 is passivized so that the undergoer NP *Sally* is associated not with the direct core position but rather with the pivot positionù*Sally was persuaded by Harry to be nice*ù it is still the undergoer NP that controls the single argument of **be nice**. Another important feature of the undergoer control construction is that when the verb in the embedded core has more than one argument in its LS, the argument that is controlled by the undergoer of the matrix core is the one that would otherwise be syntactically realized as the initial NP of the embedded core; this is true regardless of whether the argument is an actor or an undergoer with respect to the LS of the embedded verb (e.g., *Harry allowed Sally*$_i$ *[____*$_i$ *to visit Kim]; Harry allowed Sally*$_i$ *[____*$_i$ *to be visited by Kim]; *Harry allowed Sally*$_i$ *[Kim to visit____*$_i$*]*).

3.1.2.6 Intransitives

The last two constructions that I will consider are the actor and undergoer intransitive constructions, which are exemplified in (1g); these sentences are reproduced below and illustrated in Figure 19.

i. actor intransitive: Harry left.
ii. undergoer intransitive: Harry died.

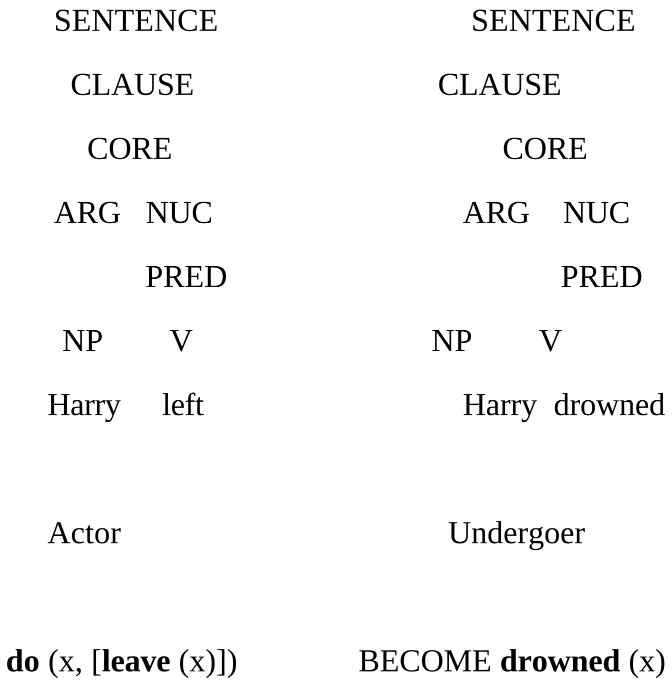


Figure 19: Representation of Actor and Undergoer Intransitive Constructions

Both clauses contain a single core which has a nucleus and a single argument position. The difference between the two constructions lies in the LSs and the nature of the macroroles that are linked to the NPs. According to the actor-undergoer hierarchy, the argument of **do**, which dominates all activity predicates regardless of whether or not they are agentive, is a prototypical case of an actor. This means that the NP of an intransitive sentence with an activity predicate will always take the actor macrorole, as shown in the left-hand figure above. By contrast, the actor-undergoer hierarchy indi-cates that the single argument of a state predicate is a prototypical undergoer. Hence, the NP of an intransitive sentence with a state predicate (or with an achievement predicate that derives from a state predicate) will always be linked to the undergoer macrorole, as shown in the right-hand figure above. It is noteworthy that the linking pattern in the actor intransitive construction can be considered canonical, since in general the pivot NP of an English sentence usually corresponds to the actor macrorole; on the other hand, the linking pattern in the undergoer intransitive construction can be considered noncanonical, since it deviates from the normal situation.

3.2 Processing

The previous section focused on the abstract nature of the computational problem that the syntactic comprehension system must solve. The goal there was to specify in terms of a well-motivated grammatical theoryùnamely, RRGùthe syntactic and semantic structures, as well as the syntactic-semantic linking patterns, of several different types of English constructions. In this section I move on to the next level of analysis, which concerns the on-line processing operations and resources that are dedi-cated to assembling syntactic and semantic structures and to linking the former to the latter. My goal here is to provide RRG-based characterizations of the operations and resources that are necessary for understanding the basic meaning (i.e., who's doing what to whom) of sentences instantiating the constructions described in the previous section. Because very little work has been done to date on developing a processing model for RRG, my proposals will be pitched at a fairly general level and must be considered tentative.

3.2.1 Parsing and Interpretation

"Parsing" and "interpretation" are technical terms that are frequently used in the psycholinguistic literature. From the point of view of RRG, these terms can be defined as follows: parsing is the process of creating the constituent structures and assigning the syntactic relations of sentences, and interpretation is the process of establishing correspondences between NPs, macroroles, the arguments of predicates, and the concepts expressed by specific nouns. These two kinds of processes are essential for syntactic comprehension, and I will discuss the general properties of each one in turn.

3.2.1.1 Parsing

There are two ways to approach parsing in RRG. One way is to view it as a process of incremental syntactic tree formation driven by simple input-output mapping operations. This is the conception of parsing that is most widely assumed in the psycholinguistic literature (e.g., Dowty et al. 1985; Frazier 1987; Kempen & Vosse 1989; Caplan 1992; Clifton et al. 1994). Basically, these operations take lexical or syntactic categories as input and create elements of constituent structure as output. For example, if a sentence begins with the expression *The dog* . . . , the series of operations shown below on the left would lead to the immediate assembly of the constituent structure shown on the right ("-->" means "given the unit on the left as input, activate the unit on the right as output"):

a. N --> REF

b. REF --> NUC_N

c. NUC_N --> $CORE_N$

d. $CORE_N$ --> NP

e. NP --> ARG

ARG
NP
$CORE_N$
NUC_N
REF
N

Additional operations would enable the parser to go beyond the tall tree extending from N to ARG and predict that other nodes and branches should appear in the constituent structureùin particular, that an ARG must be dominated by a CORE, and that a CORE must have a CLAUSE and a SENTENCE above it and a NUC and a PRED below it. These anticipated elements of the constituent structure would then get confirmed when the verb of the sentence is encountered, since the lexical category of verb triggers the firing of another series of operations which lead to the construction of these same elements. Further operations must be devoted to assigning syntactic relationsùe.g., pivot, direct core argumentùto appropriate NPs. Thus, according to this view of parsing, the syntactic comprehension system contains a large but finite set of basic mapping operations that are collectively sufficient for creating the constituent structures and assigning the syntactic relations of all possible sentences.

An alternative way to handle parsing in RRG is to treat it as a process of activating and combining syntactic templates that contain precompiled information. This approach is not as popular as the previous one, but an increasing number of researchers are exploring its potentialùresearchers coming not only from a background in sentence proces-sing (e.g., Trueswell & Tanenhaus 1994; Trueswell et al. 1995; MacDonald et al. 1994; Pearlmutter & MacDonald 1995), but also from a background in grammatical analysis (e.g., Jurafsky, in press; Langacker 1987, 1991; Van Valin & LaPolla, in press). The basic idea is that in addition to having a mental dictionary or lexicon that stores morphemes, words, and fixed multiword expressions, people have a syntactic inventory or "syntacticon" that stores complex syntactic units consisting of already assembled constituent structure and, in some cases, already assigned syntactic relations. For instance, there is a family of templates for NPs, including a template for the tall thin tree shown on the previous page, a template for the genitive construction "NP of NP" (e.g., *the box of oranges, the father of the bride*), a template for the possessive construction "NP's NP" (e.g., *the cat's tail, the play's final act*), and so on. There is also a family of templates for cores, including a template for a core with a nucleus and a single argument position (see the intransitive constructions in Figure 19), a template for a core with a nucleus and two argument positions, one a pivot and the other a direct core argument (see the transi-tive active construction in Figure 11), a template for a core with an attached periphery (see the backgrounding passive construction in Figure 12), and so on. Furthermore, there are various templates for complex sentences, such as a template for a clause con-taining two cores, one matrix and the other dependent (see Figures 14-18), a template for a sentence containing two clauses (e.g., for clausal coordination like *Steve went running and then he took a shower*), etc. According to this approach, templates in the syntactic inventory have a resting threshold of activation that is determined by their frequency of occurrence in the language. During the course of on-line sentence processing, multiple templates are activated in parallel to different degrees, and the ones that are most con-sistent with the input are preserved, whereas the ones that do not fit the input are sup-pressedùa functional organization which is in accord with numerous constraint satis-faction models of pattern recognition (Bechtel & Abrahamsen 1991; Churchland & Sejnowski 1992). The complete constituent structure of a sentence is then assembled by joining together templates at different levels of hierarchical structure, like snapping together Lego pieces.

The two different ways of viewing parsing in RRG are equally coherent from a theoretical standpoint, and I am not aware of any empirical data that strongly favors one over the other (although there is, of course, ongoing debate over the relative merits and shortcomings of each general approachùe.g., see Frazier 1995). In what follows, I will assume the second approach, since it is the view adopted by RRG. With respect to the processing requirements for the specific English constructions described in section 3.1.2, I propose a rough distinction between, on the one hand, parsing operations for creating simple constituent structures, which I define as those containing a single core, and, on the other hand, parsing operations for creating complex constituent structures, which I define as those containing more than one core. This leads to the classification of constructions shown in Table 1 below:

	Construction Type															
Parsing Operation	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Assemble simple constituent structure	x	x													x	x
Assemble complex constituent structure			x	x	x	x	x	x	x	x	x	x	x	x		

Table 1: Syntactic STM for Constructions (Abbreviations: A=active, P=passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa= active undergoer control, UCp=passive undergoer control, AI=actor intransitive, UI=undergoer intransitive)

3.2.1.2 Interpretation

I turn now to the second general kind of process in syntactic comprehensionùnamely, interpretation. As stated earlier, from the perspective of RRG, interpretation is essentially a matter of linking; more specifically, it involves establishing correspondences betweeen NPs, macroroles, the arguments of predicates, and the concepts expressed by particular nouns. I will discuss each of these types of correspondence in turn.

Several factors influence the process of linking NPs to macroroles, including constituent structure, morphology, and verb-specific properties. The canonical linking pattern for English is manifested in the transitive active construction shown in Figure 11 (p. 67). Here the preverbal pivot NP is linked to the actor macrorole and the postverbal direct core NP is linked to the undergoer macrorole. Many researchers have argued that because this pattern is highly frequent, the syntactic comprehension system treats it as a kind of default (e.g., Bever 1970; Bates & MacWhinney 1989; Caplan 1992). The passive construction shown in Figure 12 (p. 68) reverses this canonical linking pattern, since it requires that the preverbal pivot NP be linked to the undergoer macrorole and the object of *by* be linked to the actor macrorole. This deviation from the standard syntactic-semantic mapping relation is signaled explicitly by three different "cues": the auxiliary, the perfect participial form of the verb, and the preposition *by*. Hence, in order to interpret passive sentences correctly, the syntactic comprehension system must be able to detect these morphosyntactic cues. Because passive sentences have an atypical linking pattern, one would expect them to be more difficult to understand than their active counterparts, and this has been confirmed in several psycholinguistic experiments (Slobin 1966; Forster & Olbrei 1973; Osterhaut & Swinney 1993).[1]

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[1] It is worth noting, however, that Bever et al. (1989) found significant individual differences in the processing of active and passive sentences as a function of familial handedness. While right-handed individuals who have all right-handers in their families comprehend active sentences much more quickly than corresponding passives, right-handed individuals who have some left-handers in their families comprehend passive sentences slightly faster than corresponding actives. This is part of a more general tendency for familial right-handers to rely

The importance of verb-specific properties in interpretation is exemplified by the subject-to-subject raising constructions shown in Figures 14 and 15 (pp. 74-5) and by the undergoer control construction shown in Figure 18 (p. 78). In the two raising constructions, the predicate **seem** is marked with the feature [0MR], which has the effect of blocking the normal interpretive process of linking the pivot NP in the constituent structure to a macrorole associated with the predicate's LS. And in the undergoer control construction, the process of linking an NP in the matrix core to a macrorole associated with an argument in the embedded verb's LS is guided by the semantic properties of the matrix verb, in accordance with the RRG "theory of control." Thus, in order to correctly interpret subject-to-subject raising sentences and undergoer control sentences, the syntactic comprehension system must be sensitive to special properties of the semantic representations of verbs.

Another important point about establishing correspondences between NPs and macroroles is that although the standard linking process involves mapping an NP in a core to a macrorole associated with the LS of the predicate in the same core, many of the constructions described in section 3.1.2 require a more complex kind of linking process. One such process, which I refer to as cross-core linking, involves mapping an NP in a matrix core to a macrorole associated with the LS of a predicate in a dependent core. This kind of linking is necessary for the noncanonical subject-to-subject raising construction (Figure 15, p. 75) and the noncanonical object-to-subject raising construction (Figure 16, p. 76). In fact, it is worth emphasizing that in the case of these two constructions, the pivot NP is linked *only* to a macrorole associated with the LS of the predicate in the dependent core. Another complex form of linking, which I refer to

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on morphosyntax more than familial left-handersùsince the morphosyntax of passives is more challenging than that of actives, familial right-handers get slowed down more than familial left-handers.

as cross-clausal linking, involves mapping an NP in a matrix clause to a macrorole associated with the LS of a predicate in a peripheral clause. This is required for all four relative clause constructions and for both cleft constructions, exemplified below for ease of reference (the gaps are strictly for expository purposes; there are no actual empty categories in the constituent structures):

a. subject-subject relative: *The man$_i$ [that ____$_i$ saw Sally] knows me.*
b. subject-object relative: *The man$_i$ [that Sally saw ___$_i$] knows me.*
c. object-subject relative: *I know the man$_i$ [that ____$_i$ saw Sally].*
d. object-object relative: *I know the man$_i$ [that Sally saw ____$_i$].*
e. subject cleft: *It was the man$_i$ [that ____$_i$ saw Sally].*
f. object cleft: *It was the man$_i$ [that Sally saw ____$_i$].*

In the object-subject and object-object relative clause constructions as well as in the two cleft constructions, the head of the complex NP is first linked to a macrorole associated with the LS of the predicate in the matrix clause, and is then linked to a macrorole associated with the LS of the predicate in the peripheral clause. By contrast, in the subject-subject and subject-object relative clause constructions, the head of the complex NP is first linked to a macrorole associated with the LS of the predicate in the peripheral clause, and is then linked to a macrorole associated with the LS of the predicate in the matrix clause.

Although the foregoing consideration of how correspondences are established between NPs and macroroles is far from complete, it provides a useful framework for classifying the constructions described in section 3.1.2 according to the operations that they do and do not share. Such a classification is presented in Table 2.

Before moving on to discuss how correspondences are established between macroroles and the arguments of predicates, I would like to briefly consider one further issue. Recent work in linguistics has shown that grammatical constructions such as passive, dative, causative, locative, etc., are typically associated with rather specific semantic properties (Wierzbicka 1988; Pinker 1989; Jackendoff 1990; Levin 1993). For instance, the prepositional dative construction [NP V NP to NP] is associated with the meaning "X causes Y to go to Z" (e.g., *Sally threw the frisbee to Harry, Sally handed the box to Harry*), whereas the double object dative construction [NP V NP NP] is associated with the meaning "X causes Z to have Y" (e.g., *Sally threw Harry the frisbee, Sally handed Harry the box*). Given that such construction-specific meanings can exist, it is natural to wonder if some, even many, of the syntactic templates in the "syntacticon" include long-term memory associations between particular NPs and particular macroroles. Thus, it may be the case that the template for the transitive active construction is stored in memory with already established links between the pivot NP and the actor macrorole on the one hand, and the direct core NP and the undergoer macrorole on the other. Similarly, the template for the backgrounding passive construction may be stored in memory with already established links between the pivot NP and the undergoer macrorole on the one hand, and the oblique NP and the actor macrorole on the other; indeed, to get even more concrete, this template may also have a long-term association between the preposition category in the constituent structure and the lexical node for the specific preposition *by*. An approach like this is currently being pursued by several different researchers working independently, and it will be interesting to see where it will lead (e.g., Langacker 1987, 1991; Fillmore et al. 1988; Goldberg 1995; Van Valin & LaPolla, in press). In what follows, I will assume that such an approach is on the right track.

I turn now to the second type of correspondence that must be established when interpreting sentencesùnamely, correspondences between macroroles and argument positions in the LSs of predicates. This issue is essentially about how the semantic relations of predicates are processed. Specific semantic relations (i.e., notions like agent and patient, possessor and possessed, perceiver and perceptual target) are presumably not computed on-line, since they are directly determined by the content and configur-ation of the predicate's LS. For instance, because the predicate **see** (x,y) expresses an activity of visual perception, its first argument is necessarily a perceiver and its second argument is necessarily a perceptual target. With regard to higher-order macroroles, they could either be computed on-line according to the actor-undergoer hierarchy, or they could be stored as components of the long-term memory representations of predi-cates. Although I do not know of any empirical data that bears on this issue, I will adopt the working hypothesis that the latter possibility is true. When this assumption is added to the assumption made earlier that syntactic templates often include long-term associa-tions between NPs and macroroles, it becomes clear that a large part of the process of interpretation involves forming "bridges" between NPs and arguments via activation of the same macroroles. This is illustrated in Figure 20, where the red lines symbolize the correspondences:

SENTENCE
CLAUSE
CORE
ARG   NUC   ARG
PRED
NP   V   NP

Actor   Undergoer

see' (x,y)

Figure 20: Correspondences between NPs, macroroles, and arguments

In order to fully interpret a sentence, i.e., determine "who's doing what to whom," one last type of correspondence must be establishedùspecifically, between the arguments of predicates and the concepts expressed by the nouns in the sentence. This kind of correspondence is what enables a stable representation of the meaning of the sentence to be maintained in short-term semantic memory. Consider, for instance, the processing of the sentence *Harry saw Sally*, which is illustrated in Figure 21. The first step is to activate the abstract lexical units for the words (these units are triggered by the phonological forms of the words, which are not shown in the figure; for evidence supporting the reality of abstract lexical units, see Damasio et al. 1996). Each of these lexical units then activates, in parallel, its associated syntactic and semantic representations. Thus,

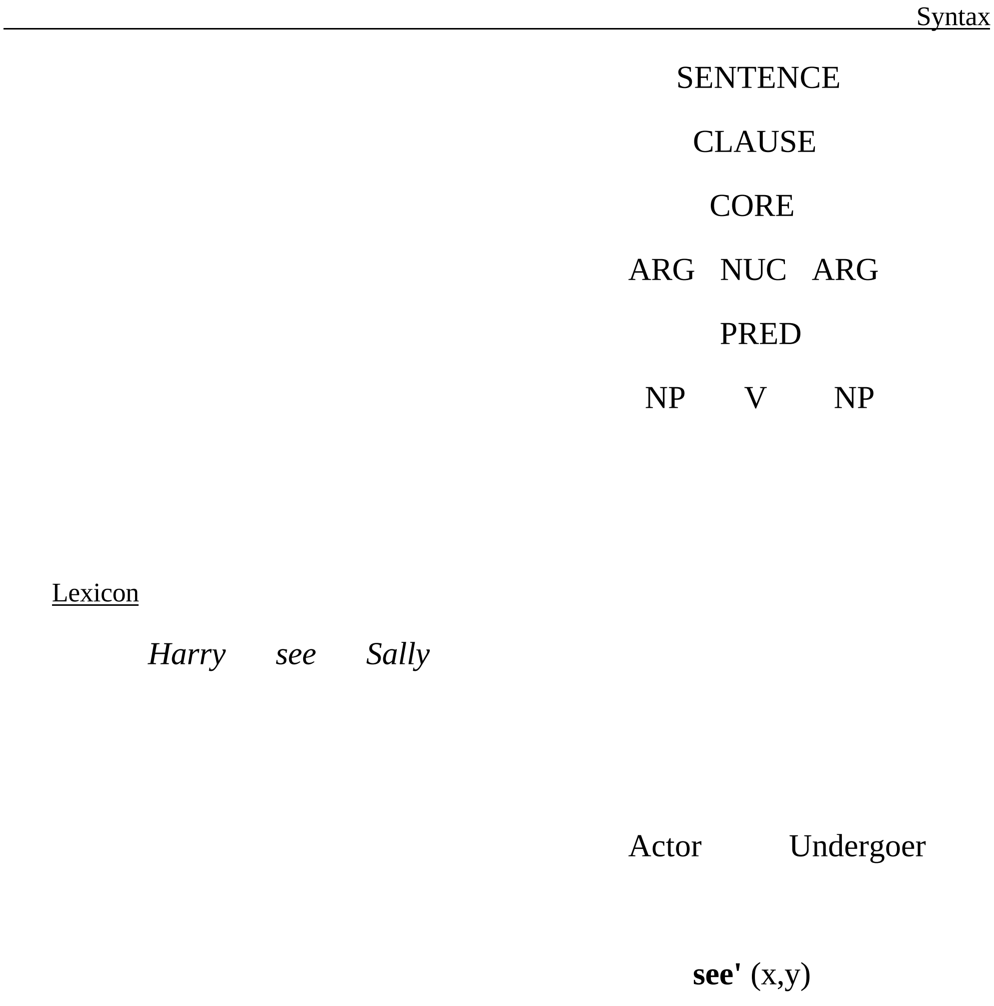

Figure 21: Correspondences between argument positions and noun concepts

Harry and *Sally* activate NPs in the syntactic component and the concepts **Harry** and **Sally** in the semantic component, and *see* activates a V in the syntactic component and the predicate **see** in the semantic component. Within the syntactic component, multiple templates compete for dominance until the one that is most consistent with the input is selected, that being the transitive active template. The pivot NP of this template causes the actor macrorole to be activated, and the direct core NP causes the undergoer macrorole to be activated; these correspondences are established because of long-term memory associations between the respective syntactic and semantic units. Meanwhile, within the semantic component the first argument of **see** automatically activates the actor macrorole, and the second argument automatically activates the undergoer macrorole; again, these correspondences are established by virtue of long-term memory associations.

The final step of the interpretation process is to establish the appropriate correspondences between the two arguments of the predicate and the two noun concepts. A close inspection of Figure 21 reveals that the linking between arguments and noun concepts is actually already availableùjust follow the black lines: a chain of correspondences exists between the concept **Harry**, the lexical unit *Harry*, the pivot NP, the actor macro-role, and the first argument of **see**; and another chain of correspondences exists between the concept **Sally**, the lexical unit *Sally*, the direct core NP, the undergoer macrorole, and the second argument of **see**. These two long chains of correspondences provide grammatically mediated linkings between the arguments of the predicate and the concepts expressed by the nouns. But once these indirect correspondences have been established, it is possible to form direct correspondences between the arguments and noun concepts, so that the meaning of the sentence can be maintained in semantic short-term memory after the lexical units and syntactic template have been deactivated. Such direct correspondences are marked with red lines in the figure. I will discuss a possible mechanism for establishing correspondences later in this chapter (see º3.3.2.3, esp. pp. 128-30).

3.2.2 Processing Resources

In addition to requiring operations for parsing and interpretation, syntactic comprehension also requires several different kinds of processing resources that enable the system to function efficiently, especially when dealing with unusally challenging types of constructions. I will focus on the following resources: syntactic short-term memory (henceforth, syntactic STM), and attentional control. Both of these resources have been the subject of recent research on sentence processing, although the former has been studied far more intensely than the latter. I will discuss each one in turn.

3.2.2.1 Syntactic STM

Syntactic STM consists of a limited-capacity buffer that retains constituent structures in an activated or semi-activated state until they can be fully interpreted, after which point they are deactivated so that further syntactic information can enter the buffer (Caplan 1992; Carpenter et al. 1994; Gibson, in press). In short, syntactic STM is a resource for "the remembrance of things parsed" (Pinker 1994: 201). This resource is necessary for processing a variety of constructions. Perhaps its most straightforward function is simply to hold "dangling" elements of constituent structure until they can be completed and mapped into the semantic representation of the sentence. For example, the constituent structure for the initial NP of a sentence, such as *The big red apple* . . . , must be retained in syntactic STM until the predicate of the sentence is encountered and its LS is accessed; then correspondences can be established between the NP, the appro-priate macrorole, and the appropriate argument in the LS of the predicate.

Syntactic STM also plays an important role in the processing of constructions that involve local syntactic ambiguity. For instance, whenever the complementizer *that* is encountered after a noun (e.g., *The man that* . . .), it signals that a relative clause is coming up. This leads to the immediate assembly of a constituent structure for an NP with a periphery containing a dependent clause. However, the complementizer does not provide any information whatsoever about the internal structure of the upcoming clauseùthat is, it doesn't indicate whether the clause is a subject-subject relative, a subject-object relative, or some other type of relative.[2] Recent research suggests that in cases of ambiguity like this, the syntactic comprehension system adopts the strategy of creating several possible constituent structures and maintaining all of them until disambiguating input is encountered (Hickok 1993).

Another context in which syntactic STM is important is constructions in which the pivot NP is separated from the matrix predicate by intervening material, such as a sequence of prepositional phrasesùe.g., *The park in the central part of the city next to the zoo is a good place to run*). In cases like this, syntactic STM is needed to "bridge the distance," so to speak, from the pivot NP to its predicate. Two of the constructions described in section 3.1.2 require this kind of processingùnamely, the two center-embedded relative clause constructions:

a. subject-subject relative: *The man [that saw Sally] knows me.*
b. subject-object relative: *The man [that Sally saw] knows me.*

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[2] By contrast, other languages have relative pronouns that do provide such information and thus ease the burden of syntactic comprehension for the listener. While English does preserve the distinction between *who* and *whom*, this is fading out of usage.

As indicated by the brackets, in both of these constructions the relative clause intervenes between the pivot NP and the matrix predicate, and hence syntactic STM is needed to keep the NP in an activated state.

Yet another context in which syntactic STM is crucial is constructions that require filler-gap integration. In such constructions, an NP does not appear in its normal position adjacent to its predicate but rather in a "higher" syntactic position. As a result, the NP cannot be interpreted immediately and hence must be retained in memory until the appropriate predicate is encountered (or, as some researchers say, until the syntactic "gap" where the NP would normally appear is encountered), at which point the NP can finally be interpreted. Several of the constructions described in section 3.1.2 require this kind of processing. First of all, consider the four relative clause constructions and the two cleft constructions, instances of which are shown below with the filler-gap relations marked explicitly:

a. subject-subject relative: *The man*$_i$ *[that* ____$_i$ *saw Sally] knows me.*
b. subject-object relative: *The man*$_i$ *[that Sally saw* ___$_i$*] knows me.*
c. object-subject relative: *I know the man*$_i$ *[that* ____$_i$ *saw Sally].*
d. object-object relative: *I know the man*$_i$ *[that Sally saw* ____$_i$*].*
e. subject cleft: *It was the man*$_i$ *[that* ____$_i$ *saw Sally].*
f. object cleft: *It was the man*$_i$ *[that Sally saw* ____$_i$*].*

In the subject-subject relative (a), object-subject relative (c), and subject cleft (e) constructions, syntactic STM is not required for filler-gap integration because the predicate in the embedded clause is encountered immediately after the complementizer (as noted above, however, syntactic STM is still needed for the subject-subject relative construction in order to hold the pivot NP until the matrix predicate is identified). By contrast, in the subject-object relative (b), object-object relative (d), and object cleft (f) constructions, syntactic STM is needed for filler-gap integration, since the NP must be retained until the predicate in the embedded clause is encountered.

Consider now the two noncanonical raising-to-subject constructions exemplified below:

g. subject-to-subject raising: *Sally*$_i$ *seems to Harry [____*$_i$ *to be tall].*
h. object-to-subject raising: *Sally*$_i$ *is easy [for Harry to see ____*$_i$*].*

Both of these constructions require syntactic STM for purposes of filler-gap integration. In the subject-to-subject raising construction (g), the pivot NP cannot be interpreted until the predicate in the dependent core is identified, and while this NP is being held in memory the oblique NP must be associated with an argument in the LS of the matrix predicate. Similarly, in the object-to-subject raising construction (h), the pivot NP must be retained in memory until the predicate in the dependent core is encountered, at which point this NP as well as the other NP must be interpreted simultaneously. With regard to the two canonical raising-to-subject constructions, neither one involves filler-gap integration, and therefore neither one depends on syntactic STM for this function.

Finally, consider the undergoer control construction, exemplified by the sentence *Harry persuaded Sally*$_i$ *[____*$_i$ *to be nice].* In this construction, an NP in the matrix core must be linked to a macrorole associated with an argument in the LS of the verb in the dependent core. However, because the controller NP is followed immediately by the embedded verb, syntactic STM should not be necessary. On the other hand, when the matrix core is passivizedùe.g., *Sally*$_i$ *was persuaded by Harry [____*$_i$ *to be nice]*ùthe controller NP is separated from the embedded verb by intervening material, and for this reason the NP must be held in syntactic STM until the verb is encountered.

As with the various operations for parsing and interpretation, it is useful to summarize the preceding discussion by classifying the constructions described in section 3.1.2

according to whether or not they require syntactic STM. Such a classification appears in Table 3 below.

A number of studies have focused on the time-course of filler-gap integration (Fodor 1989, 1995; Garnsey et al. 1989; Nicol & Swinney 1989; Boland et al. 1990; Tanenhaus et al. 1990; Kluender & Kutas 1993; Osterhaut & Swinney 1993; Nicol 1994). These studies have employed sophisticated methodologies involving event-related potentials (ERPs) and cross-modal lexical priming (CMLP). Overall, the studies reveal two important properties of on-line filler-gap integration. First, although the constituent structure of the "filler" NP is maintained in a fully activated state throughout the time that it is held in syntactic STM, the semantic representation associated with this NPùthat is, the concept expressed by the head nounùis maintained in only a partially activated state; however, when the appropriate predicate is identified, the semantic representation of the NP is reactivated for purposes of being associated with an argument in the predicate's LS. Second, this reactivation process generally occurs approximately 400 msec after the predicate is encountered.

	Construction Type															
	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Syntactic STM			x	x		x		x		x		x		x		

Table 3: Syntactic STM for Constructions (Abbreviations: A=active, P=passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa= active undergoer control, UCp=passive undergoer control, AI=actor intransitive, UI=undergoer intransitive)

Before moving on to discuss attentional control, I should point out that syntactic STM is distinct from another kind of linguistic memory resource that is often discussed in the sentence processing literatureùnamely, verbal STM. As I mentioned in Chapter 2 (see pp. 17, 22), this latter memory resource has two components, one articulatory and the other auditory. It is used primarily for rehearsing single words, multiword sequences, and sentences, and it is typically measured by span tasks that require the subject to remember a list of semantically unrelated items for a given period of time (Baddeley 1986, 1992; Baddeley & Hitch 1994). In much of the early research on sentence processing, it was assumed that verbal STM is essential for on-line syntactic comprehension (Saffran & Marin 1975; Caramazza et al. 1981; Vallar & Baddeley 1984; Caramazza & Berndt 1985). However, more recent research suggests that this is not so. In particular, several studies have shown that brain-damaged patients who have severe impairments of verbal STM are nonetheless able to understand complex constructions that require long-distance filler-gap integration as well as other sorts of long-distance syntactic dependencies (Caplan & Waters 1990; Martin 1990; Waters et al. 1991; Martin & Romani 1994). Still, it may be the case that verbal STM contributes to syntactic comprehension in special situationsùe.g., it may provide a backup phonological representation of a sentence that can be consulted when on-line processing bogs down because of syntactic ambiguities or other challenging operations (Romani 1994), and certainly it is used when one rehearses a sentence in order to make sure that the interpretation derived from "first pass processing" is accurate.

3.2.2.2 Attentional Control

I turn now to attentional control, which is the second major processing resource for syntactic comprehension. Although the role that attention plays in syntactic comprehension has not been the subject of much investigation, there are good theoretical reasons for believing that its role is important, and there are a few studies that have provided empirical support for this view.

As in Chapter 2 (see º2.2.3, pp. 24-25), I will adopt the view that attentional control serves two closely related functions. The first is to amplify the processing efficiency of the syntactic comprehension system, usually at the expense of other mental domains. For example, this aspect of attention may be important when you are listening to someone speaking and there is a great deal of background noise, such as at a party or while standing on a busy streetcorner. The second function is to monitor the activities of the syntactic comprehension system for signs of trouble, so to speak, and when such a sign is detected, to intervene by influencing the selection of structures (e.g., syntactic templates and their associated linking patterns) in a top-down manner. For instance, this aspect of attention is what facilitates recovery from parsing breakdown after pursuing the wrong analysis of garden-path sentencesùe.g., *I thought that the Vietnam war would end for at least an appreciable chunk of time this kind of reflex anticommunist hysteria* (Pinker 1994: 213). In addition, the second function of attentional control may contribute to the processing of contructions that involve noncanonical linking patterns between NPs and macroroles, especially those constructions that are both complex and have few or no overt morphosyntactic cues for noncanonical linking.

It is precisely this last type of situation that I am most concerned with. For example, consider from a purely theoretical standpoint how the sequence of words *the man that Sally saw* might be processed when encountered in a sentential context. The words *the man* trigger the activation of an NP, and the complementizer *that* triggers the activation of a syntactic template for a relative clause. In addition, as I mentioned in the discussion of syntactic STM (see pp. 93-4), the templates for at least two possible kinds of relative clause are also activated as a way of anticipating what is likely to come next. One of these templates is for the subject-relative construction, and the other is for the object-relative construction. The subject-relative template leads to the tentative association of the head NP *the man* with the actor macrorole, and the object-relative template leads to the tentative association of the head NP *the man* with the undergoer macrorole. Moreover, since subject relatives are used more frequently in English than object relatives (Fox & Thompson 1990), the subject-relative template is activated more strongly than the object-relative template; this constitutes a "best bet" prediction about what is going to be encountered downstream. However, when the next few words are encounteredù . . . *the woman saw*ùthe prediction is violated. Since this sequence of words is more consistent with the object-relative template than with the subject-relative template, it causes the activation level of the former to increase and the activation level of the latter to decrease. Notice, though, that the only explicit cue indicating which template is the appropriate one is the order of words in the sequence. It may be the case that this bottom-up input is not sufficient by itself to enable the object-relative template and its associated linking pattern to fully overcome the subject-relative template and its associated linking pattern.

This is presumably the point at which attentional control comes into play. While it is not clear exactly how attentional control operates in computational terms, some very general speculations can be made. Imagine that a monitoring mechanism detects an "impasse" within the syntactic comprehension system and acts on this information by recruiting a decision-making mechanism that is dedicated to resolving such problems. This decision-making mechanism may then operate in either or both of two ways. First, it may intervene in a direct manner by adjusting the activation levels of the relevant templates in the right directions; in particular, it may enhance the activation level of the object-relative template and reduce the activation level of the subject-relative template. Second, it may intervene in a more indirect manner by retrieving the original sequence of auditory word forms from verbal STM and running it through the syntactic comprehension system again, but this time with extra attentional amplification so that the critical word order cue will be sufficient to determine the correct syntactic template and linking pattern. This second type of intervention is undoubtedly more time-consuming, effortful, and consciously mediated than the first and is referred to in the psycholingui-stic literature as "second-pass processing" (e.g., Caplan & Waters 1990; see also Cohen et al. 1990 on how the distinction between automatic, involuntary, and unconscious processes on the one hand, and controlled, voluntary, and conscious processes on the other, is better seen as a continuum than as a rigid dichotomy).

The computational details of how attentional control actually functions are hidden from view just like the secrets behind a magician's tricks. However, the general idea that such a processing resource is frequently needed for syntactic comprehension should not be controversial. People often have the subjective feeling that comprehending sentences that are complex and involve noncanonical linking patterns is more difficult and requires more concentration, sometimes even rehearsal, than comprehending sentences that are comparatively simple and involve canonical linking patterns. The theoretical notion of attentional control is meant to provide a scientific basisùalbeit a very rough one at presentùfor explaining this intuition as well as other data gathered from experimental research.

Within the past few years, several psycholinguistic and neurolinguistic studies have provided empirical support for the view that attentional control plays an important role in syntactic comprehension. Most of these studies have been conducted by a single research team consisting of Carpenter, Just, King, and Miyake (King & Just 1991; Just & Carpenter 1992, 1993; Carpenter et al. 1994, 1995; Miyake et al. 1994, 1995; King & Kutas 1995). Some of this team's most impressive findings come from investigations of the processing of subject-subject and subject-object relative clauses such as the ones shown below:

subject-subject relative: *The reporter that attacked the senator admitted the error*
subject-object relative: *The reporter that the senator attacked admitted the error*

In a replication of previous experiments by Holmes and O'Regan (1981) and Ford (1983), King and Just (1991) demonstrated that in a self-paced word-by-word reading task, the visual fixation times for the two consecutive verbs in subject-object relatives are significantly longer than the fixation times for the corresponding noun and verb positions in subject-subject relatives. While this difference in fixation times is probably due in part to the increased syntactic STM demands for subject-object relatives, it most likely also reflects the increased need for attentional control to regulate template selec-tion and linking in these sentences. Additional evidence consistent with this view was obtained by Just and Carpenter (1993), who showed that in a self-paced word-by-word reading task, pupil dilation increases significantly more for the two consecutive verbs in subject-object relatives than for the corresponding noun and verb positions in subject-subject relatives. Since the degree of pupil dilation is a reliable index of the intensity of processing (Beatty 1982), it is reasonable to interpret this finding as supporting the hypothesis that template selection and linking are guided by attentional control more in subject-object relatives than in subject-subject relatives. Finally, King and Kutas (1995) observed in an electrophysiological study that the two consecutive verbs in subject-object relatives elicit a distinctive brainwave pattern at the left central frontal and left lateral frontal recording sites, whereas the corresponding noun and verb positions in subject-subject relatives do not. This accords well with the other findings, since, as I will argue in section 3.3.2.5 (p. 136), both the anterior cingulate cortex and the ventro-lateral prefrontal cortex contribute to attentional control for syntactic comprehension.

In addition, King and Kutas found another processing difference between subject-object and subject-subject relatives, one that did not show up in either of the other two studies. In particular, they observed that the determiner immediately following the complementizer in subject-object relatives (e.g., *The reporter that the senator attacked* . . .) elicited an N400 response at the left Wernicke's and occipital recording sitesùa response which typically indexes the violation of an expectation or the inability to integrate an item into its preceding context. This suggests that, as I hypothesized earlier, the occurrence of the complementizer causes the subject-relative template and linking pattern to be activated more strongly than the object-relative template and linking pattern, so that when the determiner is encountered, it is a surprise, so to speak, for the syntactic comprehension system.[3] In order to get past this roadblock thrown into the path of sentence proces-sing, it makes sense to assume that top-down attentional control in required to suppress the subject-relative template and linking pattern and promote the object-relative template and linking pattern. However, it may take some time for this intervention to take place: the "impasse" signal must be detected by a monitoring mechanism; the monitoring mechanism must then recruit a special-purpose decision-making mechanism; and finally, the decision-making mechanism must specify a course of action. Hence, the observable effects of attentional intervention do not show up until the predicate of the relative clause is encountered.

It is worth noting that in all three of the studies just described, performance varied across the subjects. Specifically, while the general processing differences between the two relative clause constructions were valid for all of the subjects, they were more pronounced for some of the subjects than for others. This may be due to underlying individual differences in syntactic STM capacity, attentional capacity, or both.

Although the studies conducted by Carpenter and her colleagues focused on the differential involvement of attention in the processing of just two constructionsùsubject-object and subject-subject relative clausesùit is possible to draw inferences from these studies about the degree to which this resource contributes to the processing of the other types of constructions described in section 3.1.2. Consider first the other two relative clause constructions and the two cleft constructions, which are shown below:

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[3] King and Kutas speculate that the determiner may not have caused longer fixation times or greater pupil dilations in the other studies because the subjects were using a performance strategy of trading accuracy for speed.

a. object-subject relative: *I know the man that saw Sally.*
b. object-object relative: *I know the man that Sally saw.*
c. subject cleft: *It was the man that saw Sally.*
d. object cleft: *It was the man that Sally saw.*

Since the object-object relative (b) and the object cleft (d) both contain a noncanonical complex NP just like in the subject-object relative, the processing of these constructions may require attentional control to suppress the inappropriate syntactic template and linking pattern and facilitate the appropriate ones. By contrast, since the object-subject relative (a) and the subject cleft (c) both contain a canonical complex NP just like in the subject-subject relative, attentional control should not be needed to regulate template selection and linking.

Now consider the raising-to-subject constructions exemplified below:

e. subject-to-subject raising:
    i. canonical: *It seems to Harry that Sally is tall.*
    ii. noncanonical: *Sally seems to Harry to be tall.*
f. object-to-subject raising:
    i. canonical: *It's easy for Harry to see Sally.*
    ii. noncanonical: *Sally is easy for Harry to see.*

The linking patterns in the two canonical constructions (e-i, f-i) are fairly straightforward, so it is not likely that attentional control is needed for on-line processing. On the other hand, the linking patterns in the two noncanonical constructions (e-ii, f-ii) are atypical, and this atypicality is only signaled by a single explicit cue in each case: in the subject-to-subject raising construction, the only explicit cue is the preposition *to,* which indicates that the following NP is the experiencer of *seem;* and in the object-to-subject raising construction, the only explicit cue is the complementizer *for,* which indicates that the following NP is the actor of the predicate in the dependent core. Because there are so few explicit cues for the atypical linking patterns, it is reasonable to assume that during the processing of these constructions, attentional control may be needed to sup-press certain heuristic templates and linking patterns and facilitate the correct ones. For the subject-to-subject raising construction, the heuristic strategy is to treat the NP that is syntactically closest to the embedded predicate as being semantically associated with it; and for the object-to-subject raising construction, the heuristic strategy is to treat the first and second NPs as the actor and undergoer, respectively, of the predicate in the dependent core.

Next, consider the transitive active construction and the two passive constructions:

g. transitive active: *Harry awakened Sally*.
h. passive:
    i. foregrounding: *Harry was awakened.*
    ii. backgrounding: *Harry was awakened by Sally*.

With regard to the transitive active construction (g), it is highly unlikely that attentional control is necessary for on-line processing, since the constituent structure is very simple and the linking pattern is perfectly canonicalùin fact, it's the default. By contrast, the foregrounding and backgrounding passive constructions (h) both involve noncanonical linking patterns, with the pivot NP being mapped to the undergoer macrorole and, in the backgrounding passive, the oblique NP being mapped to the actor macrorole. Hence, one might suppose that attentional control would be needed in order to inhibit the incorrect "active" template and linking pattern and promote the correct "passive" template and linking pattern. I suspect, however, that the situation is not as straightforward as this, since the two constructions not only have very simple constituent structures but also have multiple explicit morphosyntactic cues that signal the noncanonical linking pattern: the backgrounding passive has three such cuesùthe auxiliary, the perfect participial verb form, and the preposition *by*ùand the foregrounding passive has twoùthe auxil-iary, and the perfect participial verb form. Hence, I do not think that attentional control is generally required for processing these sentences. It is worth noting, however, that if attention were needed, it would be needed more for the foregrounding passive than for the backgrounding passive, since the former construction has fewer explicit cues.

I turn now to the active and passive undergoer control constructions:

i. undergoer control:
  i. *Harry persuaded Sally to be nice.*
  ii. *Sally was persuaded by Harry to be nice.*

In order to comprehend undergoer control sentencesùeither active or passiveùan NP in the matrix core must be linked to a macrorole associated with an argument in the LS of the verb in the dependent core. However, which NP must be linked in this fashion is not signaled by any explicit marker whatsoever; instead, it is determined solely by implicit semantic properties of the matrix verb. For this reason, one might think that special attention would be needed for processing undergoer control sentences. I do not think this is the case, however, since it is likely that during the course of on-line sentence processing, the grammatically relevant semantic properties of verbs are strongly activated in an automatic fashion so that attention is not needed to detect or amplify certain features, such as the control features of control verbs (Shapiro et al. 1989; Boland et al. 1990; Garrett 1990). One might still think that attention is required for processing passive undergoer control sentences, since the default strategy of selecting the direct core NP as "controller" may have to be overriden. However, it should not be necessary to suppress one linking strategy and promote an alternative one, since there are multiple explicit cues signaling the noncanonical status of the matrix core (the auxiliary verb, the perfect participial suffix, and the preposition *by*).

Last of all are the actor and undergoer intransitive constructions:

j. intransitive:
  i. actor intransitive: *Harry applauded.*

ii. undergoer intransitive:*Harry drowned.*

Because pivot NPs are typically interpreted as actors, the actor intransitive construction (j-i) has a canonical linking pattern whereas the undergoer intransitive construction (j-ii) has a noncanonical linking pattern. In addition, the noncanonical linking pattern of the latter construction is not explicitly signaled; rather, it is determined by the implicit semantic properties of the verb. Hence, one might suppose that attentional control would be useful for establishing the correct template and linking pattern of undergoer intransitive sentences. I do not think that this inference is valid, however, for the following reasons: first, the constituent structure of the undergoer intransitive construction is very simple; and second, as I argued above in the case of undergoer control sentences, it is likely that the grammatically relevant semantic properties of verbs are strongly activated in an automatic fashion when they are encountered in the course sentence processing. Thus, for an undergoer intransitive sentence like (j-ii), the LS of the achievement predicate **drown** is probably accessed quickly, and the fact that the single argument of this LS is associated with the undergoer macrorole means that the pivot NP can only be an undergoer. Attentional control should therefore not be needed to suppress the alternative interpretation of this NP as actor. It is worth noting, however, that during the processing of undergoer intransitives like *Harry drowned,* there may be a brief period of ambiguity, since the strongest cue that the sentence is in fact an undergoer-intransitive, as opposed to a transitive sentence like *Harry drowned Sally,* is the absence of a direct core NP, and this cue cannot be registered until after the verb has been encountered. During this period of ambiguity, both the intransitive and transitive templates are probably activated, and both the achievement LS and the accomplishment LS of the verb are probably activated. I suspect, though, that the temporary ambiguity is quickly and automatically resolved once the intransitive status of the sentence is established. It may even be the case that intonational cues allow the ambiguity to be resolved before the absence of a direct core NP is registered. In English, focal stress typically falls on the final word (Ladefoged 1993), so that the intransitive sentence *Harry drowned* has focal stress on *drowned*, whereas the transitive sentence *Harry drowned Sally* has focal stress on *Sally*. During on-line processing, then, detection of focal stress on *drowned* may rapidly "tip the balance" in favor of the undergoer-intran-sitive analysis.

The foregoing discussion of the contribution of attentional control to syntactic comprehension is quite general and does not address a number of important questions, perhaps the most challenging of which is how this processing resource functions in precise computational terms. Nonetheless, I hope to have shown that there are good theoretical and empirical reasons for believing that attention plays an important role in syntactic comprehension. My overview of its contribution to each of the constructions described in section 3.1.2 is summarized in Table 4:

	Construction Type															
	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Attentional Control				x		x		x		x		x				

Table 4: Attentional Control for Constructions (Abbreviations: A=active, P=passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa= active undergoer control, UCp=passive undergoer control, AI=actor intransitive, UI=undergoer intran-sitive)

By way of concluding this section, it is useful to represent together all of the processing operations and resources that are necessary for comprehending the constructions described in section 3.1.2. Such a synthesis is provided in Table 5 below. Because this table contains a great deal of detailed information, it is worthwhile to present a more simplified table in which the various constructions are categorized according to just four critical processing factors: (1) complex parsing, (2) noncanonical linking, (3) syntactic STM for filler-gap integration, and (4) attentional control. This information is provided in Table 6.

	Construction Type															
Processing Factor	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Complex Parsing			x	x	x	x	x	x	x	x	x	x	x	x		
Noncanonical Linking		x		x		x		x		x		x		x		x
Syntactic STM			x	x		x		x		x		x		x		
Attentional Control				x		x		x		x		x				

Table 6: Four Critical Processing Factors for Constructions (Abbreviations: A=active, P=passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object

relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa=active undergoer control, UCp=passive undergoer control, AI=actor intransitive, UI=under-goer intransitive)

3.3 Neurobiology

In the previous two sections, I characterized the syntactic comprehension system at the levels of structure and processing. In this section, I shift to the final level of analysis, where the aim is to describe how the syntactic comprehension system is physically realized in the brain. I will adopt a methodological strategy called "hierarchical decomposition," which amounts to first establishing the general neural substrates of the system as a whole, then attempting to identify the brain areas that support each major subsystem, and ultimately moving further down the scale of functional-anatomical organization to the levels of cortical maps, columns, and synapses (Kosslyn & Koenig 1992; Kosslyn 1994; Posner & Rothbart 1994). My specific goals, however, are fairly modest, since I will restrict my discussion to the implementation of the syntactic comprehension system as a whole as well as the implementation of the major processing subsystems outlined in section 3.2 (i.e., parsing, interpretation, syntactic STM, and attentional control). There are several reasons for this conservative approach, one of which is that research in cognitive neuroscience typically focuses on rather high levels of functional-anatomical organization; the lower levels are the province of a closely related but different field of research called computational neuroscience (Churchland & Sejnowski 1992). The most prominent reason for concentrating on the higher levels, though, is simply that virtually nothing is known about the lower levels of implementation for the syntactic comprehension system. In fact, very little evidence is available regarding even the higher levels of implementation for this system, and the evidence that does exist is controversial. It will probably take many more decades of research before we develop a basic understanding of how syntactic comprehension is accomplished by the human brain, and it is likely that the most illuminating explanations will be pitched at the lower levels of implementation and will draw heavily on neural network computer modeling. Recent advances in research on the primate visual system have shown that distinct visual functions are carried out in segregated cortical maps consisting of strange anatomical configurations such as blobs and stripes (Zeki 1993), which suggests that the brain areas supporting linguistic functions may ultimately turn out to have any number of similarly odd designs. Only time will tell.

3.3.1 Hemispheric Asymmetry

In 1861 Paul Broca claimed on the basis of clinical data that "the faculty for articulate language" resides in the left hemisphere of the brain. In the 135 years since, this view has been corroborated by a tremendous range of additional evidence, and it is now widely accepted that in a very large number of adults, most language functions, including syntactic comprehension, are lateralized to the left hemisphere.[1] Moreover, it is known that left-hemisphere dominance for language is determined by organic rather than external factors, since it is unaffected by literacy, the number of languages a person speaks, or the type of language a person speaksùeven sign language is realized in the left hemisphere (Caplan 1987; Poizner et al. 1987). There is, however, some variability across the population with respect to hemispheric asymmetry for language. This vari-ability depends on handedness, familial handedness, and sex.

Several studies in this century have shown that about 98% of right-handed individuals have strong left-hemisphere dominance for language. Russell and Espir (1961) investigated the incidence of aphasia following left-side or right-side head wounds in right-handed war veterans, and found that 213 of 348 veterans with left-side wounds suffered aphasia, whereas only 10 of 276 veterans with right-side wounds did. Kimura (1983) conducted a similar study with right-handed stroke and tumor victims, and reported that 95 of 216 people with lesions in the left hemisphere suffered aphasia, compared to only 3 of 169 people with right-hemisphere lesions. Another source of evidence for left-hemisphere dominance for language in right-handers is the Wada test, in which sodium amytal, a short-acting barbiturate, is injected into one carotid artery, thereby temporarily paralyzing one entire hemisphere (Wada 1949). Milner et al. (1964, 1966; Milner 1974) used this technique to investigate hemispheric asymmetry for language, and demonstrated that transient aphasia occurs with left-hemisphere deactivation, but not with right-hemisphere deactivation, in 98% of right-handed subjects. The discovery that only about 2% of right-handers experience transient aphasia following right-hemisphere but not left-hemisphere deactivation is consistent with Hécaen and

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[1] Language functions that appear to be lateralized to the right hemisphere include emotional-attitudinal prosody, connotative semantics, and the kinds of reasoning necessary for establishing discourse cohesion and for understanding anomalies, as in jokes (Chiarello 1988; Joanette et al. 1990).

Albert's (1978) finding that crossed dextral aphasia occurs in only 0.4 to 2.0% of right-handers with right-hemisphere brain damage. More recently, a number of ERP and PET studies have confirmed predominantly left-hemispheric involvement in language functions, including syntactic comprehension, for right-handed individuals (see Garrett 1994 and Kutas & Van Petten 1994 for reviews of ERP studies, and Petersen & Fiez 1993, Frackowiak 1994, and Stowe et al. 1995 for reviews of PET studies).

In contrast to right-handers, left-handers have a more variable neural implementation of language functions. In a study of 123 left-handed individuals with brain damage, Goodglass and Quadfasel (1954) showed that while 53 of 65 patients with left-hemisphere lesions suffered aphasia, 50 of 58 patients with right-hemisphere lesions did too. This general pattern of results has been obtained in several similar studies (Bryden et al. 1983; Hécaen et al. 1981). Perhaps the most revealing source of evidence about the neural basis of language in the left-handed population comes from the Wada test. Mil-ner (1974) administered this test to a group of 74 left-handers and found that 51 (69%) showed left-hemisphere dominance for language, 10 (13%) showed bilateral representation, and 13 (18%) showed right-hemisphere dominance.

Another factor that influences hemispheric asymmetries for language is familial handedness. Looking first at right-handed individuals, Luria (1947) showed that those with all right-handed family members (RHF) have more severe and longer-lasting aphasia following left-hemisphere brain damage than those with some left-handed family members (LHF). However, this should not be taken to mean that LHF right-handers have right-hemisphere dominance for language, because if that were the case -we would expect to find a higher incidence of crossed dextral aphasia in LHF than in RHF right-handers, but in fact the incidence is not significantly greater for the former group (Bryden et al. 1983). Rather, it is more likely that LHF right-handers have a more diffuse, bilateral implementation of language functions than RHF right-handers. This view has received support from a series of studies conducted by Bever and his colleagues (Bever et al. 1989). One of the most intriguing findings to come out of this research is that RHF right-handers tend to rely more on grammatical than semantic information during on-line sentence processing, whereas LHF right-handers tend to exhibit the opposite preferences.

A third factor that appears to affect hemispheric asymmetry for language is sex. Several studies have reported data which suggest that males are more left-lateralized for language than females (McGlone 1980; Bryden et al. 1983; Kimura 1983, 1992, 1993). For instance, it has been observed that males are more likely than females to experience aphasia following left-hemisphere lesions. However, there are some problems with drawing strong conclusions from these studies. Caplan (1987) points out that many of the studies that have reported sex-by-laterality interactions for language are not statistically reliable, and that several other studies have failed to find such an interaction altogether. For instance, aphasia does not occur more frequently in females with right-hemisphere lesions than in males with right-hemisphere lesions (Damasio et al. 1989; Kimura 1992). On the other hand, a few recent PET studies provide solid support for the view that while right-handed males have left-hemisphere dominance for language, right-handed females have more bilateral representation (Shaywitz et al. 1995; Lock-wood et al. 1996). Unfortunately, none of these PET studies dealt with syntactic com-prehension.

Attempts to relate left-hemisphere dominance for language to neurobiological differences between the cerebral hemispheres have generally focused on a cortical region known as the planum temporale, which, on the left side, is an extension of Wernicke's area. In a classic study, Geschwind and Levitsky (1968) examined the brains of 100 right-handers and found that the length of the lateral edge of the planum temporale was longer in the left hemisphere than in the right in 65% of the cases, equal in the two hemispheres in 24% of the cases, and longer in the right hemisphere in 11% of the cases. Furthermore, the asymmetry was sometimes very dramatic, with the left planum being ten times larger than the right in some brains. Several researchers have speculated that this anatomical asymmetry is causally related to the fact that the left hemisphere is dominant for language in the vast majority of humans (Geschwind & Levitsky 1968; Galaburda 1984; Charles et al. 1994). However, there are a number of problems with this view. The finding that the left planum is bigger than the right in only 65% of the population does not dovetail with the well-established fact that the language-dominant hemisphere is the left in over 90% of the population. In addition, anatomical asymmetries of the same kind have been observed in some nonhuman primates as well as in hominids whose language capacities are controversial (Holloway 1995; Wilkins & Wakefield 1995). Finally, traditional methods of measuring the size of the planum temporale are fraught with complications (Witelson 1976). By using a new computer program that creates three-dimensional reconstructions of the cortical surface by unfolding it and laying it out like a sheet, Loftus et al. (1993) discovered that the anatomical asymmetry originally postulated by Geschwind and Levinsky is actually an illusion. In particular, they found that as many brains have a larger planum in the left hemisphere as have a larger planum in the right hemisphere.

To summarize, in the vast majority of the population, most language functions are carried out in the left hemisphere. Some factors that influence the participation of the right hemisphere in language include left-handedness, familial left-handedness, and possibly being female. Some researchers have associated left-hemisphere dominance for language to the left planum temporale, but recent studies have rendered this association problematic.

3.3.2 Intrahemispheric Localization

Numerous studies have demonstrated that within the left hemisphere, language functions involved in both comprehension and production are carried out predominantly in the perisylvian cortex (see Caplan 1987, 1994 for reviews). As shown in Figure 22, this large region of the brain includes the posterior half of the third frontal convolution

Figure 22: Left perisylvian language areas (from Fuster 1995).

(BA 44, 45, often referred to as Broca's area), the pre- and post-central gyri (BA 6, 43), the insular cortex buried within the sylvian fissure, the supramarginal and angular gyri of the parietal lobe (BA 39, 40), the posterior superior temporal gyrus (BA 22, often referred to as Wernicke's area), and the anterior superior temporal gyrus and temporal pole (BA 22, 38). Using the computer program described in the previous section, Gazzaniga (1989) created a "brainprint" illustrating the spatial contiguity of the various cortical areas making up the perisylvian language region; this is shown in Figure 23.

Figure 23: View of the "unfolded" cortical surface of the left hemisphere (from Gazzaniga 1989).

Other regions within the left hemisphere that have recently been attributed language functions include areas of the prefrontal cortex (BA 47, 10, 46ùGreenfield 1991; Deacon

1992; Grossman et al. 1992; Posner & Raichle 1994; Naidoo et al. 1995; Jaeger et al., in press), the anterior cingulate cortex (BA 24, 32ùGrossman et al. 1992; Posner & Raichle 1994), the middle temporal gyrus (BA 21ùDamasio 1992; Mazoyer et al. 1993; Damasio et al. 1996; Jaeger et al., in press), the basal ganglia and thalamus (Crosson 1990; Damasio 1992; Grossman et al. 1992), and the hippocampus (Squire et al. 1992; Jaeger et al., in press); also, portions of the right and left cerebellum have been shown to contribute to language processing (Fiez et al. 1992; Leiner et al. 1993; Posner & Raichle 1994; Silveri et al. 1994; Jaeger et al., in press; M ller, in press). In the sections that follow, I will concentrate on evidence regarding the neural implementation of the components of the syntactic comprehension system.

3.3.2.1 Left Perisylvian Areas that have been Associated with Syntactic Comprehension

Since the mid-1970s, syntactic comprehension has been associated most strongly with the cortex in the vicinity of Broca's area. Prior to this time, individuals with damage to this region of the brainùi.e., Broca's aphasicsùwere thought to have just a disorder of language production, since their most prominent symptoms (often but not always occurring together) are apraxia of speech and agrammatism, the first of which involves an impairment of articulation and the second of which involves the omission of function words, inflections, and sometimes verbs, and the avoidance of complex gram-matical constructions (Kean 1985; Menn & Obler 1990; Caplan 1991). However, in 1976 Caramazza and Zurif (1976) showed that although Broca's aphasics have good single-word comprehension and are able to understand complex sentences when semantic or pragmatic cues are available, their comprehension of many types of complex sentences drops to chance when they are forced to rely solely on grammatical infor-mation. Since then, a great deal of effort has been devoted to exploring the nature of the syntactic comprehension deficits of Broca's aphasics, or agrammatic aphasics, as they are sometimes called. For present purposes, the important point is simply that these findings have led many people to infer that the cortex in and around Broca's area is necessary for syntactic comprehension (Mesulam 1990; Damasio 1992).

While this view has become quite popular, other studies indicate that it is not completely adequate. First of all, a number of cases have been reported of Broca's aphasics who have impaired language production but normal syntactic comprehension (Miceli et al. 1983; Nespoulos et al. 1984; Kolk & van Grunsven 1985). In addition, Caplan et al. (1985; see also Caplan & Hildebrandt 1988) conducted an extensive investigation of the syntactic comprehension abilities of three groups of 58, 37, and 49 aphasic patients who were unselected, i.e., who belonged to a variety of diagnostic categories and had lesions in a variety of brain regions. The researchers tested the patients' performance on a wide range of grammatical constructions, and then carried out clustering analyses to identify subgroups of patients that differed in the overall severity of their syntactic comprehension deficits. Next, the researchers attempted to correlate the subgroups with the patients' lesion sites, which were classified as either purely fron-tal, purely parietal, or purely temporal. They found that patients with lesions confined to any of the three lobes in the perisylvian cortex were equally likely to fall into any of the subgroups identified by the clustering procedure. In other words, the results showed that damage restricted to any one of these lobes can cause a severe disruption of syntactic comprehension, no disruption whatsoever, or any degree of disruption. The inference that Caplan et al. draw from these findings is that the neural implementation of the major components of the syntactic comprehension system is not universal but rather appears to vary across individuals. Caplan (1994) suggests that the specific localization of these components is largely determined by genetic factors. This view is plausible simply because there must be genetic variation across individuals with regard to linguistic capacity; otherwise language could never have evolved. Further support for Caplan's view comes from a recent study demonstrating that while individual brains typically exhibit considerable variation in the gyral/sulcal pattern and in the relative size of different cortical areas, the brains of monozygotic twins show very little variation along these parameters, especially in the left hemisphere, which is dominant for language (Tramo et al. 1995; see also Whitaker & Selnes 1976).

Although Caplan et al.'s study is clearly very important, it has the limitation of not providing very narrow lesion localization data for the patients. Lesions were classified as either purely frontal, purely parietal, or purely temporal, but each of these lobes contains a very large amount of cortex. Thus, it is possible that two patients who are both treated as having frontal lesions actually have lesions affecting nonoverlapping areas of the frontal lobe. In such an event, if one patient suffers syntactic comprehen-sion deficits whereas the other does not, the most appropriate inference would be that the former patient's lesion affected a subarea of the frontal lobe which is necessary for syntactic comprehension whereas the latter patient's lesion did not. Moreoever, it could be that the subarea that is damaged in the former patient is one that typically plays an important role in syntactic comprehension. The upshot is that we should not be too quick to accept Caplan et al.'s view that the localization of the major components of the syntactic comprehension system is variable across the population.

Several other studies provide data that give some support to Caplan et al.'s view. Vignolo et al. (1986) examined the CT scans of 37 global aphasics with severe production and comprehension deficits, and found that 22 had lesions including both Broca's and Wernicke's areas, eight had lesions extending from Broca's area to the anterior part of the temporal lobe, three had lesions in the parietal-occipital region, and four had deep lesions affecting the insular cortex. Following an investigation of the syntactic compre-hension abilities of nine groups of aphasic patients, Naeser et al. (1987) concluded that although damage to the posterior two thirds of the superior temporal gyrus seems to cause the most severe deficits, damage to the surrounding frontal, parietal, and temporal areas can also produce deficits in some individuals. Finally, Ojemann (1983; Ojemann et al. 1989) reported that during intra-operative electrocortical stimulation studies, syn-tactic comprehension can be disrupted by stimulation in fairly restricted brain regions, but these critical regions vary considerably from patient to patient.

Although most of the evidence discussed so far goes against the idea that there is a systematic, universal implementation of the major components of the syntactic comprehension system, two important new studies claim to have found reliable deficit-lesion correlations. Remarkably enough, however, these studies isolate different brain regions as being crucial for syntactic comprehension. In the first study, Kempler et al. (1991) examined the relationship between syntactic comprehension ability and two measures of brain damageùone structural (CT) and the other metabolic (PET)ùin 43 aphasic patients. The major discovery was that across the entire group there was a strong correlation between syntactic comprehension impairment and glucose hypometabolism in the temporoparietal cortex. Furthermore, the severity of syntactic comprehension impairment was positively related to the degree of hypometabolism in this brain region. These findings are quite striking, but they must be interpreted with caution. A reduced metabolic rate in a specific brain area does not necessarily reflect less information processing in that area (Kosslyn 1994; Sergent 1994). And just because this group of patients has a common area of brain dysfunction does not mean that this particular area is absolutely necessary for syntactic comprehension in all of the patients. It may be the case that some of the patients' deficits are due to structural or metabolic lesions that they *don't* have in common. Such a situation is not only possible in principle, but is empiri-cally supported by the studies reviewed earlier that suggest variable localization of the components of the syntactic comprehension system.

The second study, which has not been published yet, was conducted by Dronkers et al. (submitted). These researchers assessed the syntactic comprehension abilities of 26 unselected aphasic patients, and subsequently carried out a cluster analysis to form three subgroups. Nine patients had consistently poor performance, 12 had consistently good performance, and five had mixed performance. Then they determined the common areas of brain injury for the different subgroups by applying a computer program that superimposes multiple CT scans. The results showed that while all but one of the patients in the impaired subgroup had lesions that included Broca's area, two of the patients in the normal-like subgroup did too. Moreover, three patients from each subgroup had lesions affecting Wernicke's area. When the researchers focused on a different cortical area, howeverùspecifically, the anterior third of the superior temporal gyrusùthey disco-vered that it was damaged in all of the patients in the impaired subgroup, but was spared in all of the patients making up the normal-like subgroup. The authors also review a variety of other sources of evidence that are consistent with the notion that this brain region plays a critical role in syntactic comprehension (from PET: Mazoyer et al. 1993, Stromswold et al. 1996; from patients with temporal lobe epilepsy and anterior temporal lobectomies: Milner 1958; Rochetta 1986; Frisk & Milner 1990; Shih & Peng 1992; from ERPs: Kluender & Kutas 1993; Hagoort & Kutas 1995). Dronkers et al. conclude by stating that although it is likely that many different areas within the left hemisphere contribute to syntactic comprehension, the anterior sector of superior temporal cortex may be an especially important area.

Like Kempler et al.'s study, this localization study is quite impressive, but it is not problem-free. In fact, it has the same basic weakness as Kempler et al.'s study. One cannot safely infer from superimposing lesion data from several patients that the overlapping sites are (part of) what cause the deficits, since it is always possible, on strictly logical grounds, that the deficits are due to nonoverlapping areas of damage in at least some of the cases. For instance, if three patients have lesions that include the anterior superior temporal gyrus, but one of the lesions also includes Broca's area, another also includes Wernicke's area, and the last also includes the middle temporal gyrus, it is logically possible that these patients' syntactic comprehension deficits are due to the nonoverlapping areas of damage. Thus, I believe that although the results of Dronkers et al.'s study are clearly very important, they are not entirely sufficient to warrant the conclusion that the anterior superior temporal gyrus is always necessary for syntactic comprehension.

Given that it is so hard to specify precisely a region within the left perisylvian cortex that is reliably associated with syntactic comprehension in general, it is no doubt even riskier to make any strong claims about the neural substrates of the various components of the syntactic comprehension system. Nonetheless, there is some evidence suggesting that each of the major components *tends* to be implemented in a particular region of the left hemisphere. Most of this evidence comes from studies using the PET and ERP techniques, but I should acknowedge at the outset that these studies are by no means easy to understand. Different studies sometimes produce conflicting results, and the results of virtually all of these studies contradict the results of some of the clinical studies described earlier: while the PET and ERP data suggest a fairly regular imple-mentation of processing subsystems, some of the clinical data suggest variable imple-mentation. Problems like these are vexing, but they do not require that we abandon any hope of ever making sense of the data. For instance, different findings in different PET studies may be due to different methodologies, and PET and ERP data may mask varia-bility across the subjects. Also, the subjects in PET and ERP studies are usually selected very carefully so that they are maximally similar with respect to sex, age, handedness, education, socioeconomic status, race, and so forth. Thus, it is possible that the subjects in PET and ERP studies have fairly similar neural substrates for syntactic comprehen-sion, but that the patients in clinical studies have more variable implementation, since they are not forced to meet such stringent inclusion criteria. Having quickly mentioned these difficult issues, I now proceed, albeit with some trepidation, to discuss the neuro-biology of the major components involved in syntactic comprehension. I will focus first on parsing and interpretation, and will then shift to the two processing resources of syntactic STM and attentional control.

3.3.2.2 Parsing

Grossman et al. (1992a) conducted a PET study in which one of the subjects' tasks was to determine whether or not each of a sequence of sentences contained an adjective. The results showed significant levels of activation in the left middle and inferior frontal lobeùa region encompassing Broca's areaùbut not in the left temporal or parietal lobes.[2] Since this receptive language processing task involves monitoring the categories of words, one might think that the brain areas that are activated are related to parsing. More specifically, one might think that the areas of activation reflect the process of assembling syntactic constituent structures and "scanning" them for nodes with the adjective category. This is not the only possible task analysis, however. An alternative is that the subjects were simply monitoring for *lexical* items of the adjective category, a task which does not in itself require parsing at all. Thus, although the brain areas that Grossman et al. found to be activated in this task may be related to parsing, they may instead be related to making detection judgements about the presence or absence of particular kinds of lexical items.

In another PET study, Mazoyer et al. (1993) presented 16 subjects with a variety of different types of linguistic stimuli. In two of the conditions, the stimuli were designed "to disrupt semantic integration while preserving syntax and prosody" (p. 468). Specifically, the stimuli in these conditions consisted of, first, sentences in which the content words were replaced with pseudowords and, second, sentences in which the content words were replaced with semantically unrelated words of the same grammatical category, frequency, length, and imageability. The researchers found that while neither of these conditions elicited activation in Broca's area, both of them elicited activation in the entire extent of the left and right superior temporal gyri. The posterior sectors of the left

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[2] There was also significant activation in several brain areas that are involved in the visual processing of words as well as in several areas that contribute to attention; I will discuss these latter areas later in the text.

and right superior temporal gyri were also activated in a separate condition in which the subjects simply listened to a list of words. The authors suggest that in the first two conditions the right anterior temporal activation may underlie the perception of prosody (see my footnote 11, p. 110), whereas the left anterior temporal activation may be related to parsingùor at least attempted parsing, given the distorted nature of the stimuli (recall that the stimuli involved sentences with pseudowords and semantic anomalies). On the other hand, the researchers point out that because the stimuli were so unusual, it may be that the left anterior temporal activation merely reflects verbal memory search. Also, in another condition in which the subjects listened to a story in French (their native language), activation was found not only in the left and right superior temporal gyri, but also in the left middle temporal gyrus and Broca's area. Thus, it is possible that either of these additional areas of activation is related to parsing.

In summary, although the two PET studies by Grossman et al. and Mazoyer et al. do not produce convergent results and conflict with some of the clinical data presented earlier, they do suggest that there is a tendency for parsing operations to be implemented in the anterior portion of the perisylvian cortex.

This view receives further support from several recent ERP studies of sentence processing. In an RSVP (i.e., rapid serial visual presentation) experiment, Neville et al. (1991) showed that phrase structure violations provoke a left anterior negativity that peaks between 200 and 300 msec post-stimulus. Using an auditory mode of presentation, Friederici et al. (1993) observed a similar early left anterior negativity in response to phrase structure violations. Additional replications based on violations of word category, argument structure, and inflectional agreement have been reported by R÷sler et al. (1993), M nte et al. (1993), M nte and Heinz (1994), and Friederici et al. (1995). The ERP effects produced by syntactic violations contrast in latency and neurotopography with other ERP effects produced by semantic violations. Most notably, the former effects contrast with the classic N400 effect, which results from semantic incongruity and has a bilateral temporoparietal distribution (although research with split-brain patients suggests that it is generated only by the left hemisphereùKutas et al. 1988; Kutas & Van Petten 1994). One nontrivial problem with all of these ERP studies is that they are based on linguistic violations, and so there is no guarrantee that we "know exactly what is 'expected' and therefore what is 'violated'" (Kutas & Kluender 1994:185). Another problem is that the ERP method does not allow completely reliable localization, since electrical currents not only travel across the brain and across the scalp, but are also distorted when they pass through the skull. Nonetheless, the studies mentioned above are still valuable insofar as they are consistent with the previously described PET data suggesting that parsing operations tend to be implemented in the anterior portion of the left persylvian cortex.

3.3.2.3 Interpretation

I turn now to the neurobiology of the interpretive component of the syntactic comprehension system. There are two main issues here: first, the implementation of the LSs and macroroles of verbs; and second, the implementation of the linking operations that establish correspondences between NPs, macroroles, arguments in the LSs of verbs, and concepts expressed by nouns. I will address these issues in order.

While a fair amount of work has been done during the past few years on how the meanings of concrete nouns are represented in the brain (for reviews see Caramazza et al. 1994, Damasio & Damasio 1994, and Gainotti et al. 1995), much less attention has been paid to the neural underpinnings of verb meanings, and the evidence that has been gathered does not fit together very well. Nonetheless, I will summarize the major findings and attempt to identify the most plausible possibilities regarding localization.

It is known that the "dorsal" processing stream leading from the occipital lobe through the parietal lobe to the premotor and supplementary motor cortices represents the visual motion patterns of entities, the spatial and temporal relations that obtain among entities, and schemas for executing different bodily actions (Kosslyn & Koenig 1992; Kosslyn 1994). Since this is the kind of information that verbs typically encode, one might expect that the LSs and macroroles of verbs would be represented in cell assemblies distributed throughout these regions of the brain (Damasio & Tranel 1993; Damasio & Damasio 1994). So far, however, I have not encountered any direct evidence for this hypothesis. Instead, it appears that two distinct anatomical areas in the left hemisphere, one in the frontal lobe and the other in the temporal lobe, play especially important roles in accessing and representing verb meanings.

Petersen et al. (1988, 1989; see also Posner & Raichle 1994) conducted a PET study in which one of the conditions required subjects to view a series of nouns and generate, for each one, a semantically related verb (e.g. *cake* --> *eat*). They found significant levels of activation in the ventrolateral prefrontal cortex, especially in area 47, as well as in Wernicke's area.[3] Subsequent studies led to two further discoveries about the interaction of these brain areas in the verb generation task. First, when subjects were allowed to practice the verb generation task before being scanned, all of the areas of activation seen in the first study disappeared and the only area that showed any significant activation was a completely different oneùnamely, the insular cortex (Raichle et al. 1994; see also Posner & Raichle 1994). The researchers concluded that the network of areas observed in the first study subserves nonautomatic processing for the task, whereas the single area observed in the second study subserves overlearned, automatic processing. Second, when naive subjects (i.e., subjects not allowed to practice) were imaged with both PET and ERP techniques simultaneously, it was shown that the ventrolateral prefrontal cortex is activated very quickly, about 200 msec after the noun is presented,

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[3] In addition, activation was found in the anterior cingulate cortex and in the right cerebellum. I will consider the cingulate activation later on when I discuss the neurobiology of attentional control. It is worth noting here that the overall pattern of results has been replicated in similar studies using PET (Wise et al. 1991), fMRI (McCarthy et al. 1993), and electrical stimulation (Ojemann et al. 1993).

and Wernicke's area is activated much later, about 700 msec post-stimulus (Snyder et al. 1995). Thus, it is possible that many semantic tasks could be carried out in the anterior region well before the posterior region becomes activated. Still, the entire set of results suggests that both regions of the brain contribute to the processing of verb meanings.

Support for the importance of the left frontal lobe in processing verb meanings comes from the clinical literature. Numerous studies have reported that lesions in this brain region typically disrupt the production and comprehension of verbs more than nouns (Miceli et al. 1984; McCarthy & Warrington 1985; Bates et al. 1991; Daniele et al. 1994; Kellogg 1995; Breedin & Martin 1996). None of these studies, however, distinguishes between two possible functions of this frontal region: (1) accessing the LSs and macroroles of verbs, and (2) actually representing these properties of verbs. Kosslyn and Koenig (1992) suggest that the frontal activation observed in the PET studies of verb generation reflects the former kind of operation rather than the latter. They base this speculation on the fact that other researchùe.g., in the domain of visual object recognitionùhas demonstrated that the left ventrolateral prefrontal cortex plays a role in the process of "looking up" specific information stored in memory (see also Kosslyn 1994). On their view, the actual representations of verb meanings are most likely implemented in the posterior superior temporal cortex (i.e., Wernicke's area) and perhaps also in the temporal-parietal-occipital junction. Kosslyn and Koenig's ideas about the lateral prefrontal cortex are consistent with Petrides's (1995) theory that one of the general executive functions of the ventrolateral prefrontal cortex is to actively retrieve information stored in short-term or long-term memory (see º2.1.1.4, pp. 26-7).

This approach accords nicely with the finding mentioned earlier that, in the verb generation task, the anterior region is activated much sooner than the posterior region. In addition, there is some clinical and PET data that dovetails with this approach. First, Damasio & Tranel (1993) discovered that four patients with lesions in the left frontal lobe performed normally on tests requiring the manipulation of noun concepts, but exhibited an impaired ability to retrieve verb concepts in both production and compre-hension modalities. The patients' knowledge of verb concepts was intact, however, as shown by the finding that some of the items that were failed on one experimental epoch were passed on the next, and vice versa. This suggests that a mechanism for just accessing the LSs and macroroles of verbs is implemented in the frontal region. Second, in an on-line sentence processing study, Shapiro et al. (1993) discovered that while normal subjects as well as Broca's aphasics momentarily activate all of the possible argument structures of a verb when they encounter it, Wernicke's aphasics do not. This suggests that the LSs and macroroles of verbs may actually be stored in the vicinity of the posterior superior temporal cortex. There is, however, a problem with Shapiro et al.'s resultsùin particular, if a verb-retrieval mechanism is implemented in the ventro-lateral prefrontal cortex, wouldn't we expect it to be impaired in Broca's aphasics, and hence wouldn't we expect these patients to be just as deficient as Wernicke's aphasics at activating all of the possible argument structures of verbs? Although this is a difficult question, one possible answer is that the retrieval mechanism in the ventrolateral pre-frontal cortex may not be used every time a person accesses a verb meaning; rather, it may only be necessary in tasks that require the subject to carry out a guided search through semantic memory. While the single-word tasks administered in the PET studies and in the clinical studies cited previously (including the one by Damasio and Tranel 1993) seem to tap this kind of operation, the on-line sentence processing study con-ducted by Shapiro et al. may not have.

A final piece of evidence supporting the view that the LSs and macroroles of verbs are implemented in the posterior superior temporal cortex comes from the PET study by Grossman et al. (1992a) that was mentioned in the discussion of parsing. In one of the conditions in this study, the subjects viewed various types of sentencesùactives, passives, and relativesùand were required to determine, for each one, whether or not the actor was female. Since this task involves monitoring the syntactically determined semantic relationships between noun concepts and verb concepts, it seems reasonable to assume that the brain areas that are activated contribute to representing the LSs and macroroles of verbs. The results showed that the most significant amount of activation elicited by this task was in the left posterior superior temporal cortex.

The evidence that I have presented concerning the localization of the LSs and macroroles of verbs is far from straightforward. Although the evidence suggests that two distinct regions of the left hemisphereùthe ventrolateral prefrontal cortex and the posterior superior temporal cortexùare both relevant, the precise function of each area is still a matter of controversy and remains to be elucidated (Posner & Raichle 1995). Another problem is that, as I have already mentioned, the findings summarized here are inconsistent with the studies on deficit-lesion correlations which indicate that damage to either the anterior or the posterior region does not always cause syntactic comprehension deficits. Setting these problems aside, however, the balance of evidence seems to favor the hypothesis that the semantic properties of verbs tend to be stored in the posterior superior temporal cortex, and I will assume that this view is the most plausible one in the rest of the thesis.

With respect to the second aspect of the interpretive component of the syntactic comprehension systemùnamely, the linking operations that establish correspondences between NPs, macroroles, the arguments of predicates, and the concepts expressed by nounsùthere is no solid evidence concerning implementation, and hence I have very little to say. In general, one can conceive of the neural substrates of linking operations as consisting of chains of connections between cell assemblies representing the various types of information that must be related by chains of correspondencesùspecifically, lexical units and noun and verb concepts, lexical units and NPs, NPs and macroroles, macroroles and the arguments of predicates, and, ultimately, noun concepts and the arguments of predicates. It is likely that these connections are strongly influenced by other cell assemblies that keep track of various types of cues for linking, such as word order and inflectional morphology (probably in the anterior perisylvian cortex) as well as syntactically relevant semantic properties of verbs (probably in the posterior peri-sylvian cortex).

Establishing all of the necessary correspondences between lexical, syntactic, and semantic information during the course of on-line sentence processing is one manifestation of a much larger neurocomputational problem that has come to be known as the binding problem. This problem has been studied most intensively in the domain of low-level visual perception, where it takes the following form: features of shape, color, motion, and so forth are all represented in anatomically distinct areas of the occipital lobe, so when our visual field contains several objects each of which bears these kinds of features, how does the brain manage to temporarily attribute the right features to the right objects? During the past few years, a great deal of excitement has built up over one possible solution to this problem. Basically, the idea is that transient binding is achieved by the synchronization of neural firing rates or oscillations in cell assemblies distributed throughout the relevant anatomical structures. For instance, cell assemblies representing the shape, color, and motion features of one object may all fire together in phase-locked fashion every 40 Hz, whereas cell assemblies representing the appropriate features of another object may all fire together in another phase-locked cycle that is out of synchrony with the first. This solution to the binding problem was originally presented in purely theoretical terms by von der Malsberg and Schneider (1986), but a number of researchers have recently accumulated a substantial amount of empirical evidence supporting it (for reviews see Singer 1993, 1994); moreover, a few researchers have begun to explore ways in which temporal binding can be applied to problems in domains other than vision (Hummel & Holyoak 1992; Shastri & Ajjanagadde 1993; Hummel et al. 1994; Desmedt & Tomberg 1994; Vaddia et al. 1995).

In principle, it seems that a similar binding mechanism would be useful for establishing correspondences during on-line sentence processing. To pick a highly simpli-fied example, consider how correspondences between NPs and macroroles might be established when processing a passive sentence like *Sally was seen by Harry*. A cell assembly representing the first NP initially starts to fire in synchrony with a cell assem-bly representing the actor macrorole, since there is always a high probability that the first NP of a sentence will be an actor. As the multiple cues for the passive construction are encountered, howeverùspecifically, the auxiliary, the perfect participial form of the verb, and the preposition *by*ùcell assemblies that represent these cues serve to break up the original synchronized oscillatory pattern and replace it with one that synchronizes the firing rate of the cell assembly for the first NP with the firing rate of the cell assem-bly for the undergoer macrorole. When the oblique NP is encountered, a cell assembly representing it quickly develops a synchronized oscillatory pattern with the cell assem-bly representing the actor macrorole, except this pattern is in a different phase than the other one.

Presumably, the sentence is ultimately fully interpreted by extending the first oscillatory pattern to include cell assemblies for the lexical unit *Sally*, the concept **Sally**, and the first argument of **see**, and extending the second oscillatory pattern to include cell asemblies for the lexical unit *Harry*, the concept **Harry**, and the second argument of **see**. In the end, the cell assemblies for the lexical items and the syntactic template of the passive construction can be allowed to revert to chaotic firing rates (Skarda & Freeman 1987; Freeman 1991). However, because correspondences between the noun concepts and the arguments of the predicate have been successfully established via grammatical mediation, the cell assemblies for these structures can continue to fire in distinct synchronized oscillatory patterns in semantic STM. This embodies the surviving propositional representation of the basic meaning of the sentence.

These ideas about how linking operations are carried out dynamically during on-line sentence processing are, of course, completely speculative. The functional-anatomical details of the matrix of cell assemblies that support linking can only be specified by future research involving neural network computer modeling together with empirical investigations of the microcircuitry of the left perisylvian cortex.

3.3.2.4 Syntactic STM

I shift now to the neurobiology of the first major processing resource of the syntactic comprehension systemùnamely, syntactic STM. Stromswold et al. (1996) conducted a very tightly controlled PET study which managed to isolate the probable neural substrates of this particular processing resource. In the first condition, subjects viewed a series of sentences which all contained subject-object relative clauses (e.g., *The limerick that the boy recited appalled the priest*), and in the second condition, they viewed a series of sentences that all contained object-subject relative clauses (e.g., *The biographer omitted the story that insulted the director*). In each condition, the subjects' task was to determine whether or not the sentences were semantically anomalous (e.g., *The teenager that the miniskirt wore horrified the mother* or *The woman tipped the hairdresser that pleased the haircut*). Since this task forced the subjects to parse and interpret the sentences, the researchers could be confident that they were attending closely to the stimuli. Of special interest is the well-established fact that the two types of relative clause impose different demands on syntactic STM. As I pointed out in section 3.2.2.1 (pp. 94-5), subject-object relatives place a heavy load on syntactic STM, since the pivot NP must be retained until both the embedded predicate and the matrix predicate are encountered; by contrast, object-subject relatives do not tax this processing resource, since all of the NPs can be interpreted quite rapidly. Thus, in the experiment, subtrac-tion of the blood flow map for the second condition from the blood flow map for the first condition should reveal the location of the brain area(s) that implement syntactic STM. What the researchers discovered when they carried out this subtraction was that a structure within Broca's areaùspecifically, the pars opercularisùwas significantly activated. They suggest that this brain region may subserve the memory resources necessary for comprehending sentences containing subject-object relative clauses. They acknowledge, however, that although the activation observed in this region may reflect purely syntactic STM, it could also reflect verbal STM, since the subjects could have been rehearsing the sentences to ensure correct template selection and linking (see º3.2.2.2, p. 100). Consistent with this possibility is the fact that both neuroimaging and clinical studies indicate that Broca's area contributes to the articulatory aspect of verbal STM (Vallar & Shallice 1990; Paulesu et al. 1993; Awh et al. 1995). The authors also acknowledge another, more serious problem with their resultsùspecifically, that it is difficult to reconcile the idea that Broca's area is necessary for syntactic comprehension with the many studies which show that lesions in Broca's area do not always cause syntactic comprehension deficits.

Another interesting finding emerged from Stromswold et al.'s PET study and deserves to be mentioned here. This finding is related to the differences between, on the one hand, the blood flow maps for the first two conditions and, on the other hand, the blood flow map for a third condition in which the subjects viewed a mixture of sentences with subject-object and object-subject relatives and were required to detect nonwords (e.g., *The sculpture that the artist exhibited shocked the findle; The economist predicted the recession that chorried the man*). When the blood flow map for the third condition was subtracted from the one for the first condition (i.e., the subject-object relative condition), significant activation was found in both Wernicke's area and the anterior sector the left superior temporal gyrus, this latter area being the one that Dronkers et al. (submitted) claim to be crucially involved in syntactic comprehension. However, when the blood flow map for the third condition was subtracted from the one for the second condition (i.e., the object-subject relative condition), no significant activation was found in either of these areas; moreover, similar findings resulted from subtracting the blood flow map for the second condition from the one for the first. It is possible to make sense of this pattern of data if we assume that both Wernicke's area and the anterior sector of the left superior temporal cortex were activated rather strongly in the first condition, less strongly in the second condition, and still less strongly in the third condition. Such an interpretation can explain why the differences between the first and second condition, and between the second and third condition, were *not* significant, but the differences between the first and third condition *were* significant. Now the question arises as to what this pattern of data implies about the neurobiology of syntactic comprehension. One reasonable hypothesis which is consistent with some of the other studies that I have discussed in this chapter is the following: the pars opercularis of Broca's area is involved in syntactic (and verbal) STM, the anterior sector of the left superior temporal cortex is involved in parsing, and Wernicke's area is involved in interpretation.

In this context, I should point out that there is nothing unnatural about a mechanism for short-term memory being implemented in a different brain area than the one that implements the actual representations that get held on-line. In fact, Goldman-Rakic (1987, 1995) and others (e.g., Fuster 1989; Petrides 1995) have demonstrated that a major function of the prefrontal cortex is to maintain in an activated state cell assemblies located in the posterior association cortices, especially when the environmental stimuli necessary to activate the cell assemblies in a bottom-up fashion are no longer present. Such short-term memories may be achieved through reverberatory circuits that include not just specific prefrontal and posterior cortical sites, but also the basal ganglia-thalamocortical pathways that I discussed in section 2.1.1.4 (pp. 17-27) (Goldman-Rakic 1994). Recall that in that discussion I suggested that there may be a basal ganglia-thalamocortical pathway involving the ventrolateral prefrontal cortex, which includes Broca's area (pp. 26-7). If so, this would enable the basal ganglia to use information received from the left superior temporal cortex to signal to Broca's area when it is appropriate to hold certain syntactic templates on-line and when it is appropriate to allow them to decay (this hypothesis is based on the treatment of the basal ganglia as a "cortical biasing system" in º2.2.4.1, pp. 39-42). The linguistic short-term memory functions of Broca's area may also be facilitated by dopaminergic innervation from the substantia nigra (via the mesocortical projection system); however, this is by no means certain. As I mentioned in Chapter 2 (º2.1.1.3, p. 12-14), studies with macaques show that the dopamine supply to the prefrontal cortex is strongest dorsally and weakest laterally and mesially (Williams & Goldman-Rakic 1993). Still, it is possible that evolutionary changes led to a richer dopamine supply to the lateral region of the prefrontal cortex in humans; future research is needed to determine whether this is the case.[4]

Although the ERP method does not provide spatial resolution fine enough to isolate Broca's area, a recent ERP study conducted by Kluender and Kutas (1993) does provide support for the more general idea that the anterior portion of the left perisylvian cortex plays an important role in syntactic STM. These researchers monitored the electrophysiological activity of subjects' brains from thirteen recording sites while they were processing visually presented sentences that require filler-gap integration. A wide range of constructions were used as stimuli, including yes/no-questions and WH-questions that

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[4] Neuroscientists often take macaques to be "model" or "representative" primates and assume that their findings can safely be generalized to the human brain, but there are some serious problems with this kind of reasoning (Tooby & Cosmides 1989; Preuss 1995). Over 200 different species of primates have been identified, and although all of them have certain traits in common, each has a variety of unique evolutionary specializations as well. Macaques and humans share a long history of common ancestry, and this is reflected in a relatively large number of shared features, such as eyes set together in the front of the face rather than on the sides, dextrous hands with opposable thumbs and nails instead of claws, and a complex social organization requiring the cognitive ability to keep track of a large number of ever-changing dominance and mating relationships. On the other hand, the macaque and human lineages diverged about 25 million years ago, and since then each one has adapted to different ecological and social conditions. For instance, macaques have evolved cheek pouches for hiding food from higher-ranking individuals, as well as a social organization based on a stable core of closely related females. By contrast, humans have evolved such features as bipedalism, language, concealed female ovulation, and male parental investment. Unique evolutionary specializations like these make extrapolations from macaque brains to human brains inherently suspicious, because when we consider a particular aspect of macaque neurobiology, there is no direct evidence indicating whether or not it is also part of human neurobiology. As Preuss (1995: 1229) puts it, "How can we tell whether we are studying the neural analogues of the opposable thumb and frontated orbits, rather than something akin to a cheek pouch?" Consideration of the mesocortical dopaminergic projection system is but one of an unlimited number of specific instances of this problem.

varied in terms of gap site. There were two primary points of interest in each sentence: first, immediately after the filler NP; and second, immediately after the gap. Simplified examples of the yes/no-questions, along with controls, are presented below (fillers are indicated by italics, gap sites by blank lines, and points of measurement by capital letters):

ERPs to Function Words Immediately Following Fillers

a. Target Items:
    i. subject: Has she forgotten *who* ____ IS . . . ?
    ii. object: Has she forgotten *what* THEY . . . ?
b. Control Items:
    i. that: Has she forgotten that THEY . . . ?
    ii. if: Has she forgotten if THEY . . . ?

ERPs to Function Words Immediately Following Gaps:

c. Target Items:
    i. subject: Can't you remember *who* ____ tried to scare him INTO . . . ?[5]
    ii. object: Did he wonder *who* he could coerce ____ INTO . . . ?
d. Control Items:
    i. that: Can you believe that he was able to lure them INTO . . . ?
    ii. if: Did he wonder if he could coerce her INTO . . . ?

With regard to the post-filler measurements, Kluender and Kutas observed that between 300 and 500 msec after the function words in the object condition (a-ii), a distinct effect of enhanced left anterior negativity (LAN) occurred. This effect was not seen, however, at the corresponding positions in either the subject condition (a-i) or the two control conditions (b-i,ii). The researchers suggest that the LAN effect indexes the need to suspend interpreting *what* and instead retain it in syntactic STM. In addition, they note that the absence of a LAN effect in the subject condition is not really surpris-

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[5] The actual gap in this sentence is after *who*, but ERPS were measured at *into* because this is the point that corresponds to the point immediately following the gap in the subsequent example. Hence, it may be best to think of this sentence as another control for the critical object-gap condition.

ing, since the post-filler function word is a verbal element that unambiguously indicates that the filler serves as its subject and thus does not need to be held in syntactic STM until a gap is encountered. With regard to the post-gap measurements, the very same pattern of results was obtained. A LAN effect appeared between 300 and 500 msec after the function words in the object condition (c-ii), but not at the corresponding positions in either the subject condition (c-i) or the two control conditions (d-i,ii). Kluender and Kutas interpret this occurrence of the effect as a reflection of the retrieval or reactivation of the semantic properties of the filler for purposes of being associated with the predicate. Although other grammatical constructions that require syntactic STM (see Table 3) were not used in the study, there is a clear prediction that they should elicit LAN effects at the post-filler and post-gap positions as well. In summary, the results of this ERP study are consistent with the results of Stromwold et al.'s (1996) PET study in relating syntactic STM to the cortex in the vicinity of Broca's area.

3.3.2.5 Attentional Control

The last component of the syntactic comprehension system whose neural substrates I will consider is the processing resource of attentional control. I will argue that one brain areaùthe anterior cingulate cortexùdefinitely contributes to attentional control, and that two othersùthe ventrolateral prefrontal cortex and the basal gangliaùare likely to contribute as well.

In the discussion of basal ganglia-thalamocortical circuits in Chapter 2, I mentioned several studies which suggest that the anterior cingulate cortex plays an important role in monitoring the activities within particular mental domains and, when necessary, influencing response selection in a top-down fashion by suppressing inappropriate responses and promoting appropriate ones (see º2.1.1.4, pp. 23-5). And in the discussion of attentional control earlier in this chapter, I argued that similar operations may be needed in order to regulate template selection and linking during the on-line processing of certain types of challenging grammatical constructions, such as object-gap relative clauses (see º3.2.2.2, pp. 98-107). Thus, a clear prediction is that the left anterior cingulate cortex should be activated when subjects process these types of constructions, but not when they process simpler types of constructions, such as subject-gap relative clauses. This prediction has received support from two recent PET studies.

The first study is the one by Stromswold et al. (1996) that I described in the previous section. As I said before, the researchers found significant activation in Broca's area for subject-object relatives (e.g., *The limerick that the boy recited appalled the priest*), but not for object-subject relatives (e.g., *The biographer omitted the story that insulted the director*), which suggests that Broca's area is involved in syntactic STM. In addition, the researchers reported significant activation in the left anterior cingulate cortex during the processing of subject-object relatives but not during the processing of object-subject relatives. It is reasonable to suppose that this activation reflects the intervention of attentional control to regulate template selection and linking. More precisely, the activation may reflect the attentional processes involved in, first, detecting an impasse in on-line sentence processing and, second, responding to this impasse by suppressing the incorrect subject-gap template and its associated linking pattern and promoting the correct object-gap template and its associated linking pattern.

It is noteworthy that there is a connection here, albeit a tenuous one, with my earlier speculations about how linking operations may be mediated neurophysiologically by synchronized oscillatory patterns among participating cell assemblies (see º3.3.2.3, pp. 128-31). Recent theoretical and experimental work on how such patterns may provide a solution to the more general "binding problem" has led to the hypothesis that attention is one of the chief mechanisms influencing the buildup of patterns and the competition between rival patterns. Thus, it may be the case that the left anterior cingulate cortex regulates linking during sentence processing by manipulating the synchronized oscillatory patterns between the relevant cell assemblies.

The second PET study is the one by Grossman et al. (1992a) that I mentioned earlier in the sections on the neurobiology of parsing and interpretation (see º3.3.2.2, p. 122, and º3.3.2.3, p. 127-8). Recall that in one condition subjects were presented with a series of sentences and had to determine whether each one contained an adjective, and in another condition subjects were again presented with a series of sentences and this time had to determine whether the actor in each one was female. In both of these conditions, significant activation was observed in the left anterior cingulate cortex. A justified speculation is that in the first condition this brain area serves to amplify the processing efficiency of parsing operations and detect the presence of adjectives, while in the second condition it serves to amplify the processing efficiency of linking operations and detect the presence of female agents. A problem with Grossman et al.'s study, though, is that several different types of constructionsùactives, passives, and both subject-gap and object-gap relativesùwere included in each condition; hence, it is impossible to tell if one type of construction elicited greater anterior cingulate activation than the others.
As a consequence, Grossman et al.'s PET study does not provide as strong support as Stromswold et al.'s for the hypothesis that attentional control is needed more for the processing of object-gap relatives than for the processing of subject-gap relatives.

Further support for the view that the left anterior cingulate cortex contributes to the on-line processing of object-gap relative clauses comes from the ERP study by King and Kutas (1995) that I mentioned in section 3.2.2.2 (p. 102). Recall that these researchers monitored the electrophysiological activity of subjects' brains while they viewed subject-subject relatives and subject-object relatives (e.g., *The reporter that attacked the senator admitted the error* vs. *The reporter that the senator attacked admitted the error*). The results showed that the two consecutive verbs in the subject-object relatives elicited a long, sustained negativity over the left lateral frontal and left central frontal recording sites; by contrast, the two corresponding positions in the subject-subject relatives did not elicit this kind of waveform. In line with Kluender and Kutas's (1993) ERP study of syntactic STM, it is likely that the negativity observed over the left lateral frontal site indexes the reactivation of the semantic properties of the filler NP for linking purposes (note that this NP must be linked not only to an argument of the embedded predicate but also to an argument of the matrix predicate). As for the negativity observed over the left central frontal site, King and Kutas point out that slow waves such as this "are generally taken to reflect additional processing instigated by perceptually or conceptually difficult operations (Ruchkin et al. 1988)." For this reason, they suggest that the "standing" negativity seen in their own study reflects attentional processes implemented in the anterior cingulate cortex. It is remarkable that King and Kutas's ERP data regarding the processing of subject-object relatives dovetails perfectly with Stromswold et al.'s PET data regarding the processing of the same kind of sentences: the ERP finding of a distinctive left lateral frontal waveform corresponds to the PET finding of activation in Broca's area, and the ERP finding of a distinctive left central frontal waveform corresponds to the PET finding of activation in the anterior cingulate cortex.

Although the evidence that I have presented so far strongly suggests that attentional control is implemented in the anterior cingulate cortex, the real functional-anatomical situation may be more complicated than this. Recall that Broca's area is part of the ventrolateral prefrontal cortex (BA 45, 47, inferior 46) and that, according to Petrides (1995), this large region of the frontal lobe is involved not only in holding information from different mental domains (including the linguistic domain) active in STM, but also in making judgements about this information, i.e., operating on it in a top-down fashion (see º2.1.1.4, pp. 26-7). This opens up the possibility that Broca's area contributes to both syntactic (and verbal) STM and the decision-making or executive aspect of atten-tional control, the aspect that is relevant to regulating template selection and linking during the on-line processing of grammatically challenging sentences, such as subject-object relatives (see also Goldman-Rakic 1995). If this is the case, then some sort of division of attentional labor exists between the anterior cingulate cortex and Broca's area. The nature of such a division, however, is not clear.

Furthermore, it is likely that the basal ganglia contribute to attentional control for syntactic comprehension in several different ways. First of all, it is known that the basal ganglia influence the anterior cingulate cortex through a specialized circuit. In addition, if it is true that another circuit exists between the basal ganglia and the ventrolateral prefrontal cortex, and if it is true that Broca's area plays a role in the decision-making aspect of attentional control, then this provides another route by which the basal ganglia could influence attentional processes. Based on the discussion of the basal ganglia in Chapter 2, it is reasonable to suppose that these two circuits may operate in the following manner. During on-line sentence processing, the basal ganglia receive continuous input from the left temporal cortex and recognize in this input morphosyntactic, lexical, and semantic cues that are relevant to the parsing and interpretation of complex constructions, including ones with noncanonical linking. The basal ganglia then translate these cues into a recommendation for template selection and linking and relay this information up to the anterior cingulate and ventrolateral prefrontal cortices, where it serves to bias decision-making. Yet another way in which the basal ganglia might contribute to attentional control is through the mesocortical dopaminergic projection system (although this innervation may be weak in the anterior cingulate and ventro-lateral prefrontal cortices, but see footnote 14, p. 134). Dopamine may function in the cortex by reinforcing or boosting certain attentional processes that have been successful in similar contexts in the pastùe.g., processes that enable the proper detection of, and response to, impasses that occur when the syntactic comprehension system is confronted with complex noncanonical constructions.

Empirical support for the view that the basal ganglia contribute to attentional control comes from the PET study conducted by Grossman et al. (1992a). In both of the critical linguistic conditions in this studyùfirst, viewing sentences and determining whether each one contains an adjective, and second, viewing sentences and determining whether the actor in each one is femaleùsignificant activation was found not only in the cortical areas described previously, but also in the left caudate nucleus and the left thalamus.[6] As I mentioned above, however, the design of this study makes it impossible to tell if these activations were stronger for the sentence types that putatively require attentional control (e.g., object-gap relative clauses) than for the sentence types that do not (e.g., simple transitive actives). The PET study conducted by Stromswold et al. (1996) should also provide information about the role of the basal ganglia in sentence processing; how-ever, the basal ganglia were not among the authors' designated ROIs (i.e., regions of interest), and as a result they do not mention the basal ganglia anywhere in their paper. This is unfortunate, since it would be interesting to know if the basal ganglia were acti-vated more during the processing of subject-object relatives than during the processing of object-subject relatives, as the ideas presented above would predict.

3.3.2.6 Summary

I have reviewed a wide range of evidence concerning the neural implementation of the syntactic comprehension system. Taken together, the evidence leads to the follow-ing hypotheses. In the vast majority of the population, the syntactic comprehension system is realized in the left hemisphere, and the primary factors influencing variable lateralization are handedness, familial handedness, and sex. Within the left hemisphere, the major components of this system are realized primarily in the perisylvian cortex.

A few studies have claimed that certain areas of the perisylvian cortex are especially important for syntactic comprehensionùe.g., Broca's area, the temporoparietal region, and

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[6] Grossman et al. do not indicate whether the ventral striatum was also activated. This is important because it is the ventral striatum, not the caudate, that is involved in a circuit with the anterior cingulate cortex. The caudate migtht be involved, however, in a circuit with the ventrolateral prefrontal cortex, but nothing is known about this for sure. It is possible that the ventral striatum was also activated in the study, but that this activation could not be distinguished from the activation of the caudate.

the anterior superior temporal cortexùbut other studies have shown that damage restricted to any of the three lobes in the perisylvian cortexùfrontal, parietal, and temporalùmay or may not affect syntactic comprehension abilities. Given these latter findings, it is possible that the neural substrates of the major components of the syntactic comprehension system vary across individuals. Nonetheless, additional evidence suggests that there are "central tendencies" for the localization of these components. There seems to be a tendency for parsing to be implemented in the anterior sector of the perisylvian cortex (perhaps especially in the anterior superior temporal cortex) and for interpretation to be implemented in the posterior sector (perhaps especially in Wernicke's area). In addition, it appears that syntactic STM tends to be implemented in the anterior perisylvian cortex (primarily Broca's area) and that this processing resource may receive support from the basal ganglia. Finally, there are good reasons to believe that several brain areas contribute to attentional control: the anterior cingulate cortex, Broca's area, and the basal ganglia.

3.4 Predictions about Syntactic Comprehension in Parkinson's Disease

Now that a rough multilevel model of the normal syntactic comprehension system is in place, it can be used as a frame of reference for formulating and testing predictions about what types of English constructions we would expect to be easy or difficult for early-stage, nondemented PD patients to comprehend, given the background information about the neuropathology and neuropsychology of PD provided in Chapter 2. This final section of Chapter 3 is devoted to formulating predictions about the syntactic comprehension abilities of PD patients, and Chapters 4 and 5 are devoted to describing previous studies as well as new studies that address these predictions.

I will begin by briefly recapitulating the most distinctive features of PD. Neuro-pathologically, PD causes degeneration of the dopaminergic projection systems of the basal ganglia. The nigrostriatal system is affected in all patients, leading to dysfunction in the putamen and, to a lesser degree and in only about 50% of patients, in the caudate. The dopamine reduction in the putamen and caudate prevents these structures from efficiently processing their cortical and thalamic input, and this in turn leads to the "demodulation" of several areas in the frontal lobe that receive the output of the basal ganglia. Since the putamen is involved in the motor circuit, all patients develop motor disorders, and since the caudate is involved in the dorsolateral and orbitofrontal circuits (and perhaps also a ventrolateral circuit), around 50% of patients develop cognitive disorders. The mesocortical dopaminergic projection system is also compromised in PD, but not as severely as the nigrostriatal system. This leads to moderate dopamine depletion not only in the ventral striatum, which is involved in the anterior cingulate circuit, but also in a number of limbic sites (amygdala, hippocampus) as well as in the frontal cortex (these projections may be more dense in the dorsal than the lateral or mesial regions). This aspect of the disease contributes to the cognitive deficits exhibited by patients.

Neuropsychologically, around 50% of early-stage, nondemented PD patients display a kind of "environmental dependency syndrome" which is similar to that seen in patients with lesions to the prefrontal cortex. In a variety of cognitive domains, they perform well on tasks that provide clear, explicit guidelines for behavior, regardless of whether the tasks are simple or complex, routine or nonroutine; however, they perform poorly on tasks that require self-regulated problem-solving or response formation, or internal attentional control for shifting from one mental set to another or for maintaining a given mental set in the face of interference from competing ones. More generally, the patients suffer a decline in their abilty to concentrate, to flexibly alternate among different trains of thought, and to construct imaginary scenarios without environmental support. It is likely that this constellation of "executive" or "frontal type" impairments arises because cell assemblies in the prefrontal cortex are no longer receiving appropriate "boosting" or reinforcement from either the relevant basal ganglia-thalamocortical circuits or the mesocortical dopaminergic innervation.

Given this neuropathological and neuropsychological profile, how would we expect PD patients to perform with the kinds of English constructions described in this chapter? The most straightforward prediction is that around 50% of PD patients should have trouble understanding those constructions that depend on attentional control. As shown in Table 4 (p. 107), these constructions are as follows:

a. relative clause:
    i. subject-object relative: *The man that Sally saw knows me.*
    ii. object-object relative: *I know the man that Sally saw.*

b. cleft:
    i. object cleft: *It was the man that Sally saw.*

c. raising-to-subject:
    i. subject-to-subject raising:
        a. noncanonical: *Sally seems to Harry to be tall.*
    ii. object-to-subject raising:
        a. noncanonical: *Sally is easy for Harry to see.*

I argued in section 3.2.2.2 that all of these constructions are likely to require attentional control in order to suppress a high-frequency, canonical template and linking pattern and promote a low-frequency, noncanonical template and linking pattern. Although the foregrounding and backgrounding passive constructions (e.g., *Harry was seen/Harry was seen by Sally*) also involve low-frequency, noncanonical templates and linking patterns, they should not require attentional control because, unlike the constructions listed above, they contain multiple overt morphosyntactic cues that signal their atypical status;

moreover, they are structurally simpler than the relative, cleft, raising, and control constructions, since they only involve a single core. With regard to the active and passive undergoer-control constructions (e.g., *Harry persuaded Sally to be nice/Sally was persuaded by Harry to be nice*), I argued that even though the determination of the "controller NP" depends on implicit semantic properties of the matrix verb, attentional control should not be required because these semantic properties are easily accessible; in addition, for the passive version of the construction, the noncanonical status of the matrix core is clearly marked. As for the undergoer-intransitive construction, it involves implicitly signaled noncanonical linking, but special attention should not be needed to regulate the linking process because, first, the constituent structure is extremely simple, and second, as with the undergoer-control constructions, the proper linking strategy is determined by readily available semantic properties of the verb.

With regard to the underlying neurobiology, I argued in section 3.3.2.5 that the decision-making component of attentional control which is responsible for regulating template selection and linking in a top-down manner has a distributed implementation in the brain. Several sources of evidence indicate that the anterior cingulate cortex is crucially involved. In addition, the proposals advanced by Petrides (1995) lead to the possibility that the ventrolateral prefrontal cortex (more narrowly, Broca's area) contributes as well. Finally, there are both theoretical and empirical reasons for believing that the basal ganglia contribute in two waysùfirst, by means of circuits with the anterior cingulate cortex and, in theory, with the ventrolateral prefrontal cortex; and second, by means of meso-cortical dopaminergic innervation of these two cortical sites. Since it is known that the anterior cingulate cortex is "demodulated" in PD because of disruption of both the associated basal ganglia-thalamocortical circuit and the meso-cortical dopaminergic projection system, this provides a solid neural foundation for the prediction that PD patients should have difficulty understanding the constructions listed above. Furthermore, if it is really the case that Broca's area contributes to attentional control for syntactic comprehension, and if this area really is influenced by the basal ganglia through both a circuit and direct dopaminergic innervation, then this provides another avenue by which the processing of the constructions listed above could be impaired in PD.

What about the other subsystems that are necessary for syntactic comprehension? I argued that parsingùi.e., assembling constituent structures and assigning syntactic relationsùtends to be implemented in the anterior portion of the left perisylvian cortex. It is difficult to localize parsing operations more precisely than this, but, taken together, the studies reviewed in section 3.3.2 suggest that it is more likely that these operations are carried out in the anterior superior temporal cortex than in Broca's area. If this hypothesis is correct, then we should not expect PD patients to have a basic parsing deficiency, since, although the anterior superior temporal cortex sends input to the basal ganglia, it does not receive output from the basal ganglia, nor does it receive a significant dopaminergic innervation from the mesocortical projection system. On the other hand, it is important to note that other modulatory neurotransmitter systems are mildly affected in early PD. In particular, the ascending cholinergic system is affected in many patients (DuBois et al. 1983, 1991), and this system projects rather densely to the superior temporal cortex, especially in the left hemisphere (Amaducci et al. 1981). Thus, it is possible that acetylcholine plays a role in parsing (Mimura et al. 1995), and that the reduction of this chemical in PD degrades the efficiency of parsing to a slight degree.

Next, consider interpretationùi.e., the processes of accessing the LSs and macro-roles of predicates and establishing correspondences between NPs, macroroles, the arguments of predicates, and the concepts encoded by nouns. I argued in section 3.3.2.3 that the LSs and macroroles of predicates may be stored in the posterior region of the left perisylvian cortexùi.e., in Wernicke's area and perhaps also the supramarginal gyrus (BA 40). If this localization hypothesis is correct, we would not expect the LSs and macroroles of predicates to be disturbed in PD, since this cortical region is not involved in a reciprocal circuit with the basal ganglia, nor does it receive a significant dopaminergic innervation. Nonetheless, there is still the possibility that the mild cholinergic depletion mentioned above adversely affects semantic processing in the posterior perisylvian cortex to a slight degree. Another point that I made in section 3.3.2.3 was that correspondences between lexical, syntactic, and semantic structures are dynamically formed during on-line sentence processing via synchronization of the firing rates of the cell assemblies that represent the relevant structures. Thus, the establishment of correspondences could be disrupted if brain damage causes the "time windows" of activation for cell assemblies representing different types of structures to become discordant. Accounts of this sort have been offered for developmental dysphasia, dyslexia, and the syntactic comprehension deficits in agrammatic Broca's aphasia (Llinßs 1993; Mer-zenich 1993; Friederici 1995; for a theoretical discussion of lesion-induced "hetero-chrony"ùi.e., slowing of some neural processes vis-ß-vis othersùsee Brown 1988, 1994). With regard to PD, some researchers have claimed that patients exhibit brady-phrenia, i.e., a general slowing of thought processes, a kind of "psychic akinesia" (Rogers et al. 1987; Morris et al. 1988; Pillon et al. 1989). However, in a thorough review of the literature on this topic, DuBois et al. (1991) show that significant cognitive slowing only occurs during the performance of complex tasks that draw heavily on executive functions subserved by the prefrontal cortex. For this reason, it does not seem likely that the basic ability to establish correspondences during syntactic comprehension is impaired in PD patients.

The last component of the syntactic comprehension system to be considered is syntactic STM. I argued in section 3.3.2.4 that this processing resource tends to be implemented in the anterior region of the left perisylvian cortex, probably in Broca's area. Hence, whether we should expect PD patients to have intact or impaired syntactic STM depends on whether this cortical area participates in a reciprocal circuit with the basal ganglia and/or receives a significant dopaminergic innervation from the meso-cortical projection system. In both this chapter and the previous one, I have made it clear that although there is a good chance that these anatomical pathways exist, their reality has not been confirmed. The status of syntactic STM in PD is therefore an open issue to be resolved through psycholinguistic experimentation. The studies that I will describe in the next two chapters will provide evidence bearing on this issue.

Chapter 4: Previous Studies of Syntactic Comprehension Deficits in Parkinson's Disease

A tremendous amount of research has been devoted to understanding and treating a wide range of cognitive deficits exhibited by PD patients; in fact, one major medical database (MEDLINE) lists over 200 references within just the past two years. However, very little of this research has focused on the linguistic abilities of such patients. Of the handful of the studies that have addressed language production in this population, the most prominent findings are as follows. At the articulatory level, PD patients sometimes have motor speech disorders (Critchley 1981; Scott et al. 1984; Darkins et al. 1988; Illes et al. 1988; Illes 1989). At the lexical level, they often have word-finding difficulties (Matison et al. 1981; Cooper et al. 1991; Auriacombe et al. 1993). Finally, at the grammatical level, they tend to use simplified sentence structures with an increase in the ratio of open-class items (nouns, verbs, adjectives) to closed-class items (determiners, auxiliaries, prepositions, etc.) as well as an increase in the frequency and duration of hesitations and pauses—in short, they display a very mild Broca's aphasia (Cummings et al. 1988; Illes et al. 1988; Illes 1989).

With regard to language comprehension, I am not aware of any reports of phonological or lexical impairments. However, several studies conducted within the past five or six years have shown that roughly half of PD patients have mild to severe syntactic comprehension deficits. The first study to document such deficits was conducted by Philip Lieberman and his colleagues at Brown University (Lieberman et al. 1990; see also Lieberman et al. 1992). Soon after this, another study was published by a research team in Greece (Natsopoulos et al. 1991). Inspired by these new discoveries, Murray Grossman and his colleagues at the University of Pennsylvania launched a whole series of detailed studies designed to isolate both the functional and neurobiological bases of the deficits (Grossman et al. 1991, 1992a, 1992b, 1993a, 1993b, 1994; Geyer & Grossman 1995; Seidl et al. 1995; Grossman, in press). Finally, a study comparing the sentence processing abilities of PD patients and Broca's aphasics was recently conducted by a group led by Patrick McNamara at Buffalo State College (McNamara et al., in press).

The goal of this chapter is to summarize and critically evaluate this small literature on syntactic comprehension deficits in PD.[17] I will argue that although all of the studies provide a considerable amount of interesting data, many of them suffer from problems involving experimental design, data analysis, and/or the explanation of performance profiles. With regard to the predictions that I outlined in the concluding section of the previous chapter, although three of the studies that I will review—the two by Lieberman et al. and the one by McNamara et al.—do not provide data that can be used to directly test those predictions, all of the other studies provide data that are relevant to many of them. Before commencing with the review, I will first discuss some methodological issues that must be considered in doing neuropsychological research.

4.1 Some Methodological Issues in Neuropsychology

Interpreting the performance of brain-damaged patients on syntactic comprehension tasks—or on any mental tasks, for that matter—is risky business because a number of factors complicate the process of inferring the nature of the functional disturbance from

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[17] I will not discuss the study by Natsopoulos et al. (1991), however, because although the researchers worked with Greek-speaking PD patients, they did not interpret their results in light of certain features of this language, such as that it is pro-drop, has a rich case system much more like Polish or Russian than English, and has free word order. Hence, it is difficult to draw any meaningful conclusions from their findings.

the observed pattern of sparing and loss of ability. I will mention four such factors before proceeding with the review of disorders in PD.[18]

One complicating factor is that patients frequently develop strategies or heuristics that enable them to compensate, at least to some degree, for their injury. For instance, patients whose syntactic comprehension abilities have been disrupted may rely to a great extent on semantic and pragmatic cues (e.g., animacy and plausibility) for determining "who's doing what to whom" (Caplan & Hildebrandt 1988). Because of this, researchers must design their materials very carefully and try to separate out good performance that is due to compensatory strategies from good performance that is due to preserved normal functioning of the syntactic comprehension system.

Another complicating factor involves the interpretation of both single and double dissociations. In a single or one-way dissociation, a patient exhibits intact comprehension of construction A but impaired comprehension of construction B. Such a dissociation may be due to a selective disruption of some structure(s) or operation(s) that are unique to construction B, but this need not be the case, since construction B may simply require more processing resources than construction A. If the patient's brain damage somehow reduced the overall processing efficiency for syntactic comprehension, the patient would exhibit the performance profile that is in fact observed (see Caplan & Hildebrandt 1988 and Kemmerer 1994a for several case studies that illustrate this kind of situation). In a double dissociation, one patient has intact comprehension of construction A and impaired comprehension of construction B, while another patient shows the exact opposite pattern of performance. It is an article of faith among many neuropsychologists that double dissociations cannot be explained without assuming that each of the two abilities involved depends on some independent structure(s) or operation(s) that could be selectively disrupted (e.g., Teuber 1955; Weiskrantz 1968; Caplan

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[18] I should emphasize that when I refer to "patients" in this section, I am speaking not of PD patients but of brain-damaged patients in general, ususally ones with stroke-induced language disturbances.

1987; Caramazza 1984, 1986, 1992; Ellis & Young 1988). However, Shallice (1988) has argued that, in principle, double dissociations could emerge from a variety of different types of nonmodular architectures, and recently there have been several demonstrations that double dissociations can indeed arise through random or coarse-grained lesions to neural network computer models that contain no modular structure (Chater & Ganis 1991; Farah 1994; Plaut 1995). The implication is that although it is often legitimate to account for double dissociations in terms of separate mechanisms, researchers should be aware that other explanations are technically possible and in some cases may even be more appropriate.

A third complicating factor is that the manner and context in which syntactic comprehension is measured may affect performance. For instance, Tyler (1992) found that some patients display normal sentence processing abilities when measured with on-line tasks (e.g., word monitoring, lexical decision, or speeded grammaticality judgement), but perform poorly when measured with off-line tasks (e.g., sentence-picture matching or "acting out" a sentence by manipulating toy figures). In addition, patients sometimes perform poorly on one kind of off-line task but perform well on another—e.g., Badecker et al. (1991) describe a patient who exhibited impaired syntactic comprehension when measured with a sentence-picture matching task, but performed above chance on the same materials when the task involved figure manipulation. It has also been shown that some patients perform poorly on syntactic comprehension tasks when the stimuli are presented at a normal speaking rate, but perform better when the stimuli are presented more slowly (Lasky et al. 1976; Blumstein et al. 1985; Baum 1988; see also Pashek & Brookshire 1982; Nicholas & Brookshire 1986). Finally, Bates et al. (1987) reported that non-neurological patients in the orthopedic ward of a hospital performed worse than non-neurological control subjects on a syntactic comprehension test—a finding which suggests that general stress can reduce syntactic comprehension abilities. Taken together, these studies all indicate that it is important for researchers to avoid depending too much on a single method or context for assessing the syntactic comprehension abilities of brain-damaged patients.

The final complicating factor that I will mention is that if a patient performs significantly worse than normal subjects at comprehending a particular construction, this does not necessarily mean that the poor performance is a direct result of the patient's brain damage. It is always possible that the performance reflects a temporary lapse of attentional control or perhaps some quirky limitation of the individual's "premorbid" syntactic comprehension system. Of direct relevance to this issue is Miyake et al.'s (1995) recent report of several striking double dissociations in normal college students when tested in an RSVP (i.e., rapid serial visual presentation) paradigm. For instance, one subject performed significantly better on object-object relative clauses (e.g., *The bear kissed the donkey that the goat patted*) than on sentences with conjunction reduction (e.g., *The bear kissed the donkey and patted the goat*), whereas another subject had the exact opposite profile. This pattern remained stable across two different testing sessions separated by at least one week. Athough Miyake et al.'s findings are suprising, they certainly do not imply that the first subject has a selective impairment of some structure or operation that is necessary for conjunction reduction but not for object-object relatives, and that the second subject has a selective impairment of some structure or operation that is necessary for object-object relatives but not for conjunction reduction. Rather, it seems more reasonable to assume that each subject is using idiosyncratic sentence processing strategies to help them deal with the extremely rapid stimulus presentation rate of the RSVP paradigm. If the same subjects were tested again on the same materials only in conditions where the stimuli were presented at a normal rate, their performance would presumably be at ceiling for all of the constructions. The implication of Miyake et al.'s results for researchers who investigate disorders of syntactic comprehension is simply that they must be very cautious about attributing highly selective disorders to patients who appear to have trouble understanding relatively isolated constructions. Miyake et al.'s study also shows that it can be risky to rely solely on case studies (contra Caramazza 1984, 1986).

4.2 Lieberman

4.2.1 Lieberman et al. (1990)

4.2.1.1 Summary

As I mentioned earlier, the first study to investigate the syntactic comprehension abilities of PD patients was conducted by Lieberman et al. (1990). 39 patients participated in the study. The following information was provided about the patients:

- severity of PD: ranged from early (stage I) to late (stage IV)
- duration of PD: range = .5-25 yrs., mean = 6.3 yrs.
- cognitive status: eight patients were mildly demented, according to the Mini-Mental State Examination (Folstein et al. 1975); the rest were nondemented
- medication: all but five were on stable medication programs
- age: ranged from 50 to 82
- sex ratio: 28 male, 11 female
- education: ranged from ninth grade to master's degree

The patients' syntactic comprehension abilities were evaluated by means of the Rhode Island Test of Language Structure (RITLS), which was originally designed to assess comprehension in hearing-impaired children and adults. The battery contains 11 "simple" (i.e., single-verb) construction types and 9 "complex" (i.e., two-verb) construction types. There are five instances of each type, for a total of 100 items. For each item, the patient was shown three line drawings and asked to "pick the picture that means the same as the sentence that you hear" (p. 361). Although Lieberman et al. did not specify the nature of these construction types in their 1990 paper, they did so in their subsequent 1992 paper. The following list is therefore drawn from the latter paper:

"Simple" constructions:

- Pattern 1: *The book fell.*
- Pattern 2: *The girl hit the boy.*
- Pattern 3: *The boy is happy.*
- Pattern 4: *The building is a church.*
- Pattern 5: *The boy is in the wagon.*
- Imperative: *Open that door!*
- Negative: *The boy did not eat the apple.*
- Passive, reversible: *The boy was chased by the girl.*
- Passive, nonreversible: *The ball was thrown by the boy.*
- Dative: *The teacher is giving a book to the girl.*
- Expanded: *The boy is picking apples from the front of the house.*

"Complex" constructions:

- Adverbial clauses:
  - Main clause first: *The dog barked because he had no food.*
  - Subordinate clause first: *Because it was raining the girl stayed home.*
- Relative clauses:
  - Medial: *The woman who is holding the baby has a hat on.*
  - Final: *The man is watching the girl who is in the water.*
- Conjoined phrases: *Mother cooked the food and the girl set the table.*
- Deleted structures: *The boy ate his lunch but the girl didn't.*
- Non-initial subject: *The one who is calling the boy is the girl.*
- Complements, subject: *Father's washing the dishes made mother happy.*
- Complements, object: *Father wants the dog to go out.*

For each patient, the researchers reported the number of total errors, the number of errors on complex items, and the number of "error clusters," that is, the number of times that errors were made on three or more of the five tokens of a given construction type. The table in their paper that shows the results is reproduced below as Table 7:

Table 7: Results for Lieberman et al. (1990)

The authors make the following points about their results. Error clusters occurred for 14 of the constructions in the test. Ten patients (25%) had at least one error cluster. Of these ten patients, four had a cluster for the "initial adverbial clause" construction, three had a cluster for the "final relative clause" construction, and two had a cluster for the "conjunction" construction. Both the demented and the nondemented PD patients exhibited syntactic comprehension deficits, but the demented patients had more severe deficits than the nondemented patients. The most obvious manifestation of this difference was that the demented patients produced significantly more total errors, complex errors, and error clusters than the nondemented patients. More subtle differences between the performance of the demented and nondemented patients emerged when Lieberman et al. divided all of the patients into four groups:

- Group 1 (14 or more total errors, plus the presence of clusters):
  - 4 patients
  - all 4 of the patients were demented
- Group 2 (less than 14 total errors, plus the presence of clusters):
  - 6 patients
  - 2 of the patients were demented, and 4 were nondemented
- Group 3 (more than 5 total errors, and no clusters):
  - 9 patients
  - 1 of the patients was demented, and 8 were nondemented
- Group 4 (5 or less total errors, and no clusters):
  - 20 patients
  - 1 of the patients was demented, and 19 were nondemented

The authors note that no correlation was found between which of these groups a patient fell into and the patient's duration of PD, drug treatment, or educational background.

No further analysis of the data was conducted. Lieberman et al. conclude their paper by making a number of observations about their findings. First, they exclude several possible causes of the patients' performance. They suggest that because the majority of comprehension errors were for complex items, the errors "do not appear to follow from general deficits in attention, concept formation, etc." (p. 363). They also point out that vocabulary and sentence length were balanced for sentences that had both simple and complex syntax, so the errors cannot be accounted for in terms of "memory span or hearing deficits" (p. 364). Finally, they note that the motor requirements for the test were the same regardless of whether an item had simple or complex syntax, so the errors cannot be due to the patients' motor disorders. Lieberman et al. then offer what they consider to be the most plausible explanation for the results of their study. Specifically, they propose that the errors reflect "deterioration of the patients' ability to make use of the syntactic 'rules' involved in English" (p. 364). They argue that this deterioration goes hand in hand with the onset of dementia because both kinds of impairment—linguistic and cognitive—are ultimately caused by disruption of the circuits that relate the basal ganglia to the prefrontal cortex. As they put it, "the association between sentence comprehension errors and dementia noted in this study may follow from the involvement of the same frontal areas of the brain" (p. 364).

4.2.1.2 Evaluation

This study suffers from a number of problems. To begin with, it is hard to understand why Lieberman et al. included demented PD patients in the study, since there is no clear way to interpret syntactic comprehension deficits in such patients. Second, the materials were not selected for the purpose of testing a well-defined hypothesis about the syntactic comprehension abilities of PD patients. The specific nature of the construction types that were present in the test are not indicated; they are simply classified as either "simple" or "complex" on the basis of the number of verbs. Furthermore, the details of the instances of each construction type are not mentioned, but these details could have made a difference in how difficult the sentences were for the PD patients to comprehend. For instance, "pattern 1" in the set of simple constructions is exemplified by the undergoer-intransitive sentence *The book fell.* Does this mean that all five instances of this construction were undergoer-intransitives, or might there have been one or more actor-intransitives? Also, the two relative clause constructions are exemplified by subject-gap relatives, but this leaves open the possibility that some of the other instances could have been object-gap relatives. Furthermore, the initial adverbial clause construction is exemplified by the sentence *Because it was raining the girl stayed home,* where the adverbial clause is atransitive. Did all of the instances of this construction have such adverbial clauses, or were some of them intransitive, or transitive? These are not trivial matters that can be ignored, especially considering that Lieberman et al. found error clusters for the final relative clause construction and the initial adverbial clause construction.

With regard to data analysis, there are several problems. Recall that an error cluster amounts to three or more errors for a particular construction type. The number of such clusters does not appear to be reported correctly for patients 15, 16, 21, and 32 (see Table 6). In each case, the number given under the "cluster" column is incompatible with the numbers given under the "total" and "complex" columns:

- patient 15: 10 clusters are reported, but the patient could only have had a maximum of four complex clusters (since there were 14 complex errors) and three simple clusters (since there were 10 simple errors),[19] for a total of seven clusters.

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[19] I assume that the number of simple errors is the number of total errors minus the number of complex errors.

- patient 16: three clusters are reported, but the patient could only have had one complex cluster (since there were four complex errors) and could not have had any simple clusters (since there weren't any simple errors), for a total of one cluster.
- patient 21: three clusters are reported, but the patient could not have had any complex clusters (since there were only two complex errors) and could only have had one simple cluster (since there were only five simple errors), for a total of one cluster.
- patient 32: ten clusters are reported, but the patient could have had a maximum of five complex clusters (since there were 15 complex errors) and three simple clusters (since there were nine simple errors), for a total of eight clusters.

Lieberman et al. claim that, altogether, clusters were made for 14 different construction types; however, they only identify three of them, apparently the ones that were the most common: initial adverbial clause, conjunction, and final relative clause. What were the other 11 construction types? Moreover, the authors do not indicate which patients had clusters on which constructions, so there's no information about whether the clusters cluster, so to speak. Finally, the authors do not discuss the non-clustered errors at all. This is a significant oversight, because if a patient made two errors on a given construction, it would amount to performance which is only 60% correct (3 out of 5). It seems likely, for instance, that patient 2 made two errors on several constructions, since he made 20 total errors but had no clusters.

When we turn to Lieberman et al.'s explanation for their results, more problems emerge. They dismiss the possibility that an attentional disorder could underlie the patients' errors without even seriously considering it. This is somewhat surprising given the abundant literature prior to 1990 documenting reduced attentional resources in PD patients. Similarly, the authors dismiss the possibility that a "memory span" deficit could contribute to the patients' errors without distinguishing between verbal STM and syntactic STM. Finally, with respect to the authors' proposal that the errors reflect "deterioration of the patients' ability to make use of the syntactic 'rules' involved in

English" (p. 364), it is so vague as to be uninformative. Are they suggesting that the patients have a parsing impairment? If so, what types of structures or operations do they think are impaired? Also, because the proposal focuses on the association, at both functional and neurobiological levels, between syntactic comprehension deficits and general cognitive deficits (i.e., dementia), it does not take into consideration what might be going on with the nondemented patients.

4.2.2 Lieberman et al. (1992)

4.2.2.1 Summary

Lieberman et al.'s second study was designed with not only PD but also Broca's aphasia in mind. Broca's aphasia typically involves motor speech abnormalities as well as sentence production and comprehension deficits. Several researchers have suggested that it can result from extensive damage to the subcortical pathways that relate the left ventrolateral prefrontal cortex, including Broca's area, not only to other cortical areas but also to the basal ganglia (Naeser et al. 1982; Stuss & Benson 1986; Alexander et al. 1987; Metter et al. 1989).[20] However, it is often not possible for researchers to localize lesions well enough to confirm this hypothesis. Since PD directly affects circuits relating the basal ganglia to the prefrontal cortex, Lieberman et al. proposed that "it can serve as an 'experiment-in-nature' to resolve the question of whether the linguistic deficits associated with Broca's aphasia can derive from damage to subcortical pathways to prefrontal cortex" (p. 170). Some support for this view had already been provided by the studies mentioned earlier (see the introduction to this chapter) demonstrating dysarthria as well as mild agrammatic production in some PD patients, but Lieberman et al. were interested in investigating this issue further, especially the connection between motor speech abnormalities and syntactic comprehension. In addition, Lieberman et al. were interested in investigating whether PD patients who exhibited deficits in both

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[20] This view assumes that a circuit exists between the basal ganglia and Broca's area.

speech and syntactic comprehension would also exhibit deficits on cognitive tasks known to be affected by prefrontal cortical damage.

40 PD patients were recruited for the study. 20 of these patients were classified as "moderate" (stage III), and the other 20 were classified as "mild" (stage I-II). All of the patients were nondemented and were either unmedicated or on stable medication programs. With regard to other demographic features, the patients were similar to those who participated in the previous study.

The researchers administered three different kinds of tests to the patients. First, they evaluated the patients' motor speech abilities by measuring voice-onset time (VOT) for stop consonants in syllable initial position. Since Broca's aphasics are known to have impaired VOT (Blumstein et al. 1980), this was used as a "probe" to determine whether the subcortical pathways that are disrupted in PD are the same as those that may be disrupted in Broca's aphasia. Second, the researchers evaluated the patients' syntactic comprehension abilities by giving them the Rhode Island Test of Language Structure (RITLS)—the same test that was used in their first study. Finally, they evaluated the patients' cognitive abilities by giving them a battery of standardized neuropsychological tests that are often used to measure frontal lobe function—specifically, the Selective Reminding Test, which assesses the ability to encode and retrieve items in short-term memory; the Odd Man Out Test, which assesses the ability to maintain a mental set; the New Dot Test, which assesses visuospatial processing; the Digit Span Test, which has two components (forward and backward) that differ in how much con-centration they require; and, finally, a test of verbal fluency, which assesses the ability to generate names for members of a predetermined semantic category.

The results for the VOT and RITLS components of the study are shown in Tables 8A (for the moderate patients) and 8B (for the mild patients); these tables are both reproduced from Lieberman et al.'s article. The columns labeled "1-50" and "51-100" represent the "simple" and "complex" sentences, respectively, on the RITLS. The column labeled "% VOT overlap" refers to the percent of trials when the VOT for voiced and unvoiced stop consonants merged.

Lieberman et al. make the following points about the data. First, the moderate patients had significantly higher error rates and response times than the mild patients on the RITLS. In addition, both moderate and mild patients had significantly higher error

Table 8A: Results for moderate patients (Lieberman et al. 1992)

Table 8B: Results for mild patients (Lieberman et al. 1992) rates and response times on the complex sentences than on the simple sentences. With regard to the VOT measurements, nine patients were found to have abnormalities similar to those found in Broca's aphasics. Of these patients, seven were moderate (patients 1, 6, 13, 14, 16, 18, and 20 in Table 7A) and two were mild (patients 1 and 4 in Table 7B). As a group, these nine patients had significantly greater total errors, complex errors, error clusters, and response times on the RITLS than the other patients in the study. Among the seven moderate patients in this group, error clusters occurred for three construction types: simple expanded, initial adverbial clause, and complement subject clause. None of the mild patients with impaired VOT had error clusters. Finally, with regard to the results of the neuropsychological tests, Lieberman et al. report that moderate patients performed significantly worse than mild patients on the Odd Man Out Test and the backward part of the Digit Span Test, indicating greater difficulty with set maintenance and concentration. On the remaining tests, the two groups performed equally well. Also, although the authors do not state it explicitly, they imply that for the moderate patients there was a correlation between poor performance on the neuropsychological tests and poor performance on the speech and syntactic comprehension tests.

In the discussion section of their paper, Lieberman et al. briefly address the question of why the seven moderate patients with impaired VOT had certain error clusters and not others on the RITLS. After quickly rejecting a number of possible areas of sentence processing difficulty—vocabulary, memory, attention, and "long-distance syntactic dependencies" (p. 181)—they conclude that "syntactic complexity appears to have been a factor contributing to RITLS sentence comprehension deficits" (p. 182). In addition, they return to the question of whether the neuropathological bases of PD and Broca's aphasia are related. They argue that because several PD patients exhibited speech and syntactic comprehension deficits similar to those found in Broca's aphasics, it is reasonable to suppose that Broca's aphasia can in fact arise from damage to the pathways that relate the basal ganglia to the ventrolateral prefrontal cortex. More specifically, they suggest that in both populations, the speech problems may be caused by disruption of the circuit involving the putamen and the motor cortex, whereas the syntactic problems (which actually encompass both comprehension and production) may be caused by disruption of the circuit involving the caudate and the ventrolateral prefrontal cortex. Lieberman et al. also point out that, as hypothesized at the beginning of the paper, the PD patients who exhibited both speech and syntactic comprehension deficits also exhibited cognitive deficits that reflect prefrontal cortical dysfunction—in particular, deficits in set maintenance (as measured by the Odd Man Out Test) and deficits in concentration (as measured by the backward part of the Digit Span Test).

4.2.2.2 Evaluation

Methodologically, this study was better designed that the first one. Not only did the researchers set out to test a bold, imaginative hypothesis about the relation between PD and Broca's aphasia, but they were much more careful than before about selecting patients. Demented patients were excluded from participation, and the patients that did participate were divided into two narrowly defined groups. Despite these virtues, however, the study did have the following methodological problem: the RITLS was used again to assess syntactic comprehension, so all of the drawbacks of this test that I mentioned earlier apply here, too.

As far as data analysis is concerned, Lieberman et al. did not describe in detail how the patients performed on the RITLS. Although they state that among the moderate patients who had VOT abnormalities, errors clusters were made on three construction types (simple expanded, initial subordinate clause, and complement subject clause), they do not indicate precisely which patients had which clusters. In addition, nothing is said about the kinds of errors that the patients without VOT abnormalities made on the RITLS. Table 7A shows that four moderate patients without VOT abnormalities could have had at least one error cluster for both simple and complex constructions (4, 8, 9, and 19), and four others could have had at least one error cluster for just complex constructions (2, 3, 7, and 10). Similarly, Table 7B shows that two mild patients without VOT abnormalities could have had at least one error cluster for both simple and complex constructions (5 and 7), and five others could have had at least one error cluster for just complex constructions (9, 10, 11, 15, and 19).

Lieberman et al. provide very little specific information about how the patients performed on the RITLS, and they do not devote much space to explaining their results. Still, it must be pointed out that the vague notion of "syntactic complexity" is not sufficient to account for the particular error clusters made by the moderate patients with VOT abnormalities. In order to develop an understanding of these patients' syntactic comprehension abilities, it seems to me that quite a bit of further research would be required. First, Lieberman et al. would need to construct a theory of the processing requirements of each construction in the RITLS, so as to have a frame of reference for characterizing disorders. Then they would need to test the patients again, perhaps with a larger sample of instances of the constructions (say, ten instead of five), to see if the patients continue to show the same patterns of performance.

With regard to Lieberman et al.'s proposals concerning the relation between PD and Broca's aphasia, several problems can be discerned. First of all, the authors do not present any data about how Broca's aphasics perform on the RITLS, so there's no direct support for their claim that PD patients and Broca's aphasics have similar syntactic comprehension deficits. Furthermore, the authors do not discuss any of the detailed studies that have investigated the syntactic comprehension abilities of Broca's aphasics using materials other than the RITLS. In fact, many of these previous studies indicate that on some construction types, Broca's aphasics perform differently than the PD patients that participated in Lieberman et al.'s study. For instance, Broca's aphasics often perform at chance on reversible passives (e.g., Caramazza & Zurif 1976; Caplan & Hildebrandt 1988; Berndt et al. 1996), but Lieberman et al.'s PD patients did not have any difficulties with these sentences (at least no difficulties were reported). Conversely, some of Lieberman et al.'s PD patients had trouble with "simple expanded" sentences, but Broca's aphasics generally perform well on sentences like these (Schwartz et al. 1987). Also, with respect to deficits in sentence production, Broca's aphasics are definitely more severely impaired than PD patients.

Turning to the neurobiological issues, Lieberman et al. argue that the alleged similarity of the linguistic deficits in PD and Broca's aphasia lends support to the idea that Broca's aphasia can result from damage that only affects the (putative) circuit relating Broca's area and the basal ganglia. It is tempting to think that this view is refuted by the evidence mentioned above showing that the linguistic deficits in the two populations are not really so similar. Indeed, one might suppose that when Broca's aphasia results from left anterior lesions, the damage must affect the cortex in the vicinity of Broca's area and not merely the pathways beneath the cortex. This line of reasoning does not actually overturn Lieberman et al.'s proposal, however, because the way in which the subcortical circuit is damaged in PD is different from the way in which it is assumed to be damaged in Broca's aphasia. In PD, the circuit is rendered dysfunctional, whereas in Broca's aphasia it is assumed to be completely, or almost completely, destroyed. Therefore, it must be granted that these differences in neuropathology could, at least in principle, give rise to differences in linguistic abilities. Further research on the neuropathological basis of Broca's aphasia is necessary to resolve this issue.

4.3 Grossman

I turn now to the series of studies conducted by Murray Grossman and his colleagues (Grossman et al. 1991, 1992b, 1993a, 1993b, 1994; Geyer & Grossman 1995; Seidl et al. 1995; Grossman, in press). These studies constitute the majority of work that has been done on syntactic comprehension deficits in PD and collectively represent a cohesive, sustained research project dedicated to showing that these deficits are due primarily to an impairment of attentional control. I will first review the studies that focus on the functional nature of the deficits, and then I will shift to the studies that focus on the neuropathological substrates of the deficits.

4.3.1 Grossman et al. (1992b)

4.3.1.1 Summary

Grossman et al.'s first major study included 20 PD patients with the following characteristics:

- severity of PD: 25% stage 1, 60% stage 2, 15% stage 3
- duration of PD: mean = 5.57 yrs, SD = 3.74 yrs.
- cognitive status: nondemented, according to DSM-III criteria (American Psychological Association 1980) and the Mini-Mental State Examination (Folstein et al. 1975)
- depression: 0%
- medication: 100%

- age: mean = 61.9 yrs., SD = 7.04 yrs.
- education: mean = 14.6 yrs., SD = 3.02 yrs.
- handedness: right

12 control subjects matched for age and education were also recruited for the study.

Three experiments were conducted. In Experiment 1, Grossman et al. tested the syntactic comprehension abilities of the patients by using a probe verification technique in which the examiner first reads a "target" sentence to the patient and then reads a "probe" sentence to the patient; the probe is a question about the meaning of the target, and the patient's task is to answer the question correctly—e.g., *The eagle was chased by the hawk. What did the chasing?* The stimuli varied along three dimensions. First, one third of the target sentences were "simple" (active or passive), another third contained a terminal relative clause with an adjective, and the final third contained a center-embedded subject-gap or object-gap relative clause. Second, for half of the target sentences the interpretation was semantically constrained, and for the other half it was not. Third, half of the items had corresponding voice between the target and probe sentences, and the other half had noncorresponding voice. Examples of the stimuli are shown in Table 9, which is reproduced from Grossman et al.'s article.

Table 9: Stimuli for Experiment 1 (Grossman et al. 1992b)

It is important to note, however, that this table is somewhat misleading, since it only provides examples of some of the sentence types that were used in the study. Based on the description of the materials in the methods section of the article, it appears that there were actually 24 different sentence types and eight instances of each type, for a total of 96 items; the entire set of sentence types is shown below (the items marked with an asterisk are the ones that appear in Grossman et al.'s table):

A. Simple sentences:

- Constrained:
  - Corresponding voice:
    - Active: *The eagle chased the worm. What did the chasing?*
    - *Passive: *The worm was chased by the eagle. What was chased?*
  - Noncorresponding voice:
    - *Active: *The eagle chased the worm. What was chased?*
    - Passive: *The worm was chased by the eagle. What did the chasing?*
- Nonconstrained:
  - Corresponding voice:
    - *Active: *The eagle chased the hawk. What did the chasing?*
    - Passive: *The eagle was chased by the hawk/ What was chased?*
  - Noncorresponding voice:
    - *Active: *The eagle chased the hawk. What was chased?*
    - Passive: *The eagle was chased by the hawk. What did the chasing?*

B. Subordinate sentences:

- Constrained:
  - Corresponding voice:
    - *Active: *The cat chased the balloon that was black. What did the chasing?*

Passive: *The balloon was chased by the cat that was black. What was chased?*

Noncorresponding voice:

*Active: *The cat chased the balloon that was black. What was chased?*

Passive: *The balloon was chased by the cat that was black. What did the chasing?*

Nonconstrained:

Corresponding voice:

Active: *The skunk chased the porcupine that was hungry. What did the chasing?*

*Passive: *The skunk was chased by the porcupine that was hungry. What was chased?*

Noncorresponding voice:

Active: *The skunk chased the porcupine that was hungry. What was chased?*

*Passive: *The skunk was chased by the porcupine that was hungry. What did the chasing?*

<u>C. Center-embedded sentences:</u>

Constrained:

Corresponding voice:

*Subject-gap: *The car that hit the tree was green. What did the hitting?*

Object-gap: *The tree that the car hit was green. What did the hitting?*

Noncorresponding voice:

*Subject-gap: *The car that hit the tree was green. What was hit?*

Object-gap: *The tree that the car hit was green. What was hit?*

Nonconstrained:

Corresponding voice:

*Subject-gap: *The car that hit the truck was green. What did the hitting?*

*Object-gap: *The car that the truck hit was green. What did the hitting?*

Noncorresponding voice:

Subject-gap: *The car that hit the truck was green. What was hit?*

Object-gap: *The car that the truck hit was green. What was hit?*

The results were as follows. Overall, 55% of the patients performed significantly worse than the control subjects. All three of the stimulus dimensions led to performance differences between PD patients and control subjects, as shown in Figures 24-26. There was an effect of grammatical complexity such that simple sentences were easier to comprehend than sentences with terminal relative clauses, which in turn were easier

to comprehend than sentences with center-embedded relative clauses (Figure 24). In addition, there was an effect of semantic constraint such that constrained sentences were easier to comprehend than nonconstrained sentences (Figure 25). Finally, there was an effect of voice correspondence such that items with corresponding voice were easier to comprehend than items with noncorresponding voice (Figure 26).

Some other results that are worth noting are as follows. The patients were only slightly more impaired at comprehending simple passive sentences than simple active sentences; the difference was not significant. They were most impaired at comprehending sentences with center-embedded object-gap relative clauses; this effect was significant when compared with simple active sentences, simple passive sentences, sentences with terminal relative clauses, and sentences with center-embedded subject-gap relative clauses. Within the subgroup of PD patients who exhibited syntactic comprehension deficits, there was quite a bit of variability in performance. Moreover, when the patients were tested a second time on a subset of the same materials, it was found that individual patients also display considerable session-to-session variability, which may be due to fluctuating levels of dopamine in the basal ganglia and/or prefrontal cortex.

In attempting to explain their findings, the authors argue that although it is conceivable that PD patients have a disruption of grammatical structures and/or the operations necesssary for parsing and interpretation, this is unlikely because, in contrast to

Broca's aphasics, they did not perform at chance on passives. In addition, such an impairment would presumably lead to fairly consistent rather highly variable session-to-session performance. Instead, the authors suggest that the impairment may involve processing resources such as memory and/or attention.

In Experiment 2, Grossman et al. adminstered a large battery of neuropsychological tests to the same PD patients and control subjects that participated in Experiment 1. The aim was look for correlations between the patients' syntactic comprehension deficits and their scores on various measures of memory, attention, and language. The tests were as follows:[21]

A. Measures of memory:

Word recall: Reproducing three low imageability words in the correct order at 1 and 5 min after presentation; correct repetition was the criterion for registration, and verbal interference material occupied the time between presentation and recall; full credit was given for reproducing a target word spontaneously and half credit for reproducing the correct word in response to a cue.

Long-term memory: Recalling the current president and seven previous presidents, with full credit given for producing the name and half credit given for producing any other facts.

Semantic memory: The number of items produced in response to a target superordinate semantic category that violated the semantic coherence of the target category.

B. Measures of attention:

Orientation: Assessing the patients' knowledge of personal facts, current location and permanent address, and current day, date, and season with a 10-item questionnaire.

Digit span: Repeating digit sequences presented at a rate of one/sec, with the sequence length beginning at three items and a failure criterion of missing two sequences at a given length.

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[21] The descriptions are taken directly from Grossman et al.'s article.

Word registration: The number of trials required to repeat three low imageability words in the correct order immediately after presentation.

Calculations: Responding correctly to four word problems that require some arithmetic computations.

C. Other measures of language skills:

Automatic speech: Saying the days of the week in the correct order without prompting.

Phonemic discrimination: Discriminating between eight pairs of CVCs which differed by one phonemic feature on half of the trials.

Repetition: Repeating four sentences which varied iin length (up to 13 words) and grammatical complexity.

Category fluency naming: Producing the names of as many different items as possible from target semantic categories (vegetables, furniture) and target letter categories (C, L); 1 min was allowed for naming to each target category.

Confrontation naming: Naming four black-and-white drawings and four objects, with full credit given for producing the name and half credit given for name production in response to a semantic or phonologic cue.

Oral semantic comprehension: Understanding and responding appropriately to six orally presented grammatically simple requests that were increasingly complex semantically.

Paragraph comprehension: Answering eight questions about information presented in a fifth grade level written paragraph that consisted of six grammatically simple sentences.

Oral expression: Using spontaneous speech to describe the subject's house; grammatical structure, semantic coherence, and speech clarity were scored.

Written expression: Using spontaeous writing to describe the subject's job or hobby; grammatical structure, semantic coherence, and writing mechanics were scored.

The only memory or attention test on which the PD patients performed significantly worse than the control subjects was recall of three nonimageable words five minutes after presentation. For the language tests, differences were found on category fluency naming, oral semantic comprehension, oral expression, and written expression. With regard to correlations between performance on the syntactic comprehension test and performance on the neuropsychological tests, the only significant correlation to emerge was with oral semantic comprehension. Grossman et al. acknowledge that, at first glance, these findings do not support the hypothesis that the PD patients' syntactic comprehension deficits are due to impaired processing resources such as memory and/or attention. However, they are quick to point out that the neuropsychological tests

> may not be related closely enough to the particular, material-specific or task-specific attention and memory mechanisms that may contribute to sentence comprehension. Indeed, some have suggested that there is a special-purpose STM mechanism that is dedicated to sentence comprehension and differs in some important ways from nonlinguistic or general-purpose mnestic mechanisms (Berwick & Weinberg 1984; Marcus 1980). (pp. 368-9)

In Experiment 3, Grossman et al. evaluated syntactic STM and attentional control for receptive sentence processing in the same PD patients and control subjects. The materials consisted of 80 pairs of target and probe sentences similar in form to those used in Experiment 1. The patients were asked to perform two tasks for each item: judge the acceptability of the target sentence and, if acceptable, respond to the probe question. To assess syntactic STM, Grossman et al. used 16 well-formed target sentences with relative clauses and probes that varied as to whether they pertained to information located in adjacent portions of the target (e.g., *The eagle chased the hawk that was fast. Which bird was fast?*) or to information located in nonadjacent portions of the target (e.g., *The eagle that chased the hawk was fast. Which bird was fast?*). Eight items of each type were used. The results showed that, as a group, the PD patients did not differ significantly from the control subjects on the "adjacent" items. More importantly, as a group the PD patients also did not differ significantly from the control subjects on the "nonadjacent" items, i.e., the items that tax syntactic STM. Based on these findings, Grossman et al. state that syntactic STM "does not appear to play a significant role in PD patients' sentence comprehension impairment" (p. 371).

To assess attentional control for receptive sentence processing, the investigators used the remaining 64 pairs of target and probe sentences. 56 of these items involved ill-formed target sentences. 33% of the violations involved a change in the position of a closed-class morpheme (e.g., *The eagle chased that the hawk was fast*). Another 33% of the violations involved a change in the phonological shape of a closed-class morpheme that rendered it anomalous (e.g., changing *that* to *gat*). The final 33% of the violations involved a missing closed-class morpheme (the complementizer *that* in sentences with relative clauses, the auxiliary verb *was* in passive sentences, or the preposition *by* in passive sentences). The results indicated that, as a group, the PD patients performed significantly worse at detecting violations than the control subjects. Furthermore, the patients performed differently for the three types of violations. Detecting changes of morpheme position was easier than detecting changes of phonological form, which in turn was easier than detecting omissions of morphemes (Figure 27). It is important to note, however, that, as with Experiment 1, there was considerable variation in performance across the patients. The individual patient profiles for all three experiments are shown in Table 10, which is reproduced from Grossman et al.'s article.[22]

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[22] The abbreviations for this table are as follows: (1) education in years; (2) duration of disease; (3) O=minimal tremor, R=right predominance, L=left predominance; (4) Hoehn & Yahr stage; (5) overall sentence comprehension; (6) simple sentences; (7) sentences with terminal relative clauses; (8) sentences with center-embedded relative clauses; (9) corresponding voice; (10) noncorresponding voice; (11) semantically constrained sentences; (12) semantically nonconstrained sentences; (13) items probing information from adjacent sentence segments; (14) items probing information from nonadjacent sentence segments; (15) detection of missing grammatical morpheme; (16) detection of position change of gram-matical morpheme; (17) detection of phonological change of grammatical morpheme; (18) orientation (max.=10); (19) digit span; (20) registration; (21) calculation; (22) STM for 1 min. delay (max.=4); (23) STM for 5 min. delay (max.=4); (24) long-term semantic memory (max.=10); (25) number of semantic category violations during category naming; (26) number of errors in expressing automatic speech sequen-ces; (27) phonological discrimination (max.=10);

Grossman et al. conclude by proposing that syntactic comprehension deficits in PD may be due, to a large extent, to an impairment of a special-purpose selective-attentional resource which is necessary for receptive sentence processing:

> We believe that the pattern of impaired comprehension is most consistent with a deficit in a selectional mechanism. Within the context of a grammatical processor, this processing component may actively attend to the presence and nature of critical grammatical morphemes that mark the structure of a sentence under the guidance of a grammatical computation device. (p. 376).

In a different article published at about the same time as the one under discussion, Grossman et al. (1992a) characterize the nature of the attentional mechanism in a slightly different manner which is more explicitly in line with the way I described it in Chapter 3:

> [M]any sentences in English conform to a standard, subject-verb-object (SVO) word order that maps directly onto agent-action-theme thematic roles (e.g., "The eagle chased the hawk" where the subject "eagle" is the agent). SVO sentences appear to be resistant to misinterpretation by aphasic patients, suggesting that this may be something of an automatic template for sentence interpretation. Consider a non-canonical sentence where the SVO template is not successful at comprehension, since the sentence does not correspond to the typical word order or syntactic-thematic mapping. Internal attentional control may be necessary to overcome the SVO template, seek out the subtle grammatical markers that the grammatical processor uses to organize and understand non-SVO sentences, and maintain this focus during the on-line time course of the sentence. (p. 514)

4.3.1.2 Evaluation

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(28) sentence repetition (max.=10); (29) confrontation naming of objects (max.=10); (30) number of items produced in category naming; (31) number of sen-tences correctly answered; (32) number of questions correctly answered about a paragraph (max.=10); (33) production of spontaneous oral sentences (max.=10); (34) production of spontaneous written sen-tences (max.=10).

This study provides a great deal of interesting data and addresses several important theoretical issues concerning the nature of syntactic comprehension deficits in PD. However, it still contains a number of problems. I will first discuss these problems and then consider the implications of the study for the predictions that I outlined at the end of Chapter 3.

The results of Experiment 1 indicate that roughly half of PD patients have impaired syntactic comprehension. However, the results are not as valuable as they could be because they are, for the most part, quite general and do not include data about how the patients performed, either individually or as a group, on *each type* of target-probe combination in the battery. Consider, for instance, sentences with center-embedded relative clauses. Grossman et al. state that the patients performed significantly worse on center-embedded object-gap relatives than on center-embedded subject-gap relatives. But this information is not as useful as it could be, for the following reasons. Mean scores are

provided for the entire group of patients but not for just those patients who exhibited syntactic comprehension deficits. As a result, it is impossible to tell how severe the impairments are for the affected patients. In addition, Grossman et al. do not report how the patients performed on specific combinations of variables, that is to say, on specific construction types and associated probe questions. For instance, no information is available about whether nonconstrained center-embedded object-gap relatives were more difficult to comprehend than nonconstrained center-embedded subject-gap relatives when the probes were active, or when the probes were passive. Similarly, Grossman et al. point out that the patients performed only slightly worse on simple passives than on simple actives, but they do not indicate whether this finding applies to the entire set of simple active and passive sentences, or if it applies to just the items in which the only factor that could affect performance is the voice of the target (*The eagle chased the hawk. What did the chasing?* vs. *The eagle was chased by the hawk. What did the* *chasing?*) Also, the authors do not say whether the results showed an active-passive difference for the subordinate items in which the only factor that could affect performance is the voice of the target (*The skunk chased the porcupine that was hungry. What did the chasing?* vs. *The skunk was chased by the porcupine that was hungry. What did the chasing?*).

Another problem with Experiment 1 involves the design of the so-called subordinate target-probe combinations. What distinguishes these items from the simple and center-embedded items is that they all have a relative clause modifying the direct core NP of the matrix clause, and the relative clause contains only an adjective. It is difficult to see why Grossman et al. included target sentences like these, since it seems to be impossible to construct interesting probe questions to go with them. The probes that Grossman et al. in fact used focus on the matrix clause in the same way as the probes for the simple sentences, but this has the consequence of making the relative clause essentially irrelevant to answering the probe question. If, on the other hand, Grossman et al. had used probe questions that focus on the relative clause, it would have been a fairly easy task to answer them because the relative clause contains only an adjective. A better approach might have been to use target sentences that have a terminal relative clause that alternates between a subject-gap and an object-gap transitive structure, together with probes that focus on who's doing the action within that clause (e.g., subject-gap: *The man saw the car that hit the truck. What did the hitting?;* object-gap: *The man saw the car that the truck hit. What did the hitting?*). These sentences would then be instances of what I have referred to before as the object-subject and object-object constructions, and they would nicely complement the sentences in the third part of the test, which are instances of the subject-subject and subject-object constructions.

I turn now to Experiment 2. My only comment about this part of the study is that Grossman et al. did not use attention tests that place heavy demands on set regulation, even though many researchers have shown that early-stage, nondemented PD patients tend to perform poorly on such tests (see §2.2.3, pp. 34-9). If Grossman et al. had included tests like the WCST or Trail-Making (part B), they might have found correlations with the patients' syntactic comprehension deficits.

Regarding Experiment 3, the authors state that, as a group, the PD patients did not differ significantly from the control subjects on the items in the syntactic STM test where the probe question pertained to information located in adjacent portions of the target sentence. In fact, however, Table 10 shows that two patients performed at chance on these items (patient 9012 - 50%, and patient 9030 - 62.5%). Interestingly, these same patients performed above chance on the items where the probe question pertained to information located in nonadjacent portions of the target sentence, i.e., the items that tax syntactic STM (patient 9012 - 87.5%, patient 9030 - 100%). This dissociation is exactly the opposite of what one would expect if the patients had an impairment of syntactic STM. One possible explanation is that it reflects a kind of "primacy effect," or perhaps a "primacy-driven" compensatory strategy, since the patients apparently answered almost all of the probe questions by selecting the first NP in the sentence. In addition, Grossman et al. say that, as a group, the PD patients and control subjects did not differ significantly on the "nonadjacent" items in the test. But once again they neglect to mention that, according to Table 10, two of the patients were at chance (9022 - 62.5%, and 9043 - 62.5%) and a third was borderline (9045 - 75%) on these items. It is possible, therefore, that these patients have an impairment of syntactic STM. It would be interesting to know if they also exhibited a dissociation between, on the one hand, good performance on sentences with nonconstrained center-embedded subject-gap relatives and, on the other hand, poor performance on sentences with nonconstrained center-embedded object-gap relatives. As noted earlier, however, such data are not available.

As for the acceptability judgement test, the reasoning behind it appears to be as follows. Grossman et al. have a hypothesis that the patients' syntactic comprehension deficits may be due to an impairment of attentional control that makes it hard for them to detect morphosyntactic cues for template selection and linking, cues like closed-class morphemes and linear order. Their method of testing this hypothesis is to find another task that also requires attentional control for detecting morphosyntactic features—such as acceptability judgement—and see if the patients also manifest a deficit on this task. If so, the finding would support the original hypothesis. One possible caveat is that double dissociations between syntactic comprehension and acceptability judgement have been reported by Tyler (1992), so an impairment on one task does not necessarily imply an impairment on the other. Still, this does not refute the possibility that both tasks require the processing resource of attentional control.[23]

Having said that, it is important to note that there are problems not only with the materials that Grossman et al. used in the acceptability judgement test, but also with the way in the which the results were analyzed. Regarding the materials, for the sentences in which the complementizer *that* was omitted, the question of whether PD patients can or cannot detect the omission is not relevant to the question of whether their syntactic comprehension deficits are due to an impairment of attentional control. Consider the following sentences from Experiment 1:

- *The skunk chased the porcupine that was hungry. What did the chasing?/What was chased?* Not being able to detect the complementizer shouldn't affect one's ability to answer the probe question, since the question addresses the interpretation of the main clause, and the complementizer is irrelevant to this.
- *The car that hit the truck was green. What did the hitting?/What was hit?* If one cannot detect the complementizer *that,* one can still infer what hit what, because the SVO order is preserved.
- *The car that the truck hit was green. What did the hitting?/What was hit?* Here it doesn't matter if one cannot detect the complementizer *that,* since the sentence is still grammatical without it.

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[23] It is difficult to know what to make of the finding of double dissociations between syntactic compre-hension and acceptability judgement, since no one has tried to specify the nature of the cognitive processing that underlies the latter kind of task.

The implications of having trouble detecting the complementizer are more serious when the probe questions address the interpretation of the adjective, as in the target-probe combinations that were used in the syntactic STM test:

The eagle chased the hawk that was fast. Which bird was fast?
The eagle that chased the hawk was fast. Which bird was fast?

For both of these sentences, not being able to detect the complementizer should completely disrupt one's ability to answer the probe question, since the interpretation of the adjective depends crucially on the position of the complementizer in the target sentence. In light of this, it is quite interesting—indeed, perplexing—to compare all of the patients' performances on the "adjacent" condition, the "nonadjacent" condition, and the missing grammatical morpheme condition (columns 13 through 15 in Table 10). Six patients (9018, 9025, 9028, 9038, 9046, and 9056) performed poorly (and another, 9026, was borderline) on the missing grammatical morpheme condition, but performed well on both the adjacent and nonadjacent conditions:

Patient	Adjacent	Nonadjacent	Missing Morpheme
9018	100	87.5	35.29
9025	87.5	87.5	52.94
9028	87.5	100	52.94
9038	100	100	47.05
9046	100	100	17.64
9056	100	100	58.82
9026	87.5	100	70.58

This dissociation directly contradicts the point I just made about how detecting the complementizer is absolutely necessary for performing well on the sentences in the syntactic STM test. To resolve this contradiction would require knowing exactly how often these patients had trouble detecting complementizer omissions, as opposed to how often they had trouble detecting omissions of the auxiliary or preposition in passive sentences. However, this information is not available, since Grossman et al. averaged across all of the patients' scores for detecting omissions of all three types of closed-class morphemes.

Another interesting, and perplexing, observation is that of the five patients who showed dissociations between the adjacent and nonadjacent conditions, four performed poorly on the missing grammatical morpheme condition (9012, 9022, 9030, and 9045) and one was borderline (9043):

Patient	Adjacent	Nonadjacent	Missing Morpheme
9012	50	87.5	41.17
9022	100	62.5	64.71
9030	62.5	100	58.82
9045	100	75	58.82
9043	87.5	62.5	76.47

Of the two patients who did well on the nonadjacent condition and poorly on the adjacent condition (9012 and 9030), it's very hard to account for the dissociation, since an impaired ability to detect the complementizer should induce guessing, and hence chance performance, on both the adjacent and the nonadjacent conditions. Of the three patients who did well on the adjacent condition but poorly on the nonadjacent condition (9022, 9043, and 9045), a syntactic STM deficit could account for the dissociation (as I mentioned earlier), but the poor performance on the missing grammatical morpheme condition predicts that performance should be bad on both the nonadjacent condition and the adjacent condition.

Yet another strange finding is that patient 9046 had very high scores across columns five through 14 in Table 10 (i.e., the comprehension and syntactic STM conditions), but very low scores—the lowest of all, in fact—across columns 15, 16, and 17 (i.e., the acceptability judgement conditions). This suggests that the acceptability judgement task requires certain cognitive abilities that aren't required by the comprehension and syntactic STM tasks, and this patient has an impairment of those abilities. Such a view is consistent what I said earlier about double dissociations occurring between comprehension and judgement tasks.

Finally, some brief comments are in order about Grossman et al.'s evaluation of the patients' ability to detect omissions of the auxiliary and the preposition in passive sentences. As I mentioned above, the investigators combined all of the patients' scores on these two items and on the complementizer. Hence, no information is available about whether auxiliary omissions or preposition omissions are overlooked more frequently. Since Grossman et al. state that the patients did not have significantly greater difficulty comprehending simple passives than simple actives, it makes sense to assume that if the patients sometimes "miss" one of the closed-class morphemes during on-line sentence processing, they ususally detect the others and hence are able to select the correct template and linking pattern.

Now I'd like to shift gears and consider whether the results of Grossman et al.'s study confirm the predictions that I made at the end of Chapter 3 about the syntactic comprehension abilities of PD patients. First of all, the prediction that about half of early-stage, nondemented PD patients should exhibit syntactic comprehension deficits is borne out by the results. In addition, the prediction that the operations involved in parsing and interpretation should not be impaired seems to have been fulfilled. As Grossman et al. point out, evidence supporting this is that the patients displayed session-to-session variability in their performance and did not have significant difficulty understanding passive sentences. Still, it is always possible that some of the patients have impairments of certain operations that aren't necessary for processing passives but are necessary for processing other constructions—e.g., the operations of cross-core linking and cross-clausal linking (see Table 2, p. 88A). Although this is unlikely, it is consistent with the finding that the patients performed significantly worse on sentences with center-embedded object-gap relatives than on sentences with center-embedded subject-gap relatives.

With regard to processing resources, I predicted that PD patients *might* exhibit an impairment of syntactic STM. Although this prediction is consistent with the dissociation between subject-gap and object-gap relative clauses, it is inconsistent with the finding that, as a group, the patients performed as if they have intact syntactic STM. Nonetheless, three of the patients (9022, 9043, and 9045) did perform on the syntactic STM test as if they have an impairment of this processing resource. Thus, it may be the case that, at the neurobiological level, a circuit exists between the basal ganglia and the ventrolateral prefrontal cortex (more narrowly, Broca's area), but this circuit is only rendered dysfunctional in a small number of PD patients. On the other hand, Grossman et al. acknowledge that further research is needed to determine the status of syntactic STM in PD patients.

The strongest prediction that I made was that patients should perform poorly on constructions that require attentional control. Of the constructions that Grossman et al. used in their study, the only one that requires attentional control, according to the criteria set forth in Chapter 3, is the one that has a center-embedded object-gap relative clause (what I referred to in Chapter 3 as the subject-object construction). In line with the prediction, the patients' performance on this construction was significantly worse than on any of the others in the battery, including the construction with a center-embedded subject-gap relative clause (what I referred to in Chapter 3 as the subject-subject construction). Grossman et al. explain their results by suggesting that the patients have an impaired attentional mechanism which makes it difficult for them to detect or recognize morphosyntactic cues for parsing and interpretation such as the complementizer *that*. Although it may be true that the patients have trouble detecting morphosyntactic cues, I argued that their poor performance on object-gap relatives cannot be due to an inability to detect the complementizer *that,* because the sentences are still grammatical without this morpheme. My own hypothesis, which is similar to the view expressed in the quotation from Grossman et al.'s (1992a) article, is that the patients' poor performance on object-gap relatives is due to a deficient ability to use the cue of NP-NP-V word order to suppress the incorrect subject-gap template and linking pattern and promote the correct object-gap template and linking pattern. On the neurobiological level, I suspect that the basal ganglia cannot accurately identify the significance of the linear order cue and hence cannot relay an appropriate recommendation for decision-making to the prefrontal cortex (specifically, to the anterior cingulate cortex and, possibly, Broca's area). Moreover, the prefrontal cortex is deprived of mesocortical dopaminergic innervation. As a result of these disturbances, the prefrontal cortex is forced to select a template and linking pattern without any guidance from the subcortical systems, and so faulty decision-making frequently occurs.

4.3.2 Grossman et al. (1993b)

4.3.2.1 Summary

The next three studies by Grossman et al. that I will review were designed to explore in greater detail the idea that syntactic comprehension deficits in PD are due primarily to an impairment of attentional control. The first of these studies was conducted with 20 patients whose demographic characteristics were similar to those who participated in the previous study; 20 control subjects were also tested. In Experiment 1, the investigators presented the patients with 30 sentences containing a mass or count quantifier denoting a large or small amount of a substance (e.g., *Point to the picture with much/little/many/ few*). The task was to match each sentence with one of four pictures in an array (e.g., photographs of containers with much milk, little milk, many pencils, or few pencils). To carry out this task, one must attend carefully to two features encoded by the quantifier: first, the amount of substance (large or small), which is a semantic feature; and second, the type of substance (mass or count), which is a grammatical feature. 50% of the patients performed significantly worse on the task than the control subjects, and by far the majority of their errors involved the grammatical feature of the quantifier (mass or count) rather than the semantic feature (large or small amount) (Figure 28).

In Experiment 2, the investigators administered an acceptability judgement task to the same patients using 40 sentences, 24 of which had one of the following kinds of violations: inappropriate mass/count quantifier (e.g., *The jar contains much pencils*); inappropriate pluralization of noun (e.g., *The jar contains much milks*); or a combination of both previous types (e.g., *The jar contains much pencil*). 45% of the patients performed significantly worse than the control subjects on items than contained either of the first two types of violations; however, they did not differ from the control subjects on items that contained both types of violations (Figure 29).

Figure 28: Comprehension of quantifiers (Grossman et al. 1993b)

Figure 29: Judgement of quantifiers (Grossman et al. 1993b)

In Experiment 3, the investigators sought to determine if the patients' poor performance on the sentence-picture matching and judgement tasks was due to a "central" impairment of the grammatical features themselves. They administered a task in which the patients were required to complete sentences like the following: *This container has many (pointing to a picture), but the other container (pointing to another picture) has* . . . As a group, the patients did not differ from the control subjects on this task; however, inspection of the performance profiles of individual patients revealed that three patients were compromised in their ability to express the correct quantifier, and all of their errors involved the grammatical feature (mass or count) rather than the semantic feature (large or small amount).

Further inspection of how each patient performed across the three experiments (Table 11) indicated the presence of several patterns. With regard to just the first two experiments, the following four subgroups were identified (Table 12): (1) five patients were impaired on both tasks; (2) seven patients were unimpaired on both tasks; (3) five patients were impaired on the sentence-picture matching task but unimpaired on the judgement task; and (4) three patients were impaired on the judgement task but unimpaired on the sentence-picture matching task.

Table 14: Subgroups of PD patients (Grossman et al. 1993b)

Thus, while some of the patients performed consistently on both tasks, others performed inconsistently, and in fact a double dissociation emerged among the latter patients. With regard to the three patients who were impaired on the sentence completion task in Experiment 3, two were also impaired on both of the other tasks, and one was also impaired on just the sentence-picture matching task.

Grossman et al. provide an explanation for all of these patterns, starting with the double dissociations. For the five patients who were impaired on the sentence-picture matching task but unimpaired on the judgement task, the authors argue that the difficulty with matching cannot be attributed to problems with semantics, visuospatial processing, or linguistic STM. Rather,

> . . . the most likely explanation . . . is that support for the mapping of information from a sentence to a picture is inadequate. Thus, these patients can appreciate the subcategorization information represented in mass and count terms and they can appreciate the pictures representing examples of these terms, but they have difficulty

> determining the correspondence between messages represented in these two different representational formats. (p. 376)

Grossman et al. go on to suggest that an impairment of attentional control underlies the finding that virtually all of the patients' errors on the matching task involved the grammatical feature (mass or count) instead of the semantic feature (large or small amount):

> PD patients may have been focusing on the more obvious and salient "amount" characteristic of the quantifier at the expense of the subtler "type of substance" characteristic. According to this argument, it is possible that the semantic component of the quantifier essentially monopolized the selective attention mechanism in these patients, limiting their ability to attend to the grammatical subcategorization information necessary to support accurate sentence-picture matching performance. This interpretation thus emphasizes the critical role of regulating the distribution of limited attentional resources to all of the important facets of a word, not just those which are most obvious or salient. (pp. 376-7)

Turning to the three patients who had poor performance on the judgement task but good performance on the matching task, Grossman et al. concluded that all of these patients' judgement errors were on items that had inappropriate pluralization of the noun, which does not seem to be correct. According to Table 11, only one of the three patients (9095) made more errors on the "pluralization" items (25% wrong) than on the "quantifier-noun mismatch" items (12% wrong); the other two patients (9060 and 9075) had the opposite distribution of errors (9060: 12% wrong on pluralization vs. 37% wrong on adjective-noun mismatch; 9075: 12% wrong on pluralization vs. 25% wrong on adjective-noun mismatch). Still, the authors' explanation for a problem in detecting inappropriate pluralization can be applied to the single patient who made the most errors on these items. This explanation is that "there may have been difficulty selectively attending to the plural characteristic of the noun. [This] PD patient may have focused on the salient characteristics of the noun such as its semantic features, for example, at the expense of the subtle grammatical features such as the status of the plural" (p. 378). It is impossible to know for sure how the authors would attempt to account for the two patients who made more judgement errors on quantifier-noun mismatch items than on pluralization items; however, it is reasonable to suppose that they would advance the following kind of explanation. Basically, during the judgement task but not during the matching task, these patients had more trouble attending to the mass/count features of the quantifier and the noun, and/or whether these features were in agreement, than they did attending to the singular/plural status of the noun.

As for the five patients who were impaired on both the sentence-picture matching task and the judgement task, Grossman et al. offer two possible explanations. First, these patients might have an attentional deficit that prevents them from detecting subtle grammatical features such as mass/count in either type of situation. Alternatively, they might have a disruption of the procedures necessary for activating and comparing the grammatical features in the quantifier and noun. Since two of the patients in this subgroup (9097 and 9102) also performed poorly on the sentence completion task in Experiment 3, Grossman et al. suggest that they may actually have a disturbance to "a 'central' grammatical computation device that impacts on both input and output language mechanisms" (p. 379).

4.3.2.2 Evaluation

This study provides more valuable insights into the nature of linguistic deficits in PD. The addition of a discussion of individual performance profiles was particularly useful. The double dissociation that emerged is hard to account for, largely because no one in this area of research has done a careful investigation of, first, the processing operations that are necessary for carrying out acceptability judgements and, second, how these operations relate to those that are necessary for carrying out syntactic comprehension. Given this limitation, Grossman et al.'s explanation of the double dissociation strikes me as being reasonable (except for the mistake in identifying the nature of patients' errors). Perhaps at some later date it will possible to formulate a more rigorous account of the patients' performance.

The finding that about half of the patients exhibited deficits is in accord with the prediction that I made at the end of Chapter 3. In addition, the finding that virtually all of the patients' errors involved grammatical features (mass or count) as opposed to semantic features (large or small amount) is quite interesting and deserves comment. Grossman et al. claim that the reason for this differential susceptibility to errors is that the grammatical features are "subtle" whereas the semantic features are "obvious" or "salient." Although this view about the difference between the two kinds of features is hard to justify independently, it is consistent with the various neuropsychological studies which show that PD patients have greater difficulty on tasks where the cues for correct performance are implicit than on tasks where the cues are explicit (see §2.2, pp. 37-8). Indeed, one of my predictions was that a key factor influencing the syntactic comprehension abilities of PD patients should be whether morphosyntactic cues are implicit or explicit, subtle or salient (see §3.4, pp. 142-8). It could also be that grammatical and semantic cues are processed in different neurocognitive systems—in particular, grammatical cues may be processed in the anterior sector of the left perisylvian cortex while semantic cues may be processed in the posterior sector (see §§3.3.2.2 and 3.3.2.3. pp. 122-131). Since part of the anterior perisylvian cortex is affected in PD, this could account for Grossman et al.'s finding that PD patients have more difficulty with the grammatical features of quantifiers than with the semantic features.

4.3.3 Geyer and Grossman (1995)

4.3.3.1 Summary

The goal of this study was to determine whether syntactic comprehension deficits in PD are due to an impairment of grammatical processing (i.e., parsing and interpretation) or to an impairment of attentional control. The subjects included 25 PD patients similar to those who participated in the two previous studies, and 13 normal controls matched for age and education. The materials consisted of 100 sentences which had either "simple transitive" (ST) verbs or "lexical causative" (LC) verbs. Geyer and Grossman (henceforth G&G) describe the difference between these two types of verb as follows:

> In forming the intransitive entailment of a transitive sentence containing a ST verb, it is the *agent* of the transitive sentence that becomes the subject of the intransitive construction. Thus, "The girl applauded the clown" entails that "The girl applauded." By comparison, the subject of a LC verb in an intransitive sentence is the *patient* of the transitive sentence. Thus, "The woman drowned the swimmer" entails that "The swimmer drowned" and not that "The woman drowned." The mapping of syntactic roles onto thematic roles thus proceeds in a less canonical fashion for LC verbs, and moreover, this remapping is not signaled in an explicit manner.[24] (p. 193; italics in original)

Of the 100 sentences that were used in the study, 60 contained five evenly distributed LC verbs (*break, awaken, drown, sink, and turn*) and 40 contained four evenly distributed ST verbs (*eat, applaud, kick, and sketch*). The 60 sentences with LC verbs were organized as follows. 20 were active (e.g., *The woman drowned the swimmer*), 20 were passive (e.g., *The swimmer was drowned by the woman*), and 20 had what G&G call a periphrastic causative structure (e.g., *The woman made the swimmer drown*). These three different constructions were used because, according to G&G, they differ

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[24] As can be seen, intransitive sentences that contain what G&G call ST verbs correspond to what I referred to in Chapter 3 as actor-intransitives, and intransitive sentences that contain what G&G call LC verbs correspond to what I referred to in Chapter 3 as undergoer-intransitives. Note that G&G use the expression "simple transitive" (ST) to describe a type of verb that can occur in an intransitive syntactic structure. Nevertheless, I will use G&G's terminology in the rest of the review.

with respect to morphosyntactic complexity as well as the nature of the mapping between syntax and semantics:

- active:
  - complexity: very little
  - mapping: transparent
- passive:
  - complexity: more
  - mapping: noncanonical

- periphrastic:
  - complexity: even more
  - mapping: transparent

In addition, half of each of the three sentence types were semantically constrained, whereas the other half were semantically nonconstrained. Finally, comprehension was evaluated by using the probe verification technique, where a target sentence is presented first and then a probe sentence is presented; the patient's task is to say whether the probe is true of the target. All of the probes for the active and periphrastic target sentences were of the form "The N Ved"; for the passive target sentences, half of the probes were of the form "The N Ved" and the other half were of the form "The N was Ved." Overall, half of the probes were true of the target sentence whereas the other half were false. For instance, a true probe for the example target sentences above would be *The swimmer drowned* (and *The swimmer was drowned* for the passive), whereas a false probe would be *The woman drowned* (and *The woman was drowned*). Moreover, in half of the probes the NP was the same as the actor in the target sentence, and in the other half the NP was the same as the undergoer in the target sentence. The 40 sentences with ST verbs were organized in a similar fashion, except that no semantically constrained peri-phrastic sentences were included, since they would have been anomalous (e.g., *Gary made the sandwich eat*).

G&G reasoned that this experimental design would allow them to test two alternative hypotheses about why PD patients have difficulties with syntactic comprehension—first, that the difficulties are due to an impairment of grammatical processing, and second, that they are due to an impairment of attentional control:

> If PD patients are impaired in their sentence comprehension because of a grammatical processing deficit, then they should be more impaired in their understanding of passive voice sentences than active voice sentences, regardless of the type of verb, and should find the periphrastic voice sentences even more difficult to understand. However, if PD patients have a sentence comprehension deficit because of a limitation in [attentional control], then sentences with LC verbs should be more difficult to understand than those with ST verbs, and the periphrastic voice sentences should be easier to understand. (p. 193)

The results were as follows. First of all, the PD patients performed significantly worse than the control subjects on the sentences that contained LC verbs, but there was not a significant difference between the two groups on the sentences that contained ST verbs (Figure 30). This suggests that PD patients have trouble "appreciating verbs that require an atypical syntactic-thematic mapping" (p. 197). Second, no significant differences between the two groups was found for the variables of voice (active vs. passive vs. periphrastic) and semantic constraint (constrained vs. nonconstrained). These findings suggest that "a syntactic mechanism for manipulating thematic roles such as underlies the passive voice is not significantly compromised in PD patients," and that "PD patients are not using semantic information to bootstrap their comprehension of atypical verbs" (p. 197). Third, further analysis of the data revealed that the PD patients fell into two subgroups, one normal-like (10/25, 40%) and the other non-normal (15/25, 60%), and that all of the patients in the non-normal subgroup performed significantly worse on sentences with LC verbs than on sentences with ST verbs (Figure 31).

Figure 30: Comprehension of sentences containing ST and LC verbs (Geyer & Grossman 1995)

Figure 31: Subgroups of normal-like and non-normal patients (Geyer & Grossman 1995)

Finally, for the non-normal subgroup, performance on active and passive sentences with LC verbs was significantly worse than performance on active and passive sentences with ST verbs, but performance on periphrastic sentences with LC verbs was not significantly different from performance on periphrastic sentences with ST verbs (Figure 32). G&G state that this finding makes sense, because "the periphrastic sentence frame neutralizes the atypical mapping from grammatical role to thematic role seen in LC verbs" (p. 198).

Figure 32: Comprehension by non-normal patients of active, passive, and periphrastic sentences containing ST and LC verbs (Geyer & Grossman 1995).

In the discussion section of their paper, G&G point out that the patients' good performance on passive sentences containing ST verbs suggests that they do not have a generalized difficulty with parsing and/or interpretation. On the other hand, they do acknowledge that within the set of sentences with ST verbs, there was a slight decline in performance from actives to passives to periphrastics. And yet this order of difficulty was not replicated for the set of sentences with LC verbs. Thus, there is very little evidence for a primary deficit in grammatical processing. Instead, G&G argue that the best explanation for the results is that the patients have an impairment of attentional control which makes it difficult for them to detect and respond to the completely implicit syntactic-semantic mapping properties of LC verbs:

> . . . it is not simply the atypical mapping from grammatical role to thematic role that proves difficult for PD patients since they were not significantly impaired in their appreciation of passive voice sentences that require a similar type of remapping. We hypothesize instead that PD patients are compromised in their ability to use an executive system to help them detect and then make an appropriate mental decision about a subtle and atypical feature. (p. 201)

4.3.3.2 Evaluation

G&G claim that their study provides further evidence for the view that about half of PD patients have syntactic comprehension deficits that are caused by an impairment of attentional control. However, I will argue that there are several problems with the design of the study, and that these problems make it impossible to draw any strong inferences from the results.

Apparently, in their syntactic framework, G&G assume that the linking properties of LC and ST verbs are different independently of the type of syntactic construction in which they occur. This is why they focus on performance differences between, on the one hand, ST verbs in active, passive, and periphrastic structures and, on the other hand, LC verbs in active, passive, and periphrastic structures. However, from the point of view of RRG, G&G's assumption is not completely correct. As I pointed out in Chapter 3 (see §3.1.2.6, pp. 80-1), it is true that the linking properties of LC and ST verbs are different in intransitive sentences. For example, in the LC intransitive sentence *The swimmer drowned,* the pivot NP is mapped onto the undergoer macrorole (a noncanonical linking pattern, since pivots tend to be actors), whereas in the ST intransitive sentence *The girl applauded,* the pivot NP is mapped onto the actor macrorole. But when either LC or ST verbs occur in transitive sentences, the linking pattern is always canonical, since the pivot NP is mapped onto the actor macrorole and the direct core NP is mapped onto the undergoer macrorole (e.g., compare the LC transitive sentence *The woman drowned the swimmer* with the ST transitive sentence *The girl applauded the clown*). Also, when either LC or ST verbs occur in passive sentences, the linking pattern is always noncanonical, since the pivot NP is mapped onto the undergoer macrorole and the oblique NP is mapped onto the actor macrorole (e.g., compare the LC passive sentence *The swimmer was drowned by the woman* with the ST passive sentence *The clown was applauded by the girl*). With regard to periphrastic sentences containing LC or ST verbs (e.g., *The woman made the swimmer drown* vs. *The clown made the girl applaud*), it's always the case that the pivot of the matrix verb is the one doing the coercing while the pivot of the embedded verb is the one being coerced; but it's also the case that with LC embedded verbs the pivot is an undergoer vis-á-vis that verb, whereas with ST embedded verbs the pivot is an actor vis-á-vis that verb. Thus, while in my framework the two types of verbs really do have different linking patterns, according to G&G "the periphrastic sentence frame neutralizes the atypical mapping from grammatical role to thematic role seen in LC verbs" (p. 198). The upshot of this discussion is that G&G have inappropriately mixed together the variables of verb type and construction type. If PD patients have an impairment of attentional control, they might have more trouble processing LC verbs than ST verbs; however, this prediction only applies in a straightforward way to intransitive sentences, and for this reason it would have been better if G&G had tested PD patients directly on these sentence types.

Another problem with the design of the study involves the use of the probe verification technique. Specifically, the problem is that, if not carefully controlled, this technique can prevent one from knowing whether poor performance on any given type of target-probe combination is due to miscomprehension of the target sentence, miscomprehension of the probe sentence, or both. In addition, it opens up the possibility that target sentences interfere with the comprehension of probe sentences and vice versa. For instance, suppose that PD patients exhibit poor performance on items like the following: *The woman drowned the swimmer*. *The woman drowned./The swimmer drowned*. That is, suppose that patients say the first probe is true significantly more often than they say the second probe is true. How do we know if this performance is due to poor comprehension of the target sentence, poor comprehension of the probe sentence, poor comprehension of both sentences, or good comprehension of both sentences but some kind of interference between them that influences the patients' decisions, such as whether there's lexico-syntactic parallelism (i.e., whether the NP-V order in the target is the same as the NP-V order in the probe)?

Because of the way G&G designed their materials, they ended up with a paradox in the results. One possible way to resolve this paradox would be to assume that the patients' performance was in fact influenced by whether there was lexicosyntactic parallelism between target and probe sentences. Even this approach, however, may not work.

Looking first at the patients' performance on the active sentences (Figure 32), one can see that they responded correctly to 95% of the ST actives, but to only 83% of the LC actives. It is unlikely that the reason the patients performed relatively poorly on the LC actives is that they have trouble understanding the target sentences, since, as I pointed out earlier, simple transitive sentences have a canonical linking pattern regardless of whether the verb is ST or LC. So we might want to hypothesize that the underlying cause of their behavior is that they have trouble understanding the intransitive probes with LC verbs.

But then if we look at the patients' performance on the periphrastic sentences, we see that they responded correctly to 87% of both ST and LC periphrastics. This is inconsistent with the hypothesis presented above, because not only is it fairly clear who's doing what to whom in both ST and LC periphrastic target sentences, but the intransitive probes were exactly the same as those used with the active sentences. The problem is therefore as follows: if, as was hypothesized above, the patients have trouble understanding the LC intransitive probes, they should perform worse on the LC periphrastics than on the ST periphrastics.

Suppose that we abandon the hypothesis and assume instead that the patients actually have good comprehension of the LC intransitive probes. Then we can account for the equally good performance on the ST and LC periphrastics, but we cannot explain why the patients performed worse on the LC actives than on the ST actives—unless, of course, we adopt the view that the patients have trouble understanding the LC active target sentences, but this view is not only inherently implausible (for the reason mentioned earlier) but untestable as well, since the design of the experiment prevents any measure of the comprehension of the LC active target sentences independent of the comprehension of the LC intransitive probes. Hence, there's a paradox.

One way to resolve the paradox is to assume that the patients' performance was influenced by whether there was lexicosyntactic parallelism between target and probe sentences. A close inspection of the data reveals some support for this view. Consider the actives first. For the target ST sentence *The girl applauded the clown,* the correct probe *The girl applauded* is lexicosyntactically parallel to the beginning of the target, but the incorrect probe *The clown applauded* is not. Thus, patients could perform well if they were influenced by this factor, and they did in fact perform well (95%). By contrast, for the target LC sentence *The woman drowned the swimmer,* the correct probe *The swimmer drowned* is not lexicosyntactically parallel to the target, but the incorrect probe *The woman drowned* is. Thus, patients would perform relatively poorly if they were influenced by this factor, and they did in fact perform relatively poorly (83%).

Now consider the periphrastics. For the ST periphrastic sentence *The clown made the girl applaud,* the correct probe *The girl applauded* is lexicosyntactically parallel to the final NP-V sequence of the target, but the incorrect probe *The clown applauded* is not. Thus, patients could perform fairly well if they were influenced by this factor, and they did perform fairly well (87%); the fact that they didn't perform as well as on the active ST sentences may be due to the greater grammatical complexity of the periphrastic construction. The same argument applies to the LC periphrastics: *The woman made the swimmer drown*. *The swimmer drowned* (parallel, correct) / *The woman drowned* (nonparallel, incorrect).

One reason why the lexicosyntactic parallelism approach to resolving the paradox may not be valid is that it is rather hard to reconcile with the results for the passives. Here are the data:

- ST passives (95%):
  The clown was applauded by the girl. *The clown applauded* (incorrect)
  The girl applauded (correct)
  The clown was applauded (correct)
  The girl was applauded (incorrect)

- LC passives (79%):
  The swimmer was drowned by the woman. *The swimmer drowned* (incorrect)
  The woman drowned (correct)
  The swimmer was drowned (correct)
  The woman was drowned (incorrect)

It does not appear that the notion of lexicosyntactic parallelism can be applied to the active probes, since the N-V order of the probe sentences has no analogue in the target sentences. The notion is relevant, however, to the passive probes. For the ST passives, the influence of lexicosyntactic parallelism would lead to good performance, since the correct probe *The clown was applauded* is parallel to the target but the incorrect probe *The girl was applauded* is not. As noted above, the patients did in fact perform well on the ST passives. For the LC passives, the same story holds, except that here the patients did not perform as well. Thus, it seems as if the lexicosyntactic parallelism account is not completely adequate, and so the paradox remains unresolved.

4.3.4 Seidl et al. (1995)

4.3.4.1 Summary

To further explore the role of attentional control in PD patients' syntactic comprehension deficits, Grossman's team (Seidl et al. 1995) conducted an experiment with 18 patients who were similar to those that participated in the previous studies; 16 age- and education-matched control subjects were also tested. This experiment has not been reported fully; however, a three-page abstract has been published which describes the basic features of the design and results. The investigators used a dual-task paradigm known to be sensitive to executive attentional capacity (Baddeley et al. 1986). The theory underlying the paradigm is that performance should decline when two tasks are carried out simultaneously, since limited attentional resources must be distributed across both tasks. In subjects whose resources are severely limited, however, the decrement in performance should be greater than normal. In Seidl et al.'s study, the primary task was to answer probe questions about the meaning of orally presented sentences that were either simple, contained a center-embedded subject-gap relative clause, or contained a center-embedded object-gap relative clause. A computer measured the patients' reaction times by means of a voice-triggered device. In a "baseline" condition, no secondary task was required. In two "loading" conditions, however, secondary tasks were required that differed in the degree to which they demanded attentional resources: first, finger tapping (right and left hand in separate trials); and second, recognition span (verbal and visual in separate trials), which involved seeing two slightly different patterns of stimuli in sequence and identifying the unique property of the second one.

The results are shown in Figure 33, where "WNL" represents the control subjects. Basically, there were three main findings. First, for both control subjects and PD patients, reaction times (RTs) for syntactic comprehension were not slower in the tapping condition than in the baseline condition, but were slower, by a significant degree, in the span condition than in the tapping condition. This confirms the hypothesis that span demands more attentional resources than tapping. Second, the PD patients' RTs were significantly slower than the control subjects' RTs in the baseline condition and in both secondary-task conditions, which implies that PD patients have less attentional resources available than normal individuals. Finally, bringing in the variable of sentence type, for both control subjects and PD patients, RTs for simple sentences were faster than RTs for subject-gap relatives, which in turn were faster than RTs for object-gap relatives. These differences occurred for all three secondary-task conditions except one: for PD patients, there was no RT difference between subject-gap and object-gap relatives in the span condition, which suggests that their attentional resources were completely exhausted.

With regard to the syntactic comprehension performance of individual patients, Seidl et al. provide the following information. 16 of the 18 patients made more errors as sentences became more complex. For 13 of these 16 patients, RTs for object-relatives were more than 20% slower than for simple sentences. Also, for 14 of these 16 patients, RTs in the span condition were more than 20% greater than in the baseline condition.

Figure 33: Results of dual-task study (Seidl et al. 1995)

Seidl et al. conclude that, overall, the results support the view that PD patients have an impairment of attentional control and that this impairment contributes to their syntactic comprehension deficits.

4.3.4.2 Evaluation

Given that Seidl et al.'s report is only three pages long, not much detailed information about their study is available, and for this reason I have very few comments. The RT results suggest that PD patients have a reduction of executive attentional resources that can be allocated to two different tasks. It may be possible to relate this functional disorder to the underlying neuropathology of PD, since several recent PET studies have shown that the anterior cingulate cortex is activated more strongly as the tasks in dual-task situations become more demanding (Corbetta et al. 1991 [see §2.1.1.4, p. 24]; Fletcher et al. 1995; Stuss et al. 1995) and, as I pointed out in Chapter 2, the anterior cingulate cortex is affected in PD not only because the associated basal ganglia-thalamocortical circuit is disrupted, but also because the mesocortical dopaminergic projection system is disrupted. All of this can be tied to the syntactic comprehension deficits exhibited by PD patients because, first, other neuroimaging studies that I discussed in Chapter 3 (King & Kutas 1995; Stromswold et al. 1996) indicate that the anterior cingulate cortex contributes more to the processing of object-gap relative clauses than to the processing of subject-gap relative clauses and, second, Grossman et al. (1992b) showed that PD patients are more impaired on object-gap relative clauses than on subject-gap relative clauses, as discussed earlier in this chapter.

4.3.5 Grossman et al. (1992a)

4.3.5.1 Summary

I turn now to the first of two studies that Grossman and his colleagues have done on the neuropathological substrates of syntactic comprehension deficits in PD. The experiment used PET, and the subjects consisted of three PD patients known to have syntactic comprehension deficits and eight normal controls matched for age and education. In several places in Chapter 3, I mentioned the results of this study for the control subjects, so part of what follows will recapitulate what I said there. The stimuli consisted of visually presented sentences that were either active, passive, or contained center-embedded relative clauses; although the authors do not indicate whether the relative clauses were subject-gap, object-gap, or both, it is likely that both types were used, since this how Grossman constructed his materials for previous studies. The subjects viewed these sentences in three separate conditions: in the first condition, the task was to determine whether each sentence contained the letter "k"; in the second condition, the task was to determine whether each sentence contained an adjective; and in the third condition, the task was to determine whether a female performed the action described in each sentence.

The results are shown in Table 13.

Table 13: Changes in blood flow in "regions of interest" (ROI) as normal subjects and PD patients perform sentence processing tasks (Grossman et al. 1992a).

For the control subjects, the second and third conditions were associated with significant increases in blood flow in several brain areas compared to the first condition: bilateral anterior cingulate cortex, left dorsolateral and ventrolateral prefrontal cortex, bilateral temporo-occipital cortex (this activation was strongest in the left hemisphere), left caudate, and left thalamus. Grossman et al. note that the anterior cingulate cortex is related to attentional control (Posner & Petersen 1990; Janer & Pardo 1991), and that the left lateral prefrontal areas are related to grammatical processing (Mohr 1976; Naeser &

Howard 1978; Novoa et al. 1987; Basso et al. 1985; Nadeau 1988; Alexander et al. 1989, 1990); they acknowledge, however, that "the anatomic association between grammatical processing and left frontal cortex has not been a universal association (Mohr et al. 1978; Caplan 1987)" (p. 523). With regard to the temporo-occipital regions of activation, the authors state that they are probably involved in the decoding of graphemic input. However, no remarks are made about the caudate and thalamus. The only brain area that showed significantly increased blood flow in the third condition compared to the second condition was the left posterior[25] superior temporal cortex, which suggests that this area is involved in the processing of semantic information (Metter et al. 1989; Chawluk et al. 1990).

In contrast to the control subjects, the PD patients did not show significant increases of blood flow in any of the brain areas mentioned above except one—the left superior temporal cortex, which was strongly activated in the third condition. Grossman et al. point out that this pattern of results makes sense, given the fact that the basal ganglia and the frontal lobes are affected in PD whereas the temporal lobes are not. In relating these findings to the syntactic comprehension deficits exhibited by PD patients, the authors focus mainly on the anterior cingulate cortex, suggesting that this brain area "may play a role in modulating attention to subtle or noncanonical grammatical features of a sentence" (p. 522). As an explanation for anterior cingulate dysfunction in PD, the authors suggest that damage to the mesocortical dopaminergic projection system is a more plausible candidate than damage to the relevant basal ganglia-thalamocortical circuit, since correlations have been found between dopamine depletion in the ventral tegmental area of the substantia nigra and intellectual impairments in PD patients (Torack & Morris 1988; German et al. 1989; Rinne et al. 1989). Finally, Grossman et al. make the

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[25] Although Table 34 refers generally to "left superior temporal cortex," Grossman et al. state in their text that the activation was just in the posterior part (i.e., in Wernicke's area).

following remarks about the lack of significant blood flow increases in the left lateral prefrontal cortex in PD patients during the sentence processing tasks:

> This suggests that functional cerebral abnormalities in PD may extend beyond anterior cingulate cortex to include other anterior brain regions, and that their sentence processing deficit may even involve some compromise of grammatical computations. Detailed analyses of cognitive functioning in single cases of PD have revealed that about 10% of these patients exhibit a performance pattern that is consistent with such a grammatical deficit (M. Grossman, S. Carvell, and L. Peltzer, unpublished observations). However, this may not be the only account for the participation of middle and inferior frontal regions in the sentence comprehension deficit of PD patients. For example, mesocortical projections from the ventral tegmental area are not restricted to anterior cingulate cortex, but project widely throughout the cortical mantle in an apprarently graded fashion that is most dense anteriorly. Moreover, to the extent that there are connections between anterior cingulate and middle/inferior frontal cortices (Chavis and Pandya 1976; Pandya et al. 1981; Barbas and Mesulam 1985), there is the possibility of a functional diaschisis that reduces CBF [i.e., cerebral blood flow] in these lateral frontal regions following a cingulate dysfunction. (p. 523)

4.3.5.2 Evaluation

As I mentioned in Chapter 3 (§3.3.2.5, p. 138), Grossman et al.'s claim that the anterior cingulate cortex contributes to attentional control for sentence processing is well-supported. Thus, it is likely that in the second condition, the anterior cingulate serves to amplify the processing efficiency of parsing operations and monitor for adjectives, and that in the third condition, it serves to amplify the processing efficiency of linking operations and monitor for female agents.

A problem with Grossman et al.'s study, however, is that, as I pointed out in Chapter 3 (p. 138), several different constructions were included in each condition—actives, passives, and relative clauses—and as a consequence it is impossible to tell whether the anterior cingulate cortex plays a more important role in the processing of some of these constructions than it does in others. As noted above, Grossman et al. state that the anterior cingulate may contribute to "modulating attention to subtle or noncanonical grammatical features of a sentence" (p. 522). But of the types of constructions that were included in the study, only object-gap relative clauses would require this kind of attentional control, since only they have a noncanonical linking pattern that is signaled just by word order. Indeed, as mentioned above, other neuroimaging studies support the view that object-gap relatives but not subject-gap relatives demand the attentional resources subserved by the anterior cingulate cortex (King & Kutas 1995; Stromswold et al. 1996).

With regard to the left lateral prefrontal cortex, Grossman et al. suggest that this brain region typically implements parsing operations. While this may be true, another possibility, which I elaborated in Chapter 3 (§3.3.2.5, pp. 136-41), is that, like the anterior cingulate cortex, this region plays a role in attentional control, specifically in the decision-making aspect. Actually, my approach may be more consistent with the available data than Grossman et al.'s approach. As Grossman et al. point out in the long passage quoted above, very few, if any, PD patients seem to have an impairment of parsing operations. But if these operations were implemented in the left lateral prefrontal cortex, one would expect a much greater proportion of patients to have parsing difficulties because, as this study indicates, they have reduced blood flow in this region of the brain during sentence processing tasks. On the other hand, if parsing operations were typically implemented elsewhere—say, in the left anterior superior temporal cortex, as I suggested in Chapter 3—this explanatory problem would not arise. Moreover, if one of the functions of the left lateral prefrontal cortex was to contribute to the decision-making aspect of attentional control, the reduced blood flow in this brain region for PD patients could be accounted for quite easily, since it would fit nicely into the general picture of how these patients' syntactic comprehension deficits are due to an impairment of attentional control.

Last of all, some comments are in order about Grossman et al.'s view that the cortical dysfunction in PD is caused more by disuption of the mesocortical dopaminergic innervation than by disruption of the basal ganglia-thalamocortical circuits. This view seems to be incompatible with the results of Grossman et al.'s own study, since the finding of activation in the left caudate and thalamus for the control subjects strongly suggests that the basal ganglia-thalamocortical circuits are functionally important for syntactic comprehension. A reasonable hypothesis based on material reviewed in Chapters 2 and 3 is that these circuits serve to "bias" processing routines in the relevant cortical sites, in part by influencing how decisions are made about which templates and linking patterns should be suppressed and which should be promoted. There is, however, a potential problem with the idea that the basal ganglia-thalamocortical circuits contribute to syntactic comprehension. The lateral prefrontal cortex—certainly the dorsolateral sector and perhaps also the ventrolateral sector—is involved in a circuit with the caudate, but the anterior cingulate cortex is not; rather, it is involved in a circuit with the ventral striatum (see Figure 6). And yet Grossman et al. report that only the caudate was found to be activated in the basal ganglia. There may be a way around this problem, however. The caudate and ventral striatum are directly adjacent anatomical structures, so it may be that both of them were in fact significantly activated in the second and third experimental conditions for the control subjects. Researchers who work directly with PET data often remark that it can be extremely difficult to determine precisely whether an area of significantly high blood flow corresponds to just one or to both of two small, closely related anatomical structures. Furthermore, even though there is considerable variation in the anatomical details of individual brains, most PET studies, including Grossman et al.'s, average across the results for all the subjects instead of matching the results for each subject with an MRI image of that subject's own brain (Churchland & Churchland 1996).

4.3.6 Grossman (in press)

4.3.6.1 Summary

The most recent study conducted by Grossman and his colleagues is described very briefly in a forthcoming article that provides a general overview of the team's research on syntactic comprehension deficits in PD. The purpose of this study was to assess the syntactic comprehension abilities of PD patients in two conditions—first, when they are fully supplemented by their dopamine medication and, second, when they have been off their medication for at least 12 hours. 20 very mild patients, almost all Hoehn and Yahr Stage 1, participated in the experiment. Note that this is in contrast to the previous studies that Grossman's group has done, where the majority of patients were Stage 2. In both experimental conditions, the patients' syntactic comprehension abilities were evaluated by means of both an oral "probe question" task, like the one used by Grossman et al. (1992b), and a visual sentence-picture matching task. The stimulus sentences contained relative clauses that were either terminal or center-embedded. Grossman does not indicate whether the relative clauses were subject-gap or object-gap; however, because he says that these materials were similar to those used in the (1992b) study, it is likely that the terminal relatives contained just an adjective and that the center-embedded relatives varied between subject-gap and object-gap. Finally, the patients were also tested on a dual-task procedure in which the primary task involved detecting as quickly as possible the appearance of a circle in a random position on a computer screen, and the secondary tasks involved, first, counting from 1 to 10 (a non-demanding task) and, second, retaining in verbal STM a set of digits equal to the patient's digit span capacity (a demanding task).

The results for the syntactic comprehension tasks are shown in Figure 35. Analysis of the performance profiles of individual patients revealed two distinct subgoups: 10

of the patients performed significantly worse, overall, than the other 10; the first, "impaired" subgroup is represented in the figure by dashed lines, and the second, "intact" subgroup is represented by solid lines. For the sentences with terminal relative clauses, neither subgroup performed differently in the "off" condition than in the "on" condition for the oral comprehension task, but both subgroups performed better in the "off" condition than in the "on" condition for the sentence-picture matching task. As for the sentences with center-embedded relative clauses, when they were presented in the oral comprehension task, the intact subgroup performed better in the "off" condition than in the "on" condition, whereas the impaired subgroup performed worse in the "off" condition than in the "on" condition. When these sentences were presented in the sentence-picture matching task, the intact subgroup did not perform differently in the "off" condition than in the "on" condition, but the impaired subgroup again performed worse in the "off" condition than in the "on" condition; moreover, the impaired subgroup's decline in performance for the matching task was greater than their decline in performance for the oral task. Another finding was that for the center-embedded relatives but not for the terminal relatives, the two subgroups had roughly the same error rate in the "on" condition but diverged in the "off" condition; this occurred for both oral and matching tasks. Finally, Grossman reports that when the results for the syntactic comprehension tasks were compared with the results for the dual-task procedure, a significant correlation was found. In short, difficulty with syntactic comprehension in the "off" condition was associated with difficulty on the demanding dual-task measure in the "off" condition.

4.3.6.2 Evaluation

As in the other studies conducted by Grossman and his colleagues, about half of the patients who were investigated turned out to have syntactic comprehension deficits. The level of impairment here was, for the most part, very mild, but this may be because the patients were overwhelmingly Stage 1. The finding that the impaired subgroup performed worse on center-embedded relative clauses in the "off" condition than in the "on" condition suggests that the patients' dopamine medication improves their syntactic comprehension abilities. This implies that without the medication, the patients' dopamine depletion reduces the efficiency of the cognitive resources necessary for sentence processing—specifically, the resources of attentional control and perhaps also syntactic STM. A problem with this study, though, is that Grossman does not separate out performance on object-gap relatives from performance on subject-gap relatives. If this were done, it is likely that the patients' performance on object-gap relatives would be significantly worse than their performance on subject-gap relatives.

The finding that the intact subgroup performed worse in the "on" condition than in the "off" condition for many of the syntactic comprehension tasks is strange, but it may reflect an "overdose" effect. As I pointed out at the end of Chapter 2 (§2.2.4.3, pp. 27-9), it is likely that PD patients who do not manifest cognitive deficits do not have severe dopamine depletion in the caudate, ventral striatum, or prefrontal cortex; their dopamine depletion is restricted mostly to the putamen. Therefore, when they take medication to supplement the low levels of dopamine in the putamen, the other anatomical structures end up receiving too much of this neurotransmitter and hence become dysfunctional. It may be the case, then, that the intact patients in Grossman's study sometimes perform slightly worse when on their medication compared to when off it because the brain areas that subserve processing resources necessary for syntactic comprehension are overdosed with dopamine.

4.4 McNamara

4.4.1 Summary

The last study that I will review was conducted by McNamara et al. (in press). The aim of this study was to test the following two hypotheses. First, the authors reasoned that because the left lateral prefrontal cortex is known be important for both syntactic comprehension and working memory, and because this region of the brain is affected in PD, one would expect syntactic comprehension deficits to be related to working memory deficits in PD patients. Second, the authors proposed that because Broca's aphasia typically results from damage to the left lateral prefrontal cortex, the language abnormalities found in PD patients might resemble those found in Broca's aphasics. More specifically, they suggested that both types of patients may have qualitatively similar reductions in the "computational capacity" available for sentence processing—a notion that, for them, appears to emphasize memory resources more than attentional resources—except that the reduction is more severe in Broca's aphasics than in PD patients.

In order to test these hypotheses, McNamara et al. carried out three experiments with three groups of subjects. The first group consisted 15 PD patients with the following characteristics:

- severity of PD: mean = Hoehn & Yahr stage 2.8
- duration of PD: mean = 8.8 years
- cognitive status: nondemented, according to clinical exams and DSM-III criteria
- medication: all were on stable medication programs
- age: range = 43-73 yrs., mean = 64.7 yrs.
- sex ratio: all male
- education: mean = 12.3 yrs.
- handedness: right

The second group consisted of five Broca's aphasics with the following characteristics:

- CT- or MRI-documented, stroke-induced lesions in the left frontal lobe
- Broca's aphasia confirmed by the Boston Diagnostic Aphasia Examination
- right-sided hemiplegia
- age: range = 44-74, mean = 58.5 yrs.

- time post-onset: range = 16 months - 14 yrs., mean = 7.7 yrs.
- sex ratio: all male
- education: mean = 12 yrs.
- handedness: right

The third group consisted of five control subjects who were matched in age, education, sex, and handedness to the PD and aphasic patients. McNamara et al. conducted three experiments with these groups of subjects. The first two experiments addressed the second hypothesis described above, and the final experiment addressed the first hypothesis.

Before commencing with Experiment 1, all three groups of subjects were evaluated on the Digit Span Test, both forward and backward parts. McNamara et al. note that while the forward part of this test measures "the passive span of short-term memory or attention," the backward part "is considered to be a more effortful 'working memory' task or activity since it involves both memory capacity and the operation to reverse the digits" (p. 12). The results showed that although the three groups did not differ significantly on the forward part of the test, they did differ significantly on the backward part: the aphasics had the lowest score (2.2), the PD patients had the middle score (4.3), and the control subjects had the highest score (5.2). These findings provide some initial support for the hypothesis that aphasics have less computational capacity than PD patients, who in turn have less computational capacity than normal controls.

Experiment 1 required all of the subjects to make acceptability judgements about sentences. The authors do not mention the total number of items that were presented to the subjects; however, the design of the experiment is clear. Each set of items consisted of eight dative sentences that differed along several dimensions: half were grammatical and half ungrammatical; half were declarative and half were WH-questions; half of the declarative sentences had an extra argument and half had an adjunct; finally, half of the questions focused on the theme argument and half focused on the goal argument. A representative set of items is provided below:

decl, arg, gram: *A man brought a package to Samuel from Mary.*
decl, adj, gram: *A man brought a package to Samuel last Tuesday.*
ques, thm, gram: *What was brought to Samuel?*
ques, goal, gram: *Who was brought a package?*
decl, arg, ungram: *A man bought a package to Samuel from Mary.*
decl, adj, ungram: *A man bought a package to Samuel last Tuesday.*
ques, thm, ungram: *What was bought to Samuel?*
ques, goal, ungram: *Who was liked a package?*

Besides predicting that the Broca's aphasics would perform worse than the PD patients, who in turn would perform worse than the control subjects, McNamara et al. made three additional predictions about how the subjects would perform. First, they predicted that acceptability judgements would be harder to make for ungrammatical sentences than for grammatical sentences, "since detection of ungrammaticality probably requires a processing step over and above what would be required to interpret grammatical sentences" (p. 17). Second, they predicted that judgements would be harder to make for declarative sentences with adjuncts than for declarative sentences with extra arguments, since research on the processing of such sentence types indicates that "verb related information may be given priority in attempts at interpretation" (Shapiro et al. 1992). Finally, they predicted that judgements would be harder to make for questions about the theme than for quesions about the goal, since the former argument is inanimate and hence less salient than the latter argument.

The results are shown in Table 14.

Sentence Type	Broca's	PD	Controls
decl, arg, gram	76 (29)	76 (15)	94 (7)

decl, adj, gram	87 (17)	78 (19)	100 (0)
ques, thm, gram	79 (19)	81 (18)	100 (0)
ques, goal, gram	65 (37)	75 (31)	100 (0)
decl, arg, ungram	57 (19)	72 (20)	97 (5)
decl, adj, ungram	72 (27)	76 (19)	97 (5)
ques, thm, ungram	70 (20)	71 (30)	97 (5)
ques, goal, ungram	80 (24)	80 (20)	100 (0)
	73 (24)	76 (21)	98 (2)

Table 14: Acceptability Judgements (Percent Correct + SD)

The control subjects performed significantly better overall than either of the brain-damaged groups, but there was not a significant overall difference between the two brain-damaged groups. The only sentence type on which the Broca's aphasics performed significantly worse than the PD patients was "declarative, argument, ungrammatical." As for the investigators' predictions about differential sensitivity to various sentence types, virtually none of them were confirmed. For the Broca's aphasics, performance was worse for ungrammatical (67%) than for grammatical (76%) sentences, in accord with the prediction; however, contrary to expectation, peformance was better for declaratives with adjuncts (79%) than for declaratives with extra arguments (66%), and there were no significant differences betweeen types of questions. For the PD patients, there were no significant differences between sentence types whatsoever.

All of the subjects from Experiment 1 also participated in Experiment 2, which addressed syntactic comprehension. Again, although the authors do not indicate the total number of items that were used in this study, the design of the materials and procedure is clear. The sentences for the experiment were constructed from those for the previous experiment by adding adjunct phrases to the declarative sentences with extra arguments—e.g., *A man brought a package to Samuel from Mary last Tuesday*. After presentation of the sentence, the two questions from the previous experiment were presented—e.g., *What was brought to Samuel? Who was brought a package?* A third question was also presented that probed the agent role—e.g., *Who brought Samuel a package?* In addition, two sentences were presented for verification (i.e., true/false judgement), one with an argument phrase and one with an adjunct phrase—e.g., *A man brought a package to Samuel from Mary. A man brought a package today.*

The results are shown in Table 15 below:

Sentence Type	Broca's	PD	Controls
Questions			
Theme	57 (33)	87 (14)	100 (0)
Goal	72 (18)	70 (23)	95 (11)
Agent	65 (22)	73 (17)	80 (20)
Verification			
Argument	69 (14)	76 (17)	92 (14)
Adjunct	57 (14)	77 (18)	84 (10)
	64 (20)	77 (18)	90 (11)

Table 15: Comprehension

Here the expected overall differences between groups emerged: the Broca's aphasics were worse than the PD patients, who in turn were worse than the control subjects. McNamara et al. note that while the Broca's aphasics performed significantly better on the argument verifications than on the adjunct verifications (in line with what they expected), the PD patients were not differentially sensitive to the two sentence types. It is also interesting that the Broca's aphasics did significantly better on the goal questions than on the theme questions (in line with what the authors expected), whereas the PD patients had exactly the opposite pattern.

Experiment 3 focused on the relation between language performance and prefrontal function, and only the PD patients were included. These patients were given the Wisconsin Card Sort Test, which is traditionally regarded as a good measure of the integrity of the left lateral prefrontal cortex, especially the dorsolateral sector (see §2.1.1.4, p. 20, and §2.2.3, p. 36). The patients were divided into two groups based on their scores for the number of categories completed. Six patients fell into the "unimpaired" group (four or more categories completed), and nine patients fell into the "impaired" group (less than four categories completed). Further analysis of the data revealed that the impaired group also made more perseveratory errors than the unimpaired group, and also that WCST scores were significantly correlated with performance on the backward part of the Digit Span Test. When the investigators compared the performance of these two groups on the acceptability judgement task in Experiment 1, they obtained the following results:

Sentence Type	WCST impaired	WCST unimpaired
decl, arg, gram	79 (18)	80 (13)
decl, adj, gram	79 (18)	76 (21)
ques, thm, gram	78 (20)	87 (15)
ques, goal, gram	69 (35)	83 (12)
decl, arg, ungram	76 (14)	77 (28)
decl, adj, ungram	75 (25)	77 (9)
ques, thm, ungram	78 (29)	73 (33)
ques, goal, ungram	83 (22)	75 (25)
	77 (23)	79 (19)

Table 16: Judgement scores for WCST impaired vs. unimpaired PD patients

Overall, there was no significant difference between how the two groups performed on the judgement task. Only one sentence type—question, goal, grammatical—reached marginal significance. Next, McNamara et al. looked at how the two groups performed on the comprehension task in Experiment 2. These results are shown below.

Sentence Type	WCST impaired	WCST unimpaired
Questions		

Theme	83 (16)	94 (10)
Goal	69 (20)	71 (29)
Agent	72 (19)	72 (15)
Verification		
Argument	72 (12)	82 (23)
Adjunct	70 (17)	88 (13)
	73 (17)	81 (18)

Table 17: Comprehension scores for WCST impaired vs. unimpaired PD patients

Here the unimpaired group tended to perform better than the impaired group. There were significant differences for the verification adjunct sentences and the theme questions, plus a nearly significant difference for the verification argument sentences.

In the discussion section of their paper, McNamara et al. return to the two hypotheses that they started with. The first hypothesis was that the language problems in PD might be related to disrupted functioning in the left lateral prefrontal cortex. This hypothesis received partial support because, as the results of Experiment 3 show, although performance on the WCST was not a valid predictor of good or bad performance on the acceptability judgement task, it was a much better predictor of good or bad performance on the comprehension task. Since the WCST scores were also correlated with the backward digit span scores, the authors suggest that "the frontal dysfunction may be causing short-term memory impairment which then results in difficulties in comprehending language passages which tax working memory capacity" (p. 28-9). The second hypothesis was that PD patients and Broca's aphasics might have similar language deficits, except the deficits would be less severe in the former group than in the latter group. This hypothesis also received partial support. It was not borne out in the acceptability judgement task, since both groups performed at about the same level, with the Broca's aphasics having only slightly worse scores than the PD patients overall and significantly worse scores for only one of the eight sentence types. However, it was confirmed in the comprehension task, since the Broca's aphasics did perform significantly worse overall than the PD patients. Thus, McNamara et al. conclude that both brain-damaged groups have a decrement in the computational capacity available for sentence processing, but this decrement appears to be greater in Broca's aphasics than in PD patients.

4.5.2 Evaluation

As with the studies conducted by Lieberman et al., this study does not directly bear on the specific predictions that I made about the syntactic comprehension abilities of PD patients. The reason is that McNamara et al. did not test PD patients on any of the types of constructions that I discussed in Chapter 3. Nonetheless, several comments can be made concerning the materials, data analysis, and explanation of results in this study.

First of all, McNamara et al. seem to be most interested in how memory resources for sentence processing are affected in both PD patients and Broca's aphasics. However, I do not think that the materials for Experiments 1 and 2 were able to measure these resources very effectively. In Experiment 1, it appears that the grammaticality of all the declarative sentences depends on whether the argument structure properties of the verb are satisfied properly by the syntax. Thus, carrying out the acceptability judgement task for these sentences requires, first, that one check to see if the Completeness Constraint is satisfied—i.e., that all argument positions in the LS of the predicate are linked to NPs, and vice versa—and, second, that one check to see if the NPs are marked by the appropriate prepositions, when necessary. Performing these monitoring operations, however, does not seem to place heavy demands on syntactic STM or even on verbal STM; if anything, they place a load on attentional resources. For instance, the sentence *A man brought a package to Samuel from Mary* can be judged to be grammatical by noting for each NP, when it is encountered, that it can be linked to an open argument position in the LS of the predicate **brought**, and also by noting that the last two NPs have the correct prepositions. Similarly, the sentence *A man bought a package to Samuel from*

Mary can be judged to be ungrammatical as soon as one detects that the preposition *to* indicates that the following NP is a goal, and that this is incompatible with the lack of a goal argument in the LS of the predicate **bought**.[26] Actually, the variable of "extra argument vs. adjunct" seems to be irrelevant to the acceptability judgement task, at least for the declarative sentences that McNamara et al. provided as examples. Remarks along the same lines could be made about the question sentences that were used in Experiment 1. In my opinion, a better strategy for using the acceptability judgement paradigm to measure the memory resources needed for sentence processing would have been to design sentences whose grammaticality hinges on long-distance dependencies—e.g., *Susan didn't leave, despite many hints from her tired hosts, and neither did Bill* vs. *Susan didn't leave, despite many hints from her tired hosts, and neither was Bill* (Martin & Romani 1994).

In Experiment 2, the procedure involved presenting the subjects with a single "target" sentence and then five "probe" sentences that were supposed to evaluate comprehension. Performing well under these conditions probably requires having excellent verbal STM resources, since it is likely that one must keep rehearsing the target sentence subvocally in order to respond to all of the probe sentences.[27] As I argued in Chapter 3, however (§3.2.2.1, pp. 97-8), verbal STM is not necessary for most on-line sentence processing operations. Thus, this experiment may not have tapped any of the resources that are in fact necessary for on-line sentence processing, such as syntactic STM and attentional control. A plausible reason for the PD patients' poor performance (based on the discussion in §2.2.2, p. 32-4) is that, although their verbal STM system is essentially

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[26] Incidentally, another requirement for accomplishing acceptability judgements for these particular sentences is that one be able to discriminate between *brought and bought*. McNamara et al. do not mention whether they assessed this ability in their subjects.

[27] McNamara et al. do not indicate whether the subjects could ask the examiner to repeat the target sentence. However, McNamara has informed me through a personal communication that repetition was not allowed.

intact (Heitanen & Teräväinen 1988; Cooper et al. 1991), their ability to maintain material in verbal STM breaks down when they are forced to deal simultaneously with interfering stimuli—in this case, multiple probe sentences (Tweedy et al. 1982; Huber et al. 1989).

Turning to the topic of data analysis, my only comment is that McNamara et al. did not provide information about the individual performance profiles of their subjects, and as a consequence it is impossible to determine whether the group of PD patients diverged such that, as in Grossman et al.'s studies, half of them performed well whereas the other half performed relatively poorly.

Finally, with respect to the authors' general discussion of their results, I think they are right to be concerned about how "working memory" and "computational capacity" are affected in PD patients and Broca's aphasics. However, these complex notions must be unpacked and given precise cognitive and neurobiological definitions if we are to understand the nature of syntactic comprehension deficits in these clinical populations. McNamara et al. focus more on memory than on attention, yet they do not specify how memory is supposed to contribute to the processing of the kinds of sentences they used in their study, nor do they take into account Grossman et al.'s (1992b) finding that, as far as syntactic STM is concerned, the vast majority of PD patients do not seem to be impaired.[28] Actually, the pathbreaking research carried out by Grossman's team, as well as the broader neuropsychological research that's been done on PD, suggest that the most profitable direction to take in investigating syntactic comprehension deficits in this population may be to focus more on attention than memory. Still, it is likely that, in the end, both of these tightly interacting processing resources will be shown to play a role.

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[28] McNamara et al. do discuss Grossman et al.'s research in the introduction to their paper. But they seem to have misinterpreted Grossman et al.'s (1992b) study, since they write that "Grossman et al. pointed to short-term memory and attentional deficits as contributing factors in parkinsonian language performance" (p. 7). In fact, memory factors accounted for only a tiny proportion of the variance in Grossman et al.'s results.

4.5 Summary

All but three of the studies reviewed in this chapter provide data that are relevant to many of the predictions I made at the end of the previous chapter regarding the syntactic comprehension abilities of PD patients. One of my predictions was that roughly half of PD patients would exhibit syntactic comprehension deficits, and this prediction was borne out by the research conducted by Grossman's team. Another prediction was that such patients would perform normally not only on transitive active sentences but also on passive sentences, despite the fact that passives have noncanonical linking between syntax and semantics. This prediction was also confirmed by the studies carried out by Grossman's team. A third prediction was that PD patients would perform well on subject-subject relatives but poorly on subject-object relatives. This prediction was confirmed by Grossman's team as well. Finally, I suggested that PD patients should not have more difficulty understanding undergoer-intransitives than actor-intransitives. Although Geyer & Grossman (1995) did not directly test PD patients on these two types of intransitive sentences, they did test patients on other types of sentences containing either the kinds of verbs that occur in undergoer-intransitives or the kinds of verbs that occur in actor-intransitives. They found that, overall, performance was worse on the former group of sentences than on the latter group of sentences. This result raises the possibility that my prediction may be wrong, but it does not demonstrate this directly.

While the research carried out by Grossman's team is largely consistent with my proposals about how PD patients would perform on actives, passives, relative clauses, and intransitives, this research still has some limitations. With regard to active and passive sentences, Grossman et al. (1992b) did not indicate whether the patients' performance on these items was influenced by the voice of the probe question or by the semantic (non)constrainedness of the target sentence. Also, Geyer & Grossman (1995) found that patients performed better on active and passive sentences with "simple transitive" (ST) verbs than on active and passive sentences with "lexical causative" (LC) verbs, but I argued in my evaluation of this study that the patients' responses to the probe sentences may have been affected by whether there was lexicosyntactic parallelism between the targets and probes. With regard to relative clauses, Grossman et al. (1992b) report that the patients performed significantly better on subject-subject relatives than on subject-object relatives, but, as with the active and passive sentences, they did not indicate whether the patients were influenced by other variables such as the voice of the probe question or the semantic (non)constrainedness of the target sentence. Last of all, with regard to the intransitive sentences, in order to determine whether PD patients have more trouble understanding undergoer-intransitives than actor-intransitives, it is necessary to test them directly on these kinds of sentences. As I argued in my evaluation of Geyer and Grossman's (1995) study, this issue cannot be resolved by testing patients on other kinds of sentences that contain verbs which can occur in one or the other intransitive template. Given these considerations, further research is needed to obtain more precise information about PD patients' comprehension of actives, passives, relative clauses, and intransitives. Several of the studies that I will describe in the next chapter were designed with this goal in mind.

I turn now to the different ways in which researchers have attempted to explain the syntactic comprehension deficits exhibited by PD patients. Lieberman et al. (1991, 1992) suggest that PD patients have a basic sentence processing impairment involving, as they put it, "the ability to make use of the syntactic 'rules' of English" (1991, p. 364). In terms of the framework that I developed in Chapter 3, Lieberman et al. might say that PD patients have a disruption of parsing and/or linking operations. On the other hand, Grossman and his colleagues propose that the most significant causal factor behind PD patients' syntactic comprehension deficits is an impairment of attentional control. In addition, their research suggests that a small minority of patients may have defective syntactic STM, and that another small minority may have defective parsing and/or linking operations. McNamara et al. (in press) adopt yet another view, proposing that the major determinant of sentence processing difficulties in PD patients is a reduction of working memory resources. In response to these different approaches, I have argued that the position taken by Grossman et al. has the greatest explanatory coherence, since it is supported by not only a wide range of behavioral data about the syntactic comprehension abilities of PD patients, but also by the facts regarding the neuropsychology and neuropathology of PD. It is clear, however, that further research is needed to refine and test the hypothesis that the primary cause of syntactic comprehension deficits in PD is a disruption of attentional control. For instance, I predicted at the end of Chapter 3 that if this hypothesis is correct, PD patients should manifest certain patterns of performance on raising-to-subject sentences, cleft sentences, and control sentences. Several of the studies that I will describe in the next chapter address these predictions.

With respect to neurobiological issues, it is worthwhile to consider the implications of the studies that I have reviewed for a question that was left open in Chapter 3—namely, whether a reciprocal circuit exists between the basal ganglia and the ventrolateral prefrontal cortex. In Chapter 3, I presented evidence from the neuroimaging studies conducted by Stromswold et al. (1996) and Kluender and Kutas (1993) that the processing resource of syntactic STM tends to be localized in the ventrolateral prefrontal cortex—in particular, in Broca's area. I also suggested, based on the neuroimaging studies conducted by Petrides (1995), that the ventrolateral prefrontal cortex may also contribute to attentional control for the selection of appropriate templates and linking strategies during sentence processing. Now, if a circuit did in fact exist between the basal ganglia (more narrrowly, the caudate nucleus) and the ventrolateral prefrontal cortex, it would most likely be disrupted in roughly half of PD patients, and hence such patients would exhibit an impairment of both syntactic STM and attentional control.

The studies that I have reviewed, especially those by Grossman's team, support the idea that PD patients have impaired attentional control, but they indicate that only a few patients have impaired syntactic STM. Taken at face value, this latter finding is contrary to what one would expect if a circuit involving the ventrolateral prefrontal cortex existed. Thus, it may be the case that this cortical region is not typically affected in PD and that the problems patients appear to have with attentional control derive entirely from the fact that the anterior cingulate cortex is known to be severely affected.

On the other hand, three additional factors support the view that a ventrolateral circuit exists. First, the PET study conducted by Grossman et al. (1992a) revealed significant hypometabolism in the ventrolateral prefrontal cortex while PD patients were carrying out sentence processing tasks. Second, Grossman et al.'s (1992b) test of syntactic STM did not place very heavy demands on this processing resource; hence, future research may show that PD patients tend to perform poorly on constructions that do load heavily on syntactic STM—e.g., such patients may have trouble making grammaticality judgements for sentence pairs like the one I mentioned in the discussion of McNamara et al.'s (in press) study: *Susan didn't leave, despite many hints from her tired hosts, and neither did Bill* vs. **Susan didn't leave, despite many hints from her tired hosts, and neither was Bill* (from Martin & Romani 1994). Third, as a purely theoretical consideration, one would expect the architecture of basal ganglia-thalamocortical circuitry to be uniform across the frontal lobes. Thus, it appears that, at least for now, the existence of a ventrolateral circuit is still a genuine possibility.

Finally, a few comments are in order about issues involving neuropsychological methodology. In the first section of this chapter, I pointed out that the performance of brain-damaged patients on syntactic comprehension tests is sometimes dependent on the manner and context in which their comprehension is evaluated. Thus, patients may perform poorly on a set of material when tested in one way, and yet perform well on the same set of material when tested in a different way. It is worth emphasizing that context effects of this sort may have occurred in some of the studies with PD patients that I have reviewed. For instance, the patients in Geyer and Grossman's (1995) study may have been influenced by the details of the probe verification task that the investigators employed. Another important consideration is that all of the studies that I have reviewed, with the possible exception of Seidl et al. (1995), have relied on off-line methods of assessing syntactic comprehension. However, I mentioned in the first section that brain-damaged patients have been found who perform poorly in off-line paradigms but well in on-line paradigms (e.g., word monitoring, cross-modal lexical priming, or event-related potentials). Hence, it is possible, at least in principle, that PD patients would display normal sentence processing when measured in an on-line paradigm. If this turned out to be the case, their deficits could potentially be attributed to difficulties in the process of allocating attentional resources across the various elements of a fully interpreted sentence in order to respond to a probe. Although it is important that PD patients be tested in one or more on-line paradigms, I did not attempt to do this in any of the studies that I will describe in the next chapter. However, Grossman has informed me (personal communication) that he is currently taking the first steps in this direction.

Chapter 5: New Studies of Syntactic Comprehension Deficits in Parkinson's Disease

The studies reviewed in Chapter 4 provide a great deal of valuable information about syntactic comprehension deficits in PD; however, more research is needed in order to understand the nature of these deficits in greater detail. In this chapter I will describe a series of studies that were designed to go beyond the previous studies in two major ways. First, although the new studies test PD patients on some of the same grammatical constructions that were used in the previous studies, they also test PD patients on a variety of constructions that have not been used before. Thus, not only will I go through relative clauses, transitive actives, passives, and intransitives once again, but I will also present data on how PD patients perform with raising-to-subject, cleft, and control constructions. Second, while the previous studies only addressed some of the predictions outlined at the end of Chapter 3, the new studies address all of them. For the sake of clarity, it is worth recapitulating those predictions here.

The central hypothesis is that PD patients should perform poorly on constructions that require attentional control for regulating the selection of templates and linking strategies. Constructions that fall into this category generally have complex constituent structure (e.g., two cores) together with noncanonical linking which is signaled by only one or perhaps no explicit cues. By contrast, PD patients should not have significant trouble understanding constructions in which the only factor that increases processing difficulty is complex constituent structure, nor should they have trouble with constructions in which noncanonical linking is required but signaled by multiple explicit cues. With regard to syntactic STM, I did not originally make any strong predictions about whether it would be a source of processing difficulty for PD patients, since I did not have any evidence as to whether a ventrolateral prefrontal circuit exists which could be disrupted in these patients, thereby affecting the syntactic STM mechanism in Broca's area. As I pointed out in the concluding section of Chapter 4, however, Grossman et al. (1992b) found that the vast majority of PD patients performed well on a test of syntactic STM, which suggests that a ventrolateral prefrontal circuit does not exist, or that, if it is there, it is somehow left intact by the disease. Based on these results, I now predict that PD patients should perform well on further tests of syntactic STM.

Given all of these considerations, it is possible to specify exactly which constructions should pose comprehension difficulties for PD patients and which should not. These construction-specific predictions are shown in Table 19 below, which simply adds a "prediction for PD" row to Table 6 from Chapter 3; also, the row for "parsing" includes both single and double x's, which will be explained later in the text.

	Construction Type															
Processing Factor	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Complex parsing			x	xx	x	xx	x	xx	x	xx	x	xx	x	xx		
Noncanonical linking		x		x		x		x		x		x		x		x
Syntactic STM			x	x		x		x		x		x		x		
Attentional control				x		x		x		x		x				
Prediction for PD				x		x		x		x		x				

Table 19: Construction-Specific Predictions for PD Patients (Abbreviations: A=active, P=passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa=active undergoer control, UCp=passive undergoer control, AI=actor intransitive, UI=undergoer intransitive)

According to this table, if PD patients have trouble with complex parsing, they should be unable to process the following constructions in the normal manner: all four types of relative clause, both clefts, all four types of raising-to-subject sentences, and both types of control sentences. It is important to note, however, that not being able to process a particular construction in the normal manner does not necessarily imply that one is unable to interpret it correctly. For instance, if the construction has a canonical linking pattern, one could interpret it correctly by applying frequency-based heuristics, such as treating preverbal NPs as actors and postverbal NPs as undergoers. Thus, if PD patients have a parsing impairment, they might still manage to perform well on those complex constructions that involve canonical linking. Another way of putting it is that they would display poor comprehension of just those constructions that have complex constituent structure and noncanonical linking; these constructions are marked with double x's in Table 19, while the constructions with complex constituent structure but canonical linking are marked with single x's.

If instead PD patients have an impairment of the ability to execute noncanonical linking, they should perform poorly on the following constructions: passives (foregrounding and backgrounding), both types of object-gap relative clause, object-clefts, both types of noncanonical raising-to-subject sentences, passive control sentences, and undergoer-intransitives.

As a third possibility, if PD patients have an impairment of syntactic STM, they should have difficulty "bridging the distance" between the pivot NP and the matrix verb in the subject-subject and subject-object relative clause constructions. In addition, they should have trouble with filler-gap integration in the following constructions: both types of object-gap relative clause, object-clefts, both types of noncanonical raising-to-subject sentences, and passive control sentences.

Finally, if PD patients have an impairment of attentional control, they should perform poorly on the same set of constructions that are "marked" for syntactic STM, with the exception of the passive undergoer-control construction. Since the hypothesis I am pursuing is that PD patients do in fact have an attention disorder, I predict that these constructions are the ones that will pose difficulties for them, as shown in the bottom row of Table 19.

A total of four studies will be presented in this chapter. In section 5.1, I will describe a study in which PD patients were tested on raising-to-subject constructions. In section 5.2, I will describe a study in which PD patients were tested on subject-subject and subject-object relative clauses as well as on two types of constructions that differ only with respect to whether they require syntactic STM. In section 5.3, I will describe a study in which PD patients were tested on all four types of relative clause constructions, both types of cleft constructions, both types of control constructions, and an independent measure of syntactic STM. Last of all, in section 5.4, I will describe a study in which PD patients were tested on transitive actives, foregrounding and back-grounding passives, and actor- and undergoer-intransitives. I will conclude in section 5.5 with a general discussion of how the results of these four studies bear on the predic-tions reviewed above.

5.1 Study 1: Raising-to-Subject Constructions

5.1.1 Goals

The first study was designed to test the predictions set forth above regarding the ability of PD patients to comprehend English raising-to-subject constructions. For ease of reference, these constructions are exemplified below with the relevant structural relationships marked:

a. subject-to-subject raising:
    i. canonical (SSc): *It seems to Harry [that Sally is nice.]*
    ii. noncanonical (SSn): *Sally$_i$ seems to Harry [____$_i$ to be nice.]*
b. object-to-subject raising:
    i. canonical (OSc): *It's easy [for Harry to catch Sally.]*
    ii. noncanonical (OSn): *Sally$_i$ is easy [for Harry to catch ____$_i$.]*

As I explained in Chapter 3 (§3.1.2.4, pp. 73-8), the two canonical constructions involve direct mappings between syntax and semantics: in the SSc construction, the NP that is semantically associated with the adjective in the embedded clause is syntactically realized in its normal position as pivot of that clause; and in the OSc construction, the NP that is semantically the undergoer of the verb in the embedded core is syntactically realized in its normal position as direct argument of that core. By contrast, the two noncanonical constructions involve mappings between syntax and semantics that deviate from the standard pattern: in the SSn construction, the NP that is semantically associated with the adjective in the embedded core is syntactically realized as the pivot of the matrix core; and in the OSn construction, the NP that is semantically the undergoer of the verb in the embedded core is syntactically realized as the pivot of the matrix core.

With respect to processing difficulty, the noncanonical constructions are more challenging than the canonical constructions for the following reasons: first, the initial NP must be held in syntactic STM without a semantic role until the predicate in the embedded core is encountered (see §3.2.2.1, pp. 96); and second, attentional control is required to suppress certain heuristic interpretive strategies and promote the correct ones (§3.2.2.2, pp. 105). For the SSn construction, the heuristic strategy is to treat the NP which is syntactically closest to the adjective in the embedded core as being semantically associated with it; and for the OSn construction, the heuristic strategy is to treat the first and second NPs as the actor and undergoer, respectively, of the verb in the embedded core. Note that for both noncanonical constructions, the correct linking strategy is only signaled by a single explicit cue: in the SSn construction, this is the preposition *to,* which indicates that the following NP is the experiencer of *seem;* and in the OSn construction, the cue is the complementizer *for*, which indicates that the following NP is the actor of the predicate in the embedded core.

Another factor which may necessitate the intervention of attentional control for processing these constructions is that they probably do not occur very frequently in English. Although I do not have any precise quantitative data about this, I suspect that when speakers use the noncanonical SS construction, the experiencer argument is almost always the speaker and is hence either coded as *me* or is simply omitted and thereby left implicit—e.g., *Sally seems (to me) to be nice.* Moreover, it is often the case that speakers also omit the *to be*—e.g., *Sally seems nice*—so that what remains is a construction which is clearly far easier to process than the complex one described earlier. Similarly, my intuition is that when speakers use the noncanonical OS construction, the actor of the embedded core is often left unspecified—e.g., *Sally is easy to catch*—so that the listener's syntactic comprehension system only has to establish the correct linking pattern for a single NP, a task which is presumably less demanding of attentional control than determining the correct linking pattern for two NPs that occur in atypical order.

With regard to predictions about how PD patients should perform on raising-to-subject constructions, the hypothesis that such patients have an attention disorder clearly predicts that they should perform well on the canonical SS and OS constructions but poorly on the noncanonical SS and OS constructions. However, as Table 19 and the subsequent discussion indicate, this pattern of performance would also be consistent with three alternative hypotheses: first, that PD patients have trouble with complex parsing (recall that good performance on the canonical constructions could arise from the use of interpretive heuristics); second, that they have trouble with noncanonical linking; and third, that they have trouble with syntactic STM. Nevertheless, testing PD patients on raising-to-subject constructions is worthwhile, since the predictions are straightforward and the results will expand our knowledge of the range of constructions that pose difficulties for these patients.

5.1.2 Subjects

The subjects for the study consisted of 15 mild to moderate PD patients. All were right-handed males who were taking some form of parkinsonian medication. Other demographic features of the patients are provided in Table 20. Nine normal control subjects matched for age, sex, handedness, and education were also tested.

5.1.3 Materials and Procedure

The stimuli consisted of 12 instances of each of the four raising-to-subject constructions: canonical SS, noncanonical SS, canonical OS, and noncanonical OS. Each item was paired with a probe question which focused on the participant(s) of the second predicate, as illustrated below:

a. subject-to-subject raising:
    i. canonical: *It seems to Harry that Sally is nice.* *Who is nice?*
    ii. noncanonical: *Sally seems to Harry to be nice.* *Who is nice?*

b. object-to-subject raising:

   i. canonical: *It's easy for Harry to catch Sally.* *Who catches who?*

   ii. noncanonical: *Sally is easy for Harry to catch.* *Who catches who?*

	Age	Onset	Dur.	MCRS	H&Y	CDR	MMSE	HRSD	Edu.
JR	72	66	10	9	2	.5	26	9	16
PP	77	74	3	15	3	0	28	6	12
AK	65	56	9	15	3	.5	26	3	12
JS	57	53	4	10	2	0	30	14	14
BU	71	68	3	17	3	0	28	7	12
CV	62	56	6	4	2	0	27	4	12
WP	73	72	1	9	2	0	28	2	13
CM	61	54	7	15	3	.5	24	2	12
RD	64	63	1	12	3	0	30	2	12
TH	80	72	8	11	3	0	28	4	9
JD	69	67	2	3	2	0	30	6	18
ML	78	76	2	17	3	0	28	5	12
RZ	71	69	2	16	3	0	26	13	12
LS	76	66	10	25	3	.5	29	4	8
DB	75	71	4	12	2	0	26	5	14

Table 20: Demographic Data about PD Patients for Study 1. Abbreviations: MCRS = Modified Columbia Rating Scale (for evaluating PD; scale: 0-48 with lower being less severe); H&Y = Hoehn and Yahr Stage (scale: 0-5 with lower being less severe); CDR = Clinical Dementia Rating (scale: 0-3 with lower being less severe); MMSE = Mini-Mental State Examination (scale: 0-30 with higher being less severe); HRSD = Hamilton Rating Scale for Depression (scale: 0-62 with lower being less severe).

The 24 subject-to-subject raising sentences that were used in the experiment are listed below (* = the argument of the embedded predicate is the same as in the corresponding canonical sentence):

A. Canonical SS

1. *It seems to Susan that Bill is angry.*   *Who is angry?*
2. *It seems to Susan that Bill is nice.*   *Who is nice?*
3. *It seems to Susan that Bill is upset.*   *Who is upset?*

4. *It seems to Bill that Susan is mean.*   *Who is mean?*
5. *It seems to Bill that Susan is sweet.*   *Who is sweet?*
6. *It seems to Bill that Susan is kind.*   *Who is kind?*

7. *It appears to Susan that Bill is attractive.*   *Who is attractive?*
8. *It appears to Susan that Bill is sad.*   *Who is sad?*
9. *It appears to Susan that Bill is depressed.*   *Who is depressed?*

10. *It appears to Bill that Susan is friendly.*   *Who is friendly?*
11. *It appears to Bill that Susan is smart.*   *Who is smart?*
12. *It appears to Bill that Susan is happy.*   *Who is happy?*

B. Noncanonical SS

1. *Bill seems to Susan to be attractive.**   *Who is attractive?*
2. *Bill seems to Susan to be sad.**   *Who is sad?*
3. *Susan seems to Bill to be depressed.*   *Who is depressed?*

4. *Bill seems to Susan to be friendly.*   *Who is friendly?*
5. *Bill seems to Susan to be smart.*   *Who is smart?*

6. *Susan seems to Bill to be happy.** *Who is happy?*

7. *Bill appears to Susan to be angry.** *Who is angry?*
8. *Bill appears to Susan to be nice.** *Who is nice?*
9. *Susan appears to Bill to be upset.* *Who is upset?*

10. *Bill appears to Susan to be mean.* *Who is mean?*
11. *Bill appears to Susan to be sweet.* *Who is sweet?*
12. *Susan appears to Bill to be kind.** *Who is kind?*

As can be seen, all of the NPs are the proper names *Bill* and *Susan,* such that all of the sentences are semantically nonconstrained. The matrix verbs alternate evenly between *seem* and *appear*. The same 12 embedded predicates occur in both the canonical and noncanonical sentences. The embedded predicates that occur with *seem* in the canonical sentences occur with *appear* in the noncanonical sentences, and the embedded predicates that occur with *appear* in the canonical sentences occur with *seem* in the noncanonical sentences. In half of the sentences, *Bill* is the argument of the embedded predicate, and in the other half *Susan* plays this role. Finally, in half of the noncanonical sentences, the argument of the embedded predicate is the same as in the corresponding canonical sentence; these items are marked with an asterisk.

The 24 object-to-subject raising sentences are listed below (* = the embedded predicate has the same arguments as in the corresponding canonical sentence):

<u>A. Canonical OS</u>

1. *It's easy for Bill to find Susan.* *Who finds who?*
2. *It's easy for Bill to understand Susan.* *Who understands who?*
3. *It's easy for Bill to hear Susan.* *Who hears who?*

4. *It's easy for Susan to please Bill.* *Who pleases who?*
5. *It's easy for Susan to help Bill.* *Who helps who?*
6. *It's easy for Susan to persuade Bill.* *Who persuades who?*

7. *It's tough for Bill to catch Susan.* *Who's trying to catch who?*
8. *It's tough for Bill to satisfy Susan.* *Who's trying to satisfy who?*
9. *It's tough for Bill to impress Susan.* *Who's trying to impress who?*

10. *It's hard for Susan to see Bill.* *Who's trying to see who?*
11. *It's hard for Susan to talk to Bill.* *Who's trying to talk to who?*
12. *It's hard for Susan to control Bill.* *Who's trying to control who?*

<u>B. Noncanonical OS</u>

1. *Bill is easy for Susan to catch.* *Who catches who?*
2. *Bill is easy for Susan to satisfy.* *Who satisfies who?*
3. *Susan is easy for Bill to impress.** *Who impresses who?*

4. *Bill is easy for Susan to see.** *Who sees who?*
5. *Bill is easy for Susan to talk to.** *Who talks to who?*
6. *Susan is easy for Bill to control.* *Who controls who?*

7. *Bill is tough for Susan to find.* *Who's trying to find who?*
8. *Bill is tough for Susan to understand.* *Who's trying to understand who?*
9. *Susan is tough for Bill to hear.** *Who's trying to hear who?*

10. *Bill is hard for Susan to please.** *Who's trying to please who?*
11. *Bill is hard for Susan to help.** *Who's trying to help who?*
12. *Susan is hard for Bill to persuade.* *Who's trying to persuade who?*

All of the NPs are the proper names *Bill* and *Susan,* and there are three different matrix predicates: *be easy*, which occurs in six sentences of each type; *be tough,* which occurs in three sentences of each type; and *be hard,* which occurs in three sentences of each type. For the sentences with *be easy,* the probe question is simply *Who Vs who?,* but for the sentences with *be tough* or *be hard,* the probe question takes the more complex form *Who's trying to V who?* Although it is undesirable to have variation in the complexity of probe questions, the latter questions were necessary in order to avoid semantic incoherence; after all, a target sentence like *It's tough for Bill to catch Susan* implies that Bill probably doesn't catch Susan, so it would not be appropriate to then ask *Who catches who?* Rather, the question *Who's trying to catch who* seems more fitting.[29] The same 12 embedded predicates occur in both the canonical and noncanonical sentences. The embedded predicates that occur with *be easy* in the canonical sentences occur with *be tough* and *be hard* in the noncanonical sentences, and the embedded predicates that occur with *be tough* and *be hard* in the canonical sentences occur with *be easy* in the noncanonical sentences. In half of the sentences, *Bill* is the actor of the embedded predicate, whereas in the other half *Susan* is the actor. Finally, in half of the noncanonical sentences, the actor of the embedded predicate is the same as in the corresponding canonical sentence; these items are marked with an asterisk.

The procedure for the experiment was as follows. First, examples of each of the four constructions and probe questions were read aloud to the patients so that they could become familiar with the nature of the materials and the task. Then the 48 test sentences and corresponding questions were read aloud to the patients in a natural manner and in a quasi-random order (subject to the proviso that no more than two items of the same kind could occur in sequence). All of the patients received the same list of items, in the same randomized order. After the first 24 items had been presented, the patients were given a

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[29] A one-way analysis of variance was conducted to determine whether the patients' performance on the OS sentences with "complex" probes was significantly different from their performance on the OS sen-tences with "simple" probes. This analysis revealed no significant difference ($F(1, 54) = .99$; $p < .05$).

break for a few minutes before going on to the remaining 24 items. At the outset, the patients were informed that any of the items could be repeated as many times as was necessary for them to arrive at an answer to the probe question. The patients were also told that even though the sentences were about the same characters, they did not make up a story and each one should be dealt with on its own.

5.1.4 Results

The entire set of data is presented in Table 21, broken down by patient and construction type and with significant dissociations between performance on canonical and noncanonical construction types highlighted (these dissociations will be discussed later). Differences between PD patients and control subjects on the canonical sentences (SS and OS combined) and noncanonical sentences (SS and OS combined) were evaluated using an analysis of variance (ANOVA) with a group (PD, control) x canonicity (canonical, noncanonical) design. A significant interaction was found ($p = 0.0001$), indicating that PD patients have intact comprehension of canonical raising-to-subject sentences but impaired comprehension of noncanonical raising-to-subject sentences (PDs: mean correct canonical = 97.0%, *SD* = 6.39; mean correct noncanonical = 68.5%, *SD* = 22.4; controls: mean correct canonical = 99.6%, *SD* = 1.89; mean correct noncanonical = 94.6%, *SD* = 5.7). These results are shown in Figure 35.

Two additional ANOVAs were carried out to evaluate the differences between PD patients and control subjects on just the SS condition and just the OS condition. The first analysis had a group (PD, control) x construction type (canonical SS, noncanonical SS) design and revealed a significant interaction ($p = 0.021$), indicating that PD patients have intact comprehension of canonical SS sentences but impaired comprehension of noncanonical SS sentences (PDs: mean correct canonical SS = 97.3%, *SD* = 5.13; mean correct noncanonical SS = 76.5%, *SD* = 19.02; controls: mean correct canonical SS = 100%, *SD* = 0.0; mean correct noncanonical SS: 95.6%, *SD* = 4.22). These results are illustrated in Figure 36. The second analysis had a group (PD, control) x construction type (canonical OS, noncanonical OS) design and also revealed a significant interaction

	SS raising		OS raising	
Subject	canonical	noncanonical	canonical	noncanonical
PD				
JR	100	92	100	66
PP	100	66	100	50
SK	100	50	100	50
JS	100	58	100	58
BU	100	83	100	83
AV	100	58	75	42
WP	100	100	100	75
CM	83	75	100	83
RD	100	100	100	100
TH	100	83	100	58
JD	100	100	100	75
ML	92	83	83	75
RZ	92	92	100	17
LS	100	42	100	17
DB	100	66	92	58
Mean	*97.3*	*76.5*	*96.7*	*60.5*
Control				
1	100	100	100	92
2	100	100	100	100
3	100	92	100	92
4	100	92	100	92
5	100	100	100	83
6	100	100	100	100
7	100	92	100	100
8	100	92	100	100

9	100	92	92	83
Mean	*100*	*95.6*	*99.1*	*93.6*

Table 21: Data for Study 1 on raising-to-subject constructions

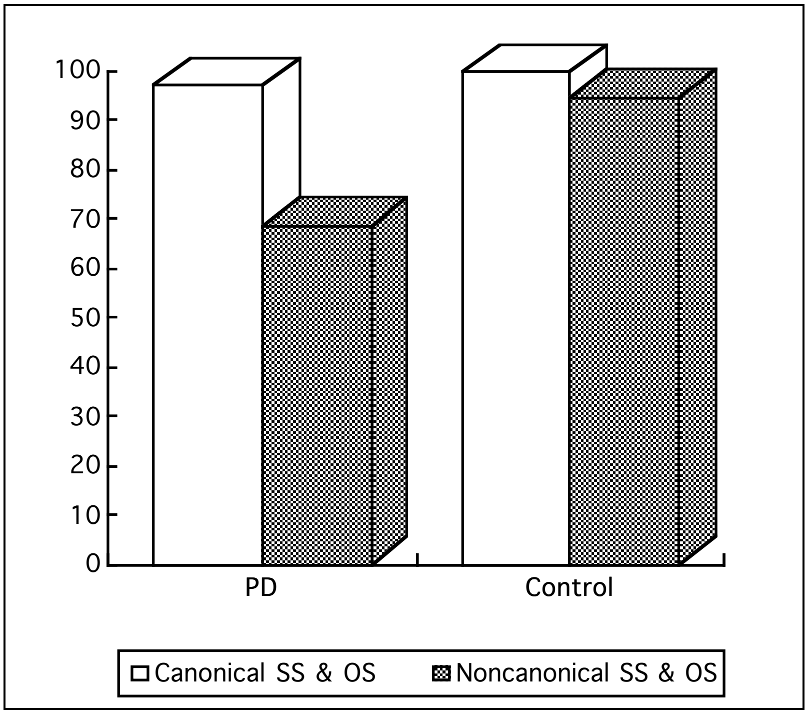

Figure 35: Comprehension of canonical and noncanonical raising-to-subject sentences by PD patients and control subjects.

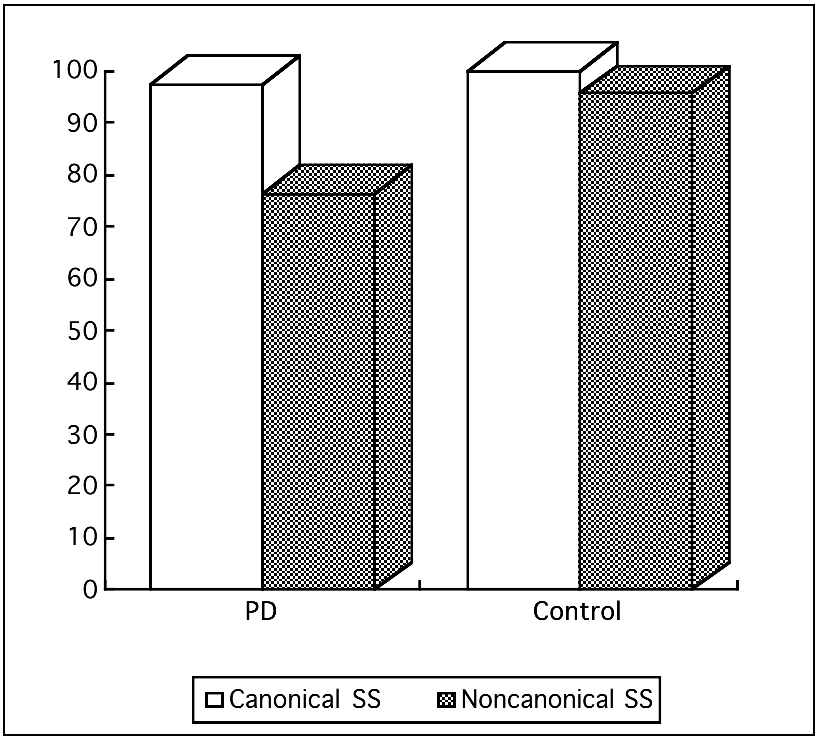

Figure 36: Comprehension of canonical and noncanonical subject-to-subject raising sentences by PD patients and control subjects.

(*p* = 0.001), indicating that PD patients have intact comprehension of canonical OS sentences but impaired comprehension of noncanonical OS sentences (PDs: mean correct canonical OS: 96.7%, SD = 7.35; mean correct noncanonical OS = 60.5, *SD* = 22.51; controls: mean correct canonical OS = 99.1%, *SD* = 2.51; mean correct non-canonical OS = 93.6%, *SD* = 6.64). These results are illustrated in Figure 37.

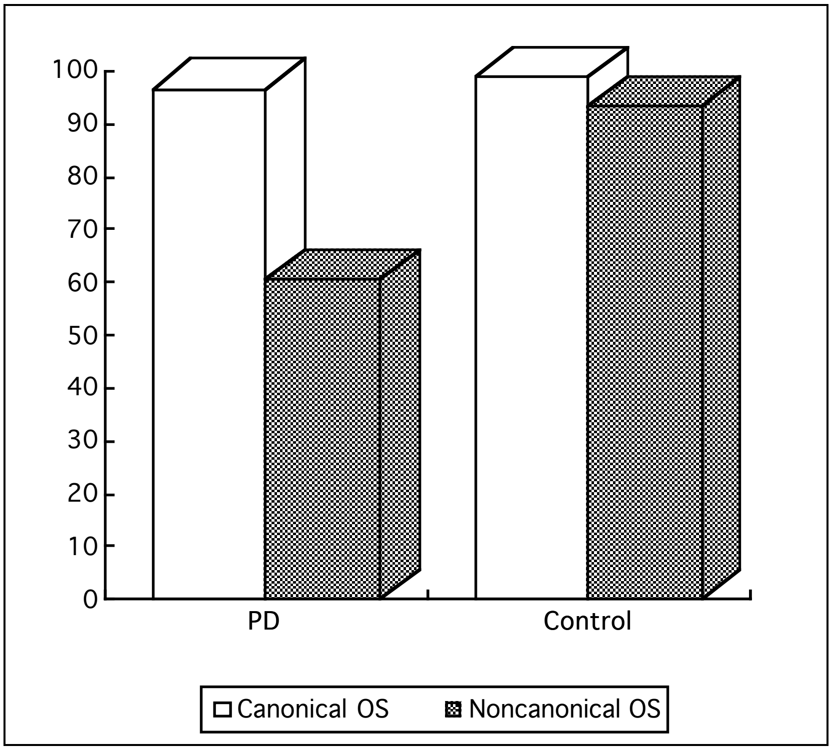

Figure 37: Comprehension of canonical and noncanonical object-to-subject raising sentences by PD patients and control subjects.

A closer investigation of the performance profiles of individual PD patients showed that the patients divided into two subgroups, one normal-like and the other non-normal. The normal-like patients did not exhibit dissociations between canonical and noncanonical constructions, whereas the non-normal patients did; these dissociations are highlighted in Table 21. All of these dissociations were found to be statistically significant by a chi-square analysis which compared observed scores with the score that would result from chance (i.e., 50%). This analysis indicated that a score of 75% or more (i.e., performing correctly on 9 or more of 12 items) is above chance ($\chi^2 = 3.0$, one-tailed $p < .05$), whereas a score of 66% or less (i.e., performing correctly on 8 or fewer of 12 items) is not different from chance ($\chi^2 = 1.34$, one-tailed $p > .05$); the score of 25% marks the beginning of the below chance region. For patient AV, who scored 75% and 42% correct on canon-ical and noncanonical OS sentences, respectively, a chi-square analysis revealed this difference to be significant ($\chi^2 = 3.56$, one-tailed $p < .05$).

In the SS condition, nine patients fell into the normal-like subgroup (canonical SS: mean=96.0%, SD=5.73; noncanonical SS: mean=89.8%, SD=8.69), and the other six patients fell into the non-normal subgroup (canonical SS: mean=98.7%, SD=2.98; noncanonical SS: mean=56.7%, SD=8.54). An ANOVA revealed a significant interaction, indicating that the non-normal patients have trouble understanding noncanonical SS sentences ($p = 0.0001$). These results are shown in Figure 38. In the OS condition, six patients fell into the normal-like subgroup (canonical OS: mean=97.6%, SD=6.42; noncanonical OS: mean=81.8%, SD=12.65), and the other nine patients fell into the non-normal subgroup (canonical OS: mean=96.3%, SD=8.89; noncanonical OS: mean=46.2%, SD=18.54). An ANOVA revealed another significant interaction, indicating that non-normal patients have trouble understanding noncanonical OS sentences ($p = 0.004$). It is noteworthy that all of the patients who fell into the non-normal SS subgroup also fell into the non-normal OS subgroup. These results are shown in Figure 39.

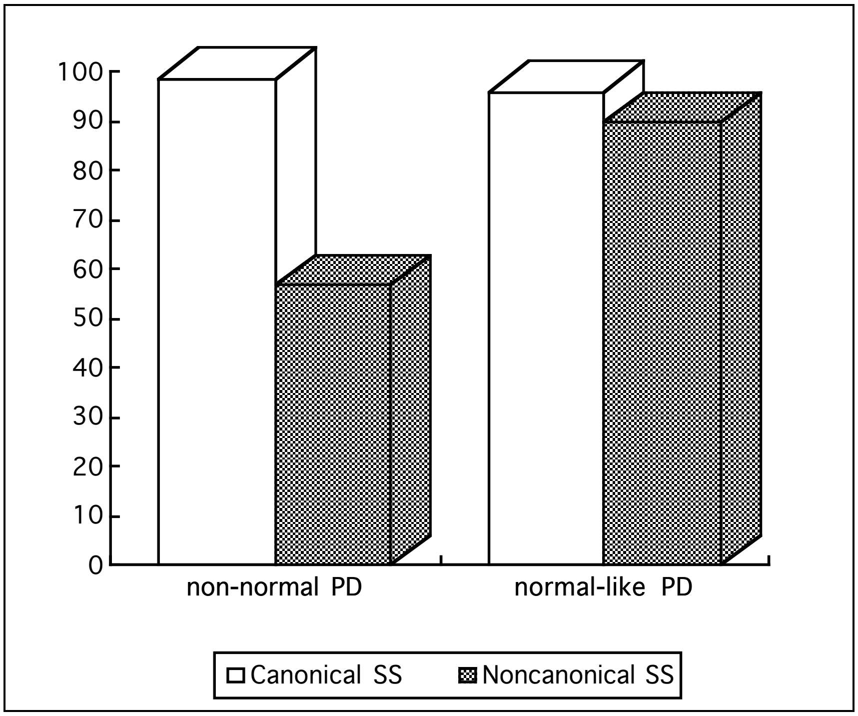

Figure 38: Comprehension of canonical and noncanonical subject-to-subject raising sentences by non-normal and normal-like PD patients

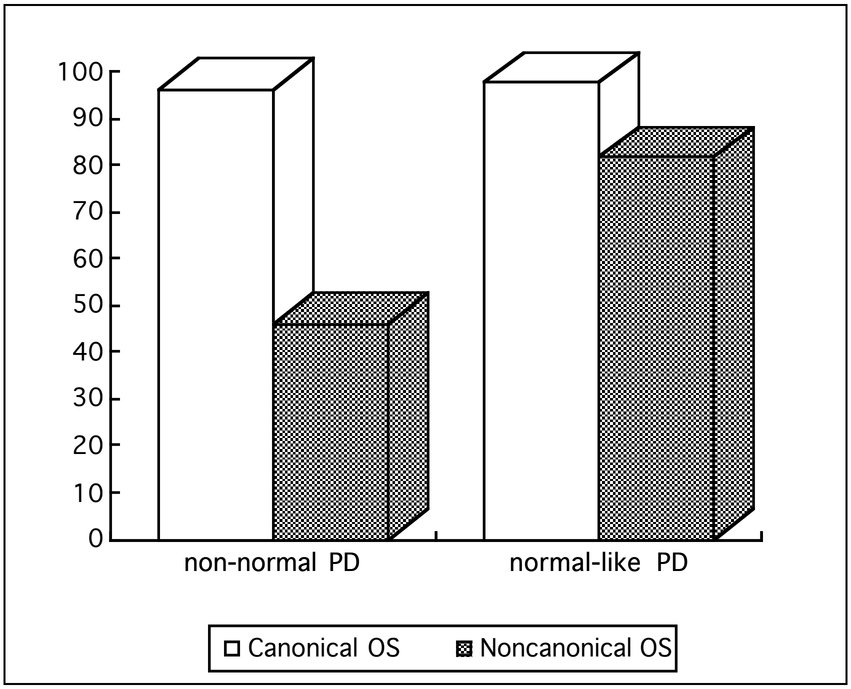

Figure 39: Comprehension of canonical and noncanonical object-to-subject raising sentences by non-normal and normal-like PD patients

5.1.5 Discussion

This pattern of results is consistent with previous studies, especially those of Grossman et al., which show that roughly 50% of PD patients have compromised syntactic comprehension abilities. More specifically, the results confirm my original prediction that such patients should have difficulty understanding noncanonical SS and OS sentences but should not have trouble with canonical SS and OS sentences. This finding is in line with the general hypothesis that syntactic comprehension deficits in PD are due to an impairment of attentional control—in particular, to a reduced ability to select and maintain an appropriate template and linking strategy and suppress an inappropriate one. However, as I pointed out in section 5.1.1, several alternative explanations of the observed pattern of performance are also available. That is to say, the results do not exclude the possibility that PD patients have problems with complex parsing, noncanonical linking, or syntactic STM, since all of these factors are just as important as attentional control for the processing of noncanonical raising-to-subject constructions.

All of the patients who performed poorly on the noncanonical SS sentences also performed poorly on the noncanonical OS sentences, but there were three patients who only exhibited poor performance on the noncanonical OS sentences (JR, TH, and SZ). This behavior was unexpected, since the noncanonical SS and OS sentences require similar kinds of parsing and linking operations as well as the same processing resources. There are, however, two closely related factors that distinguish these two construction types and that may have given rise to the differential performance. First, while the embedded predicate in the noncanonical SS construction is intransitive, the embedded predicate in the noncanonical OS construction is transitive; thus, while the patients only have to deal with one argument in the former construction, they have to deal with two arguments in the latter. Second, this difference is reflected in the complexity of the probe questions that accompanied the target sentences. The probes for the noncanonical SS sentences were quite simple—e.g., *Who is nice?*—whereas the probes for the noncanonical OS sentences were more challenging insofar as they focused on two arguments—e.g., *Who catches who?* or *Who's trying to find who?* It is conceivable that for the three patients whose difficulties were restricted to the noncanonical OS sentences, determining the correct interpretation for the single-argument noncanonical SS sentences was within their attentional capacity, but determining the correct interpretation for the two-argument noncanonical OS sentences was beyond their attentional capacity. If this is the correct explanation, the result supports the hypothesis that PD patients have an impairment of attentional control and presents a problem for the three alternative hypotheses—that such patients have an impairment of complex parsing, noncanonical linking, or syntactic STM.

It is worth commenting on the absolute levels of the scores for the PD patients who were impaired on this test. In the previous studies that I reviewed in Chapter 4, especially those conducted by Grossman et al., the patients who exhibited deficits were reported as generally performing around 75-80% correct on the most challenging sentence types—scores which are well below normal but still above chance (see, e.g., Figure 24, p., 183, which shows the results for sentences containing center-embedded relative clauses). In contrast, the patients who exhibited deficits here had means of 56.7% and 46.2% on the noncanonical SS and OS sentences, respectively. This apparent difference between the performance of Grossman et al.'s patients and the performance of the patients here may be illusory, however, because, as I pointed out in Chapter 4, Grossman et al. failed to separate out the dimensions of voice correspondence and semantic constraint. If they had done so, they might have found that a subgroup of their patients performed at chance on sentences with semantically nonconstrained, center-embedded object-gap relative clauses and probe questions in the active voice. In fact, later in this chapter I will present data showing chance performance on exactly this type of material.

5.2 Study 2: Relative Clause Constructions

5.2.1 Goals

As I pointed out in Chapter 4, a problem with Grossman et al.'s (1992b) investigation of PD patients' comprehension of sentences with center-embedded relative clauses is that they did not report how the patients performed on just those items that had semantically nonconstrained object-gap relatives with probe questions in the active voice. For reasons elaborated in Chapter 3 and in the introduction to this chapter, if PD patients have an impairment of attentional control for sentence processing, they should perform poorly on sentences like these but, in contrast, should perform well on sentences with semantically nonconstrained subject-gap relatives with probe questions in the active voice. Examples of these two types of sentences, which I will henceforth refer to as simply subject-object (SO) and subject-subject (SS) relatives (reverting back to the terminology used in Chapter 3), are shown below for ease of reference:

a. subject-object (SO) relative: *The man that Sally saw knows me.*
b. subject-subject (SS) relative: *The man that saw Sally knows me.*

On the other hand, it is crucial to note that a dissociation between poor performance on SO relatives and good performance on SS relatives could arise not only from an impairment of attentional control, but also from an impairment of complex parsing, noncanonical linking, or syntactic STM (note that in Table 19, p. 239, SS relatives are marked "x" for syntactic STM only because this resource is needed to process the main clause).

The study that I will describe in this section was designed with two main goals in mind: first, to test the predictions about PD patients' comprehension of center-embedded relative clauses; and second, to evaluate PD patients' comprehension of two other constructions which differ only with respect to whether they require syntactic STM. The latter constructions are exemplified below:

a. overt pronoun: *The boy helped the girl and then he watched TV.*
b. zero anaphora: *The boy helped the girl and then ____ watched TV.*

In (a) the second clause contains an overt pronoun in pivot position, and the gender feature of this pronoun indicates that the most appropriate interpretation of actor of that clause is the boy who was mentioned in the first clause. On the other hand, in (b) the second clause does not contain an overt pivot NP, so the correct interpretation of actor of that clause must be determined by recovering the syntactic structure of the first clause and selecting the appropriate lexical NP, which in English is always the preverbal pivot NP.[30] This phenomenon is independent of the semantic properties of the pivot NP, as shown by the fact that if the first clause is in the passive voice so that the pivot NP is an undergoer instead of an actor, it is still the pivot NP that "controls" the gap in the second clause—e.g., *The burglar was spotted by the man and then ran away.* Because the interpretation of actor of the second clause depends on the syntactic structure of the first clause, the listener must retain that syntactic structure in STM in order to correctly process the sentence. Thus, sentences of this type are useful for evaluating the syntactic STM capacity of both normal and brain-damaged individuals. It is also important to note that even though zero anaphora sentences do not contain any explicit cues indicating which NP controls the gap in the second clause, they should not require attentional control to regulate linking, since the correct strategy of selecting the pivot of the first clause as controller is actually the default strategy; in other words, it is not neces-

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[30] In other languages the rule works differently. For instance, in Dyirbal (Australia) it would be the girl in (b) who is interpreted as watching TV, and in Chukchi (Siberia) it would be whichever participant in the first clause is most topical (Comrie 1989).

sary to suppress a high-frequency but incorrect linking strategy and promote a low-frequency but correct one. This is especially true when the first clause is in the active voice, because then the pivot of the first clause plays the same semantic role in both clauses—namely, actor.

5.2.2 Subjects

The subjects for the study consisted of nine mild to moderate PD patients, all of whom were right-handed males taking some form parkinsonian medication. Further demographic characteristics of the patients are provided in Table 22. The first seven patients listed in the table also participated in Study 1 on raising-to-subject constructions. Control subjects were not tested; however, other researchers have shown that healthy elderly adults do not have significant trouble understanding the kinds of relative clause constructions that I focused on (e.g., Caplan & Hildebrandt 1988; Grodzinsky et al. 1989).

	Age	Onset	Dur.	MCRS	H&Y	CDR	MMSE	HRSD	Edu.
JR	72	66	10	9	2	.5	26	9	16
AK	65	56	9	15	3	.5	26	3	12
JS	57	53	4	10	2	0	30	14	14
CV	62	56	6	4	2	0	27	4	12
CM	61	54	7	15	3	.5	24	2	12
RD	64	63	1	12	3	0	30	2	12
DB	75	71	4	12	2	0	26	5	14
PH	74	65	9	14	3	0	27	4	12
TS	59	50	9	12	3	0	28	3	12

Table 22: Demographic Data about PD Patients for Study 2. (See Table 21 for abbreviations.)

5.2.3 Materials and Procedure

The stimuli consisted of 40 sentences and associated probe questions. These 40 items were divided into two sets of 20. One set included 10 SS relatives and 10 SO relatives; these items are listed below (* = the participant roles for the embedded predicate are the same as in the corresponding SS relative):

A. SS Relatives

1. *The boy that talked to the girl was cheerful.* *Who talked to who?*
2. *The boy that helped the girl was young.* *Who helped who?*
3. *The boy that hit the girl was thin.* *Who hit who?*
4. *The boy that criticized the girl was short.* *Who criticized who?*
5. *The boy that comforted the girl was tall.* *Who comforted who?*
6. *The girl that pushed the boy was fat.* *Who pushed who?*
7. *The girl that poked the boy was big.* *Who poked who?*
8. *The girl that insulted the boy was old.* *Who insulted who?*
9. *The girl that kissed the boy was happy.* *Who kissed who?*
10. *The girl that hugged the boy was nice.* *Who hugged who?*

B. SO Relatives

1. *The boy that the girl talked to was cheerful.* *Who talked to who?*
2. *The girl that the boy helped was young.** *Who helped who?*
3. *The boy that the girl hit was thin.* *Who hit who?*
4. *The girl that the boy criticized was short.** *Who criticized who?*
5. *The boy that the girl comforted was tall.* *Who comforted who?*
6. *The boy that the girl pushed was fat.** *Who pushed who?*
7. *The girl that the boy poked was big.* *Who poked who?*
8. *The boy that the girl insulted was old.** *Who insulted who?*
9. *The girl that the boy kissed was happy.* *Who kissed who?*
10. *The boy that the girl hugged was nice.** *Who hugged who?*

As can be seen, all of the NPs are *the boy* and *the girl,* and the same set of embedded and matrix predicates occur in both the SS and OS relatives. In half of each set of relative clauses, the boy is the actor and the girl is the undergoer, and in the other half the roles are reversed. In addition, in half of the SO relatives, the boy and the girl play the same roles as in the corresponding SS relatives; these items are marked by asterisks.

The second set of 20 sentences consisted of 10 overt pronoun sentences and 10 zero anaphora sentences, as shown below (* = the roles of the NPs for the first clause are the same as in the corresponding overt pronoun sentence):

A. Overt Pronoun

1. *The boy talked to the girl and then he went into the kitchen. Who went into the kitchen?*
2. *The girl helped the boy and then he watched TV. Who watched TV?*
3. *The boy hit the girl and then he ran down the hall. Who ran down the hall?*
4. *The girl criticized the boy and then he went for a walk. Who went for a walk?*
5. *The boy comforted the girl and then he took a shower. Who took a shower?*
6. *The boy pushed the girl and then she left the room. Who left the room?*
7. *The girl poked the boy and then she went into the bedroom. Who went into the bedroom?*
8. *The boy insulted the girl and then she visited a friend. Who visited a friend?*
9. *The girl kissed the boy and then she went to work. Who went to work?*
10. *The boy hugged the girl and then she fed the dog. Who fed the dog?*

B. Zero Anaphora

1. *The girl talked to the boy and then went into the kitchen. Who went into the kitchen?*
2. *The boy helped the girl and then watched TV. Who watched TV?*
3. *The girl hit the boy and then ran down the hall. Who ran down the hall?*
4. *The boy criticized the girl and then went for a walk. Who went for a walk?*
5. *The girl comforted the boy and then took a shower. Who took a shower?*
6. *The boy pushed the girl and then left the room.* Who left the room?*
7. *The girl poked the boy and then went into the bedroom.* Who went into the bedroom?*
8. *The boy insulted the girl and then visited a friend.* Who visited a friend?*
9. *The girl kissed the boy and then went to work.* Who went to work?*
10. *The boy hugged the girl and then fed the dog.* Who fed the dog?*

Once again, all of the participants are *the boy* and *the girl,* and the same set of matrix predicates occurs in both the overt pronoun and zero anaphora sets of sentences; indeed, these are the same predicates that appear in the relative clauses in the other sentences in the test. In the overt pronoun and zero anaphora sentences, half of the first clauses have the boy as actor and the girl as undergoer, and the other half have the roles reversed. In the zero anaphora sentences that are marked with asterisks, the roles of the NPs in the first clause are the same as in the corresponding overt pronoun sentences. In five of the overt pronoun sentences, the pronoun is coreferential with the pivot of the first clause (1, 3, 5, 7, 9), and in the other five it is coreferential with the direct argument (2, 4, 6, 8, 10). Furthermore, in the first set of five sentences, three of the pronouns have male gender (1, 3, 5) and two have female gender (7, 9), and in the second set two of the pronouns have male gender (2, 4) and three have female gender (6, 8, 10). This design was intended to prevent the PD patients from adopting a strategy of always choosing the first NP of the sentence as the actor of the second clause, since such a strategy would enable them to perform well on the zero anaphora sentences even if their syntactic STM was disrupted. In five of the zero anaphora sentences, the actor of the second clause is male (2, 4, 6, 8, 10), and for two of these five sentences, the corresponding overt pro-noun sentences also have male actors in the second clause (2, 4). In the other five zero anaphora sentences, the actor of the second clause is female (1, 3, 5, 7, 9), and for two of these sentences, the corresponding overt pronoun sentences also have female actors in the second clause (7, 9).

The procedure for the experiment was the same as for Study 1.

5.2.4 Results

The results are shown in Table 23, with significant dissociations between constructions highlighted (these dissociations will be discussed later). Looking first at the data for the relative clause constructions, a one-way ANOVA was conducted to determine whether the difference between the means for the SS and SO relatives was greater than the variance within each condition. This analysis revealed a significant difference ($F(1, 16) = 20.9$, $p < .01$), indicating that PD patients have intact comprehension of semantically nonconstrained SS relatives but impaired comprehension of semantically nonconstrained SO relatives, when comprehension is assessed with probe questions in

	Relative Clauses		Syntactic STM	
	SS	SO	Pronoun	Zero
JR	100	70	100	100
AK	90	40	100	60
JS	100	30	100	100
AV	80	20	100	80
CM	100	60	100	90
RD	100	100	100	100
DB	90	70	100	70
PH	100	70	80	100
TS	100	50	100	100
Mean	*95.6*	*56.7*	*97.8*	*88.9*

Table 23: Data for Study 2 on SS and SO relative clauses and syntactic STM

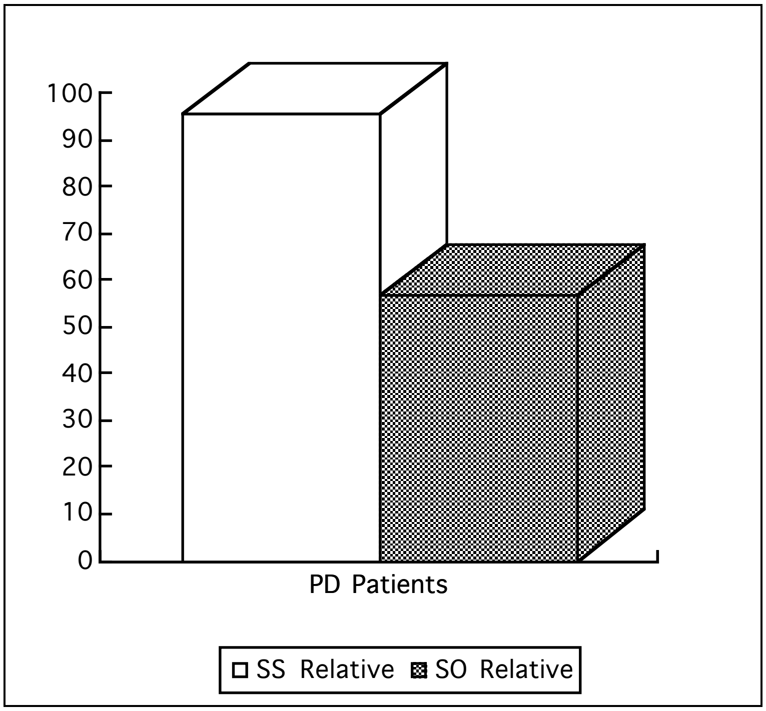

Figure 38: Comprehension of SS and SO relative clauses by PD patients

the active voice (SS: mean correct = 95.6%, *SD* = 6.85; SO: mean correct = 56.7%, *SD* = 23.09). The results are illustrated in Figure 38.

Shifting to the data for the overt pronoun and zero anaphora constructions, another one-way ANOVA was conducted, and this revealed no significant difference between the two construction types ($F(1,16) = 2.53$, $p > .05$), indicating that PD patients perform equally well on constructions that do and do not require syntactic STM (overt pronoun: mean correct = 97.8%, *SD* = 6.28; zero anaphora: mean correct = 88.9%, *SD* = 14.49). These results are shown in Figure 39.

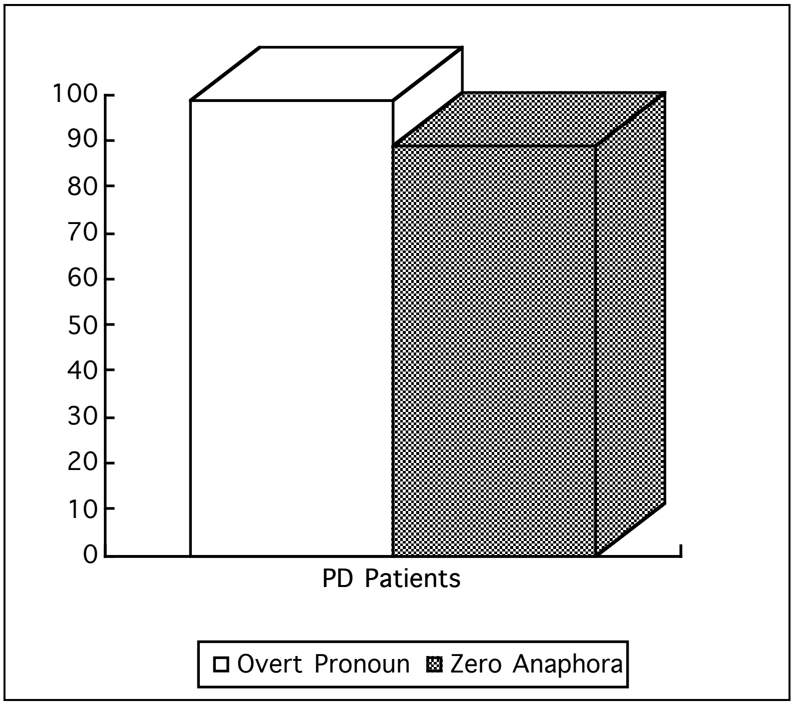

Figure 39: Comprehension of overt pronoun and zero anaphora sentences by PD patients

Perhaps the most interesting finding of this study is that a large proportion of the patients (7 of 9; 78.8%) showed a dissociation between good comprehension of SS relatives and poor comprehension of SO relatives, whereas only a small proportion of the patients (2 of 9; 22.2%) showed a dissociation between good comprehension of overt pronoun sentences and poor comprehension of zero anaphora sentences. These dissociations are highlighted in Table 23. All of them were found to be statistically significant by means of a chi-square analysis that compared observed scores with the score that would result from chance (i.e., 50%). This analysis showed that a score of 80% or higher (i.e., performing correctly on 8 or more of 10 items) is above chance ($\chi^2 = 3.6$, one-tailed $p < .05$), and that a score of 70% or less (i.e., performing correctly on 7 or fewer of 10 items) is not significantly different from chance ($\chi^2 = 1.6$, one-tailed $p >$

.05); the score of 30% marks the ceiling of the below chance region. With regard to patient DB, who scored 90% on the SS relatives and 70% on the SO relatives, it is worth noting that even though the first score is above chance and the second score is within the chance range, the dif-ference between the two scores is not significant; hence a dissociation does not exist.

5.2.5 Discussion

Overall, the patients performed very much as expected, exhibiting a significant dissociation between good comprehension of SS relatives and poor comprehension of SO relatives, but not exhibiting such a dissociation for overt pronoun sentences and zero anaphora sentences. The results for the relative clauses are consistent with the hypothesis that PD patients have an impaired ability to use attentional control to select and maintain the correct template and linking strategy when confronted with complex noncanonical constructions that contain few explicit cues. As I mentioned earlier, however, these results are also consistent with the idea that the patients have an impairment of complex parsing, noncanonical linking, or syntactic STM (note that in Table 19, p. 239, SS relatives are marked "x" for syntactic STM only because this resource is needed to process the main clause). Although the results for the overt pronoun and zero anaphora sentences do not rule out the possibility that the patients' poor performance on the SO relatives is due an impairment of complex parsing or noncanonical linking, they do rule out the possibility that this performance is due to an impairment of syntactic STM. The reason is that zero anaphora sentences require syntactic STM, but, overall, the patients performed well on them. Only two of the seven patients who performed poorly on the SO relatives also performed poorly on the zero anaphora sentences (SK and DB). Hence, while it is possible that the poor performance of these two patients on the SO relatives is due in part to an impairment of syntactic STM, such a possibility is not available for the remaining five patients.

It is striking that such a large proportion of the patients who participated in this study displayed dissociations between the SS and SO relatives. Grossman and his colleagues have found that roughly half of PD patients tend to manifest syntactic comprehension deficits, and this finding was supported by my study of how such patients perform with raising-to-subject constructions. In the study currently under discussion, however, seven of the nine patients (78.8%) performed significantly worse on the SO relatives than on the SS relatives, and eight of the nine patients performed at chance on the SO relatives (the only patient who didn't show a significant dissociation but still performed at chance on the SO relatives was DB). It is possible that this unusually high proportion of impaired patients emerged because of the small sample size; if 20 or 30 patients were tested on the same materials, perhaps the distribution of normal-like and non-normal patients would- balance out more evenly.

Finally, it is worthwhile to look more closely at the performance of the seven patients who also participated in Study 1. The results for these patients on all of the different constructions are shown in Table 24, with significant dissociations highlighted.

	Relatives		Syntactic STM		SS raising		OS raising	
	SS	SO	no	yes	C	NC	C	NC
JR	100	70	100	100	100	92	100	66
AK	90	40	100	60	100	50	100	50
JS	100	30	100	100	100	58	100	58
CV	80	20	100	80	100	58	75	42
CM	100	60	100	90	83	75	100	83
RD	100	100	100	100	100	100	100	100
DB	90	70	100	70	100	66	92	58
Mean	*94.3*	*55.7*	*100*	*85.7*	*97.6*	*71.3*	*95.3*	*65.3*

Table 24: Combined data for the seven PD patients who participated in both studies 1 and 2. (Abbreviations: STM yes = overt pronoun construction, STM no = zero anaphora construction, C = canonical, NC = noncanonical.)

As can be seen, the means for these seven patients reveal significant dissociations between the following pairs of constructions: first, SS and SO relatives; second, canonical and noncanonical SS raising; and third, canonical and noncanonical OS raising. By contrast, no significant dissociation exists between the two constructions which differ only with respect to whether they require syntactic STM—namely, the overt pronoun construction and the zero anaphora construction. In addition, the individual patient profiles are, for the most part, in accord with the predictions outlined in the introduction to this chapter.

JR, the first patient in Table 24, is the only one who presents a bit of a puzzle. He exhibited significant dissociations between SS and SO relatives and between canonical and noncanonical OS raising sentences, which is what I expected; moreover, he did not exhibit a dissociation between overt pronoun sentences and zero anaphora sentences, which is also what I expected. Taken together, these findings are consistent with the hypothesis that he has an impairment of attentional control but not an impairment of syntactic STM; the findings leave open the possibility that he has an impairment of complex parsing and/or noncanonical linking. The puzzle is that this patient did not show a dissociation between canonical and noncanonical SS raising sentences. This appears to conflict with the idea that he has an impairment of attentional control, although, as I mentioned in the discussion of Study 1, it is possible that he performed better on the noncanonical SS raising sentences than on the noncanonical OS raising sentences because the probe questions for the former sentences were somewhat simpler than those for the latter sentences. JR's performance on the SS raising sentences still leaves open the possibility that he has an impairment of noncanonical linking, because such an impairment might cause him to have greater difficulty with transitive verbs, as in the SO relatives and noncanonical OS raising sentences, than with intransitive verbs, as in the noncanonical SS raising sentences. However, his performance on the SS raising sentences seems inconsistent with the possibility that he has an impairment of complex parsing, since such an impairment would presumably affect the processing of noncanonical SS raising sentences just as much as noncanonical OS raising sentences and SO relatives.

The next patient, SK, showed dissociations across all four pairs of constructions. The fact that he performed poorly on the zero anaphora sentences suggests that he has an impairment of syntactic STM. While an impairment like this could also explain his difficulties with SO relatives and noncanonical SS and OS raising sentences, three additional hypotheses are available as well: first, that he has an impairment of attentional control; and second, that he has an impairment of complex parsing; and third, that he has an impairment of noncanonical linking.

The third patient, JS, satisfied the predictions perfectly. He exhibited dissociations between SS and SO relatives, between canonical and noncanonical SS raising sentences, and between canonical and noncanonical OS raising sentences, but he did not exhibit a dissociation between overt pronoun sentences and zero anaphora sentences. This performance profile is consistent with the view that he has an impairment of attentional control, but it is inconsistent with the view that he has an impairment of syntactic STM. The results leave open the possibility that he has an impairment of complex parsing and/or noncanonical linking.

AV's performance profile is effectively the same as JS's. The only differences worth noting are as follows: first, he had some trouble with two of the "easy" constructions—SS relatives and canonical OS raising sentences; and second, he also had some trouble with the zero anaphora sentences.

The next patient, CM, displayed the general trends of all of the predictions, but, from a statistical point of view, only satisfied two of them, these being a dissociation between SS and SO relatives, and equally good performance on overt pronoun sentences and zero anaphora sentences. Regarding the raising sentences, he performed better on the canonical versions than on the noncanonical versions, but not significantly so.

The sixth patient, RD, performed perfectly on the entire set of constructions, and so there is nothing about his profile that deserves special comment.

The performance profile of the last patient, DB, is similar in many respects to that of SK. Both patients exhibited dissociations between overt pronoun sentences and zero anaphora sentences, between canonical and noncanonical SS raising sentences, and between canonical and noncanonical OS raising sentences. In addition, both patients had greater difficulty comprehending SO relatives than SS relatives. The only difference is that SK exhibited a significant dissociation between the two relative clause constructions, whereas DB did not. Both patients appear to have problems with syntactic STM and perhaps also with attentional control, complex parsing, or noncanonical linking, except these problems may be more severe for SK than for DB, given that SK performed worse than DB on all of the various "challenging" constructions.

In sum, the results for the seven patients who participated in both Study 1 and Study 2 are compatible with the hypothesis that syntactic comprehension deficits in PD are due primarily to an impairment of attentional control. These results also suggest that syntactic STM is affected for two of the seven patients (SK and DB). Finally, the results leave open the possibility that difficulties with complex parsing or noncanonical linking contribute to the syntactic comprehension deficits in PD.

5.3 Study 3: Relative Clause, Cleft, and Undergoer-Control Constructions

5.3.1 Goals

The purpose of the third study was to address the predictions about three other sets of constructions mentioned in Table 19 (p. 248). The first set consisted of four types of relative clauses, including the two explored in Study 2: subject-subject (SS), subject-object (SO), object-subject (OS), and object-object (OO). These constructions are exemplified below:

a. subject-subject (SS): *The man that saw Sally knows me.*
b. subject-object (SO): *The man that Sally saw knows me.*
c. object-subject (OS): *I know the man that saw Sally.*
d. object-object (OO): *I know the man that Sally saw.*

The predictions are as follows. If PD patients have an impairment of attentional control, they should have difficulty understanding the two object-gap constructions (SO and OO), but should not have difficulty understanding the two subject-gap constructions (SS and OS). However, such a pattern of performance would also be consistent with three other hypotheses: first, that the patients have an impairment of complex parsing (recall that if this were the case, the patients could still perform well on subject-gap relatives by using heuristics); second, that they have an impairment of noncanonical linking; and third, that they have an impairment of syntactic STM (note that in Table 19, p. 239, SS relatives are marked "x" for syntactic STM only because this resource is needed to process the main clause).

The second set of constructions consisted of two types of clefts: subject-clefts (SC) (e.g., *It was the man that saw Sally*), and object-clefts (OC) (e.g., *It was the man that Sally saw*). The predictions for these constructions are exactly the same as for the relative clause constructions.

The third set of constructions consisted of two types of undergoer-control sentences: undergoer-control with an active matrix core (UCa) and undergoer-control with a passive matrix core (UCp). Examples of these constructions are shown below:

h. passive undergoer-control (UCp): *Sally was persuaded by Harry to be nice*. g.
active undergoer-control (UCa): *Harry persuaded Sally to be nice*.

The motivation for including this pair of contructions in the study was that, as I argued in Chapter 3 (see §3.2.2.2, esp. pp. 105-6), even though the latter construction is more complex than the former by virtue of having a passive matrix core, it should not require attentional resources because, first, the semantic properties of the verb which indicate that the "controller" NP is the undergoer are presumably strongly activated during on-line processing, and second, the status of the pivot NP as undergoer, and hence controller, is signalled by multiple explicit cues. Thus, the hypothesis that PD patients have an impairment of attentional control predicts that they should not have significant difficulty understanding either of the two undergoer-control constructions. On the other hand, it is important to note that a dissociation between poor performance on UCp sentences and good performance on UCa sentences should arise if PD patients have any of three other kinds of impairment: first, an impairment of complex parsing, because although both constructions involve complex constituent structure, the default interpretation of control sentences is to treat the postverbal NP as "controller,"[31] and so a heuristic like this would enable correct interpretation of UCa sentences but not of UCp sentences; second, an impairment of noncanonical linking, since the UCp construction but not the UCa construction requires this; and third, an impairment of syntactic STM, since the UCp

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[31] This is because undergoer-control sentences are used with higher frequency than actor-control sentences.

construction requires that the pivot NP be held in memory until the embedded verb is encountered.

In addition to the three sets of constructions described above, this study also included an independent test of syntactic STM. This test is identical to the one that Grossman et al. (1992b) used in their third experiment. Specifically, it involves target sentences with relative clauses and probe questions that focus on either adjacent or nonadjacent segments of the target. Some examples are provided below:

i. syntactic STM not required: *The boy chased the girl that is tall. Who is tall?*
j. syntactic STM required: *The boy that chased the girl is tall. Who is tall?*

In (i) the probe question addresses information contained in the same portion of the target sentence, and so syntactic STM is not required. By contrast, in (j) the probe question addresses information contained in different portions of the target sentence, and so syntactic STM is required in order to "bridge the distance" necessary to integrate all of the information. The "distance" that syntactic STM must cover in (j) is about the same as what it must cover in the other constructions that require this processing resource—namely, SO relatives, OO relatives, object-clefts, and passive undergoer-control sentences. For this reason, sentences like (j) are useful for determining whether PD patients have the syntactic STM capacity that is needed in order to successfully process the other constructions. In particular, if PD patients exhibit poor performance on these constructions but good performance on sentences like (j), their deficits cannot be attributed to an impairment of syntactic STM.

5.3.1 Subjects

The subjects for the study included 15 mild PD patients, all of whom were right-handed males taking some form of parkinsonian medication. In addition, five control subjects matched for age, sex, and education participated in the study. Further demographic features of the PD patients are provided in Table 25. It is noteworthy that the patients who participated in this study are all Hoehn and Yahr Stage 2 or 2.5, whereas a large number of the patients who participated in Study 1 and Study 2 were Stage 3 (9 of 15 patients in Study 1, and 5 of 9 patients in Study 2).

5.3.2 Materials and Procedure

The materials consisted of 10 instances of each of the 10 types of constructions described earlier, for a total of 100 items. Each item was paired with a probe question which, for all of the constructions except the two that were used to assess syntactic STM, focused on who was doing the action described in the target sentence. All of these probe questions were of the same form—namely, *Who did the V-ing?* Hence, any variation in the results cannot be attributed to variation in the form of the probe questions. For the constructions that were used to assess syntactic STM, the probe questions focused on the semantic argument of the adjective at the end of the target sentence, as illustrated in (i) and (j) above. All of the stimuli are listed below (* = the semantic roles of *the boy* and *the girl* vis-á-vis the embedded verb are the same as in the preceding set of items).

	Age	Onset	Duration	H&Y Stage	MMSE	HRSD	Education
HG	65	61	4	2	29	5	18
DJ	72	66	6	2.5	30	1	16
AW	73	66	7	2	30	3	13
JE$^{\#}$	70	64	6	-	-	-	8
JD	71	68	3	2	30	4	18
AK	68	60	8	2	29	9	12
AD	72	58	14	2.5	27	2	12

CV	65	55	10	2	30	4	12
RK	45	36	9	2	29	3	14
WP	74	72	2	2	30	1	14
JN	68	52	16	2.5	27	2	16
JS	61	55	6	2.5	29	3	14
WS	72	60	12	2	30	1	21
RZ	72	70	2	2	28	9	14
RD	66	60	6	2	29	0	12

Table 25: Demographic data about PD patients for Study 3. Abbreviations: MMSE = Mini-Mental State Examination (scale: 0-30 with higher being less severe); HRSD = Hamilton Rating Scale for Depression (scale: 0-62 with lower being less severe). # = this patient was not able to be screened for H&Y stage, MMSE, and HRSD before this thesis was completed.

A. SS Relatives

1. *The girl that pushed the boy knows me. Who did the pushing?*
2. *The girl that kissed the boy knows me. Who did the kissing?*
3. *The girl that hit the boy knows me. Who did the hitting?*
4. *The girl that caught the boy knows me. Who did the catching?*
5. *The girl that kicked the boy knows me. Who did the kicking?*
6. *The boy that chased the girl knows me. Who did the chasing?*
7. *The boy that comforted the girl knows me. Who did the comforting?*
8. *The boy that helped the girl knows me. Who did the helping?*
9. *The boy that followed the girl knows me. Who did the following?*
10. *The boy that talked to the girl knows me. Who did the talking?*

B. SO Relatives

1. *The boy that the girl pushed knows me. Who did the pushing?*
2. *The girl that the boy kissed knows me.* Who did the kissing?*
3. *The boy that the girl hit knows me. Who did the hitting?*
4. *The girl that the boy caught knows me.* Who did the catching?*
5. *The boy that the girl kicked knows me. Who did the kicking?*
6. *The girl that the boy chased knows me. Who did the chasing?*
7. *The boy that the girl comforted knows me.* Who did the comforting?*
8. *The girl that the boy helped knows me. Who did the helping?*

9. *The boy that the girl followed knows me.** *Who did the following?*
10. *The girl that the boy talked to knows me.* *Who did the talking?*

C. OS Relatives

1. *I know the girl that pushed the boy.* *Who did the pushing?*
2. *I know the girl that kissed the boy.* *Who did the kissing?*
3. *I know the girl that hit the boy.* *Who did the hitting?*
4. *I know the girl that caught the boy.* *Who did the catching?*
5. *I know the girl that kicked the boy.* *Who did the kicking?*
6. *I know the boy that chased the girl.* *Who did the chasing?*
7. *I know the boy that comforted the girl.* *Who did the comforting?*
8. *I know the boy that helped the girl.* *Who did the helping?*
9. *I know the boy that followed the girl.* *Who did the following?*
10. *I know the boy that talked to the girl.* *Who did the talking?*

D. OO Relatives

1. *I know the girl that the boy pushed.* *Who did the pushing?*
2. *I know the boy that the girl kissed.** *Who did the kissing?*
3. *I know the girl that the boy hit.* *Who did the hitting?*
4. *I know the boy that the girl caught.** *Who did the catching?*
5. *I know the girl that the boy kicked.* *Who did the kicking?*
6. *I know the boy that the girl chased.* *Who did the chasing?*
7. *I know the girl that the boy comforted.** *Who did the comforting?*
8. *I know the boy that the girl helped.* *Who did the helping?*
9. *I know the girl that the boy followed.** *Who did the following?*
10. *I know the boy that the girl talked to.* *Who did the talking?*

As can be seen, the lexical NPs in these sentences are always *the boy* and *the girl,* the matrix verb is always *know,* and the matrix clause NP which is not the head of the relative clause is always the first person pronoun—*me* in the SS and SO sentences, and *I* in the OS and OO sentences. The *knows me/I know* constituents were deliberately kept "light" in semantic weight so as not to distract the PD patients from the the relative clause. The reason for this was that I wanted to find out how PD patients would perform on relative clauses under the simplest possible conditions. In addition, the same embedded verbs recur throughout the four sets of target sentences, and the arrangement of NPs around these verbs is designed so that, for each verb, *the boy* is the actor in two of the sentences and *the girl* is the actor in the other two sentences. Finally, in four of the SO sentences, the actor is the same as in the corresponding SS sentences, and in four of the OO sentences, the actor is the same as in the corresponding OS sentences (these items are marked with asterisks).

E. Subject Clefts

1. *It was the boy that pushed the girl.* *Who did the pushing?*
2. *It was the boy that kissed the girl.* *Who did the kissing?*
3. *It was the boy that hit the girl.* *Who did the hittnig?*
4. *It was the boy that caught the girl.* *Who did the catching?*
5. *It was the boy that kicked the girl.* *Who did the kicking?*
6. *It was the girl that chased the boy.* *Who did the chasing?*
7. *It was the girl that comforted the boy.* *Who did the comforting?*
8. *It was the girl that helped the boy.* *Who did the helping?*
9. *It was the girl that followed the boy.* *Who did the following?*
10. *It was the girl that talked to the boy.* *Who did the talking?*

F. Object Clefts

1. *It was the boy that the girl pushed.* *Who did the pushing?*
2. *It was the girl that the boy kissed.** *Who did the kissing?*
3. *It was the boy that the girl hit.* *Who did the hitting?*
4. *It was the girl that the boy caught.** *Who did the catching?*
5. *It was the boy that the girl kicked.* *Who did the kicking?*
6. *It was the girl that the boy chased.* *Who did the chasing?*

7. *It was the boy that the girl comforted.*   Who did the comforting?*
8. *It was the girl that the boy helped.   Who did the helping?*
9. *It was the boy that the girl followed.*   Who did the following?*
10. *It was the girl that the boy talked to.   Who did the talking?*

The NPs and verbs in these sentences are the same as in the relative clause sentences. In addition, in each set of target sentences, *the boy* is the actor is five of the items and *the girl* is the actor in the other five items. Moreover, in four of the object-cleft target sentences, the actor is the same as in the corresponding subject-cleft item (these sentences are marked with asterisks).

G. Active Undergoer Control

1. *The boy ordered the girl to work.   Who did the working?*
2. *The girl ordered the boy to march.   Who did the marching?*
3. *The boy ordered the girl to sit down.   Who did the sitting?*
4. *The girl told the boy to run.   Who did the running?*
5. *The boy told the girl to eat.   Who did the eating?*
6. *The girl told the boy to speak.   Who did the speaking?*
7. *The boy told the girl to drink.   Who did the drinking?*
8. *The girl asked the boy to stand up.   Who did the standing?*
9. *The boy asked the girl to hurry.   Who did the hurrying?*
10. *The girl asked the boy to sing.   Who did the singing?*

H. Passive Undergoer Control

1. *The boy was ordered by the girl to work.   Who did the working?*
2. *The girl was ordered by the boy to march.   Who did the marching?*
3. *The girl was ordered by the boy to sit down.*   Who did the sitting?*
4. *The girl was told by the boy to run.   Who did the running?*
5. *The girl was told by the boy to eat.*   Who did the eating?*
6. *The boy was told by the girl to speak.*   Who did the speaking?*
7. *The boy was told by the girl to drink.   Who did the drinking?*
8. *The girl was asked by the boy to stand up.   Who did the standing?*
9. *The boy was asked by the girl to hurry.   Who did the hurrying?*
10. *The boy was asked by the girl to sing.*   Who did the singing?*

The NPs in these sentences are *the boy* and *the girl,* the matrix verbs alternate between *order, tell,* and *ask,* and there are ten different embedded verbs, all intransitive, which occur together with the same matrix verb in both constructions. Each set of target sentences is organized so that *the boy* is the actor of the embedded verb in five of the items and the *the girl* is the actor of the embedded verb in the other five items. Also, in four of the passive sentences, the actor of the embedded verb is the same as in the corresponding active sentence (these items are marked with asterisks).

<u>I. STM not required</u>

1. *The girl pushed the boy that is tall.* *Who is tall?*
2. *The girl kissed the boy that is tall.* *Who is tall?*
3. *The girl hit the boy that is tall.* *Who is tall?*
4. *The girl caught the boy that is tall.* *Who is tall?*
5. *The girl kicked the boy that is tall.* *Who is tall?*
6. *The boy chased the girl that is tall.* *Who is tall?*
7. *The boy comforted the girl that is tall.* *Who is tall?*
8. *The boy helped the girl that is tall.* *Who is tall?*
9. *The boy followed the girl that is tall.* *Who is tall?*
10. *The boy talked to the girl that is tall.* *Who is tall?*

<u>J. STM required</u>

1. *The girl that pushed the boy is tall.* *Who is tall?*
2. *The boy that kissed the girl is tall.** *Who is tall?*
3. *The girl that hit the boy is tall.* *Who is tall?*
4. *The boy that caught the girl is tall.** *Who is tall?*
5. *The girl that kicked the boy is tall.* *Who is tall?*
6. *The boy that chased the girl is tall.* *Who is tall?*
7. *The girl that comforted the boy is tall.** *Who is tall?*
8. *The boy that helped the girl is tall.* *Who is tall?*
9. *The girl that followed the boy is tall.** *Who is tall?*
10. *The boy that talked to the girl is tall.* *Who is tall?*

The NPs in these sentences are, once again, *the boy* and *the girl;* the adjective at the end of the sentences is always *tall;* and the other verbs are the same ones that appeared in the relatives, clefts and undergoer-control sentences. In each set of sentences, *the boy* is the actor of the verb in five of the items, and *the girl* is the actor in the other five items. Similarly, in each set of sentences, *the boy* is the argument of *tall* in five of the items, and *the girl* is the argument of *tall* in the other five items. Finally, in four of the "syntactic STM required" sentences, the argument of *be tall* is the same as in the corresponding "syntactic STM not required" sentence.

The procedure for the experiment was the same as in Study 1 and Study 2, with two differences. First, the patients were given three short breaks—one after the first 25 items, another after the second 25 items, and the last after the third 25 items. Second, the patients were told that even if some of the sentences sounded rather unnatural to them, they should ignore this and concentrate on who is performing the action or, alternatively, who is tall.

5.3.3 Results

The entire set of data is presented in Table 26. Differences between PD patients and control subjects were evaluated by carrying out a series of ANOVAs. All of these analyses were adjusted by a least squares means analysis in order to correct for the large discrepancy between the sizes of the two groups. The first ANOVA focused on the center-embedded relative clauses and had a group (PD, control) x construction type (SS, SO) design. A significant interaction was found (*p* = .0148), indicating that PD patients have intact comprehension of SS relatives but impaired comprehension of SO relatives (PDs: mean correct SS = 96%, *SD* = 5.96; mean correct SO = 76%, *SD* = 24.98; controls: mean correct SS = 100%, *SD* = 0.00; mean correct SO = 98%, *SD* = 4.47). These results are shown in Figure 40.

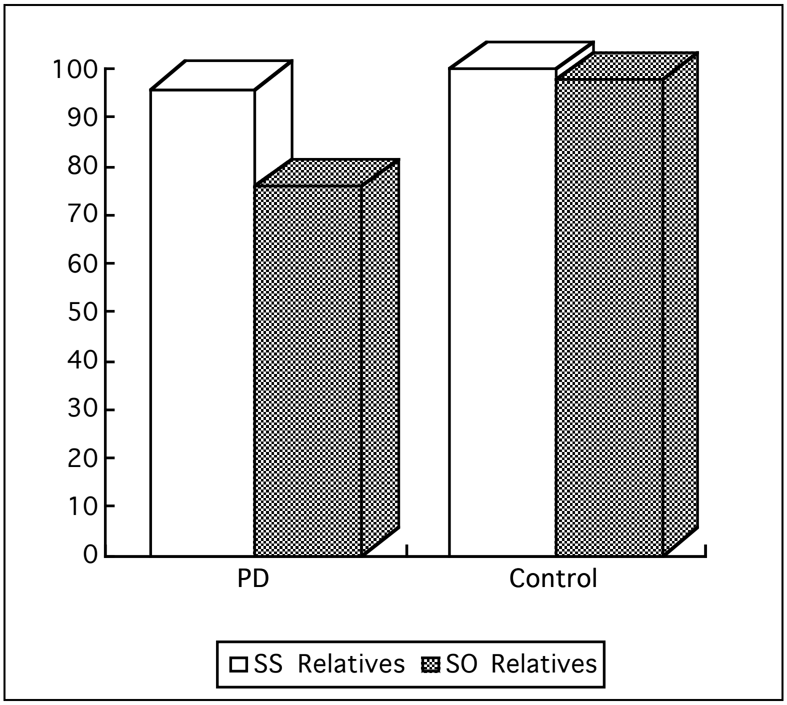

Figure 40: Comprehension of SS and SO relatives

An inspection of the individual patient profiles for the center-embedded relative clauses revealed that the patients divided into two subgroups, one normal-like and the other non-normal. This division of patients into subgroups was based on the same chi-square analyses that were used in Study 2 to show that a score of 80% or more is significantly better than chance, whereas a score of 70% or less is not significantly different from chance (see §5.2.3, p. 277). Nine patients did not exhibit a dissociation between good performance on the SS relatives and poor performance on the SO relatives, and hence these patients fell into the normal-like subgroup (their initials are as follows: HG, DJ, JE, JD, AD, RK, WP, WS, and RD). By contrast, the remaining six patients did exhibit such a dissociation, and hence these patients fell into the non-normal subgroup (they are: AW, AK, CV, JN, JS, and RZ). An ANOVA with a group (normal-like, non-normal) x construction type (SS, SO) revealed a significant interaction (*p* = .0001), confirming that the normal-like patients have intact comprehension of both SS and SO relatives, whereas the non-normal patients have intact comprehension of SS relatives but impaired comprehension of SO relatives (normal-like subgroup: mean correct SS = 98.9%, *SD* = 3.33; mean correct SO = 95.5%, *SD* = 7.26; non-normal subgroup: mean correct SS = 93.3%, *SD* = 8.16; mean correct SO = 46.7%, *SD* = 8.16). These results are shown in Figure 41.

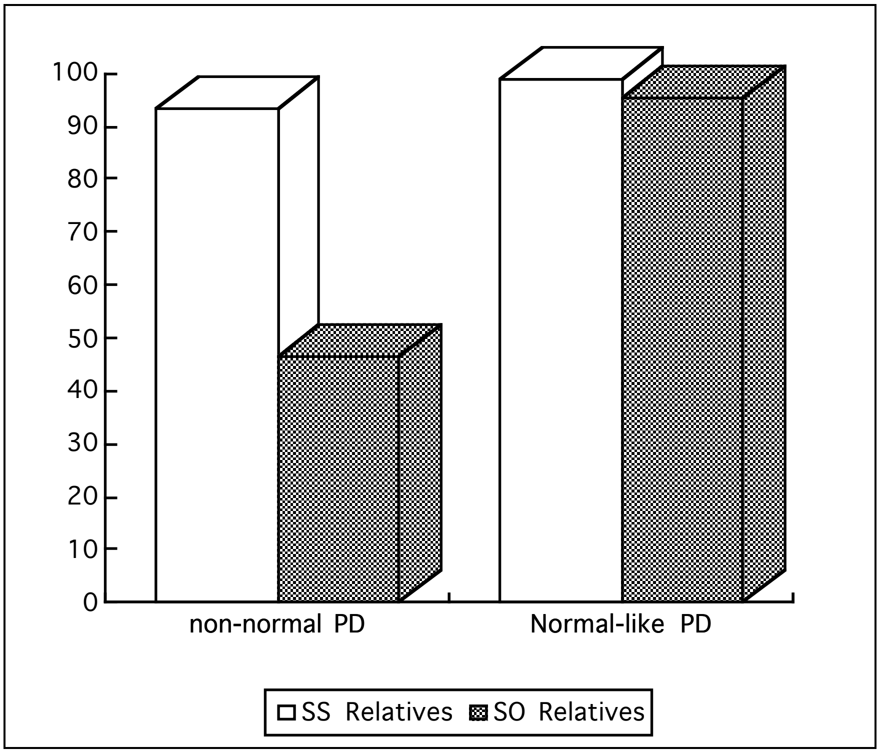

Figure 41: Comprehension of center-embedded relative clauses by non-normal and normal-like PD patients

Moving on to the terminal relative clauses, an ANOVA with a group (PD, control) x construction type (OS, OO) design revealed a barely significant interaction (*p* = .0578), suggesting that PD patients have greater difficulty understanding OO relatives than healthy control subjects (PDs: mean correct OS = 97.3%, *SD* = 7.72; mean correct OO

= 82.7%, *SD* = 22.05; controls: mean correct OS = 100%, *SD* = 0.00; mean correct OO = 98%, *SD* = 4.47). These results are illustrated in Figure 42.

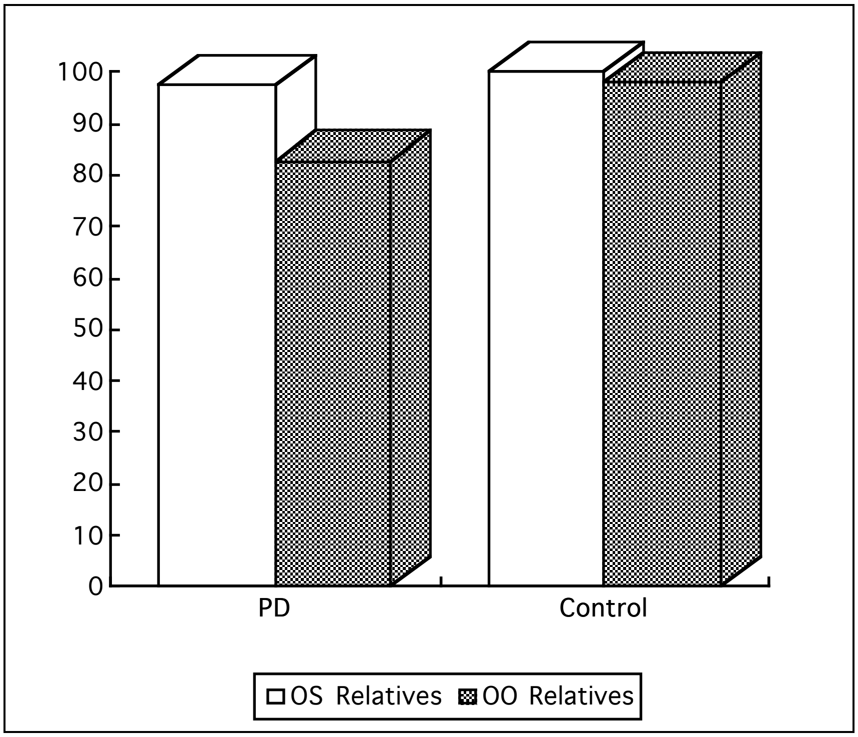

Figure 42: Comprehension of OS and OO relative clauses

As with the center-embedded relatives, an inspection of the individual patient profiles showed that the patients divided into two subgroups, one normal-like and the other non-normal. 11 patients fell into the former subgroup (HG, DJ, AW, JE, JD, AK, AD, RK, WP, WS, and RD), and four patients fell into the latter subgroup (CV, JN, JS, and RZ). All four of the patients in the non-normal subgroup were also in the non-normal subgroup for the center-embedded relatives, but two of the patients who were classified as non-normal for the center-embedded relatives are classified as normal-like here (AW and AK). An ANOVA with a group (normal-like, non-normal) x construction type (OS, OO) design revealed a significant interaction (*p* = .0001), indicating that while the normal-like patients have equally good comprehension of OS and OO relatives, the non-normal patients are differentially impaired on OO relatives (normal-like subgroup: mean correct OS = 99.1%, *SD* = 3.01; mean correct OO = 94.5%, *SD* = 6.88; non-normal subgroup: mean correct OS = 92.5%, *SD* = 15.00; mean correct OO = 50%, *SD* = 18.26). These results are illustrated in Figure 43.

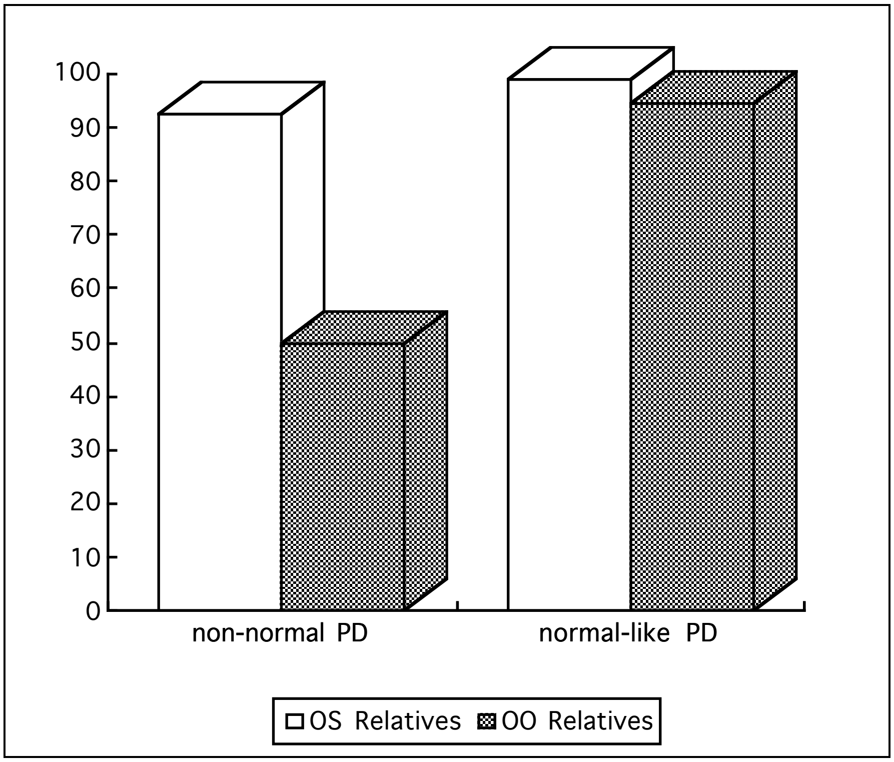

Figure 43: Comprehension of OS and OO relative clauses by non-normal and normal-like PD patients

The next analysis focused on the cleft sentences. Overall differences between PD patients and control subjects were evaluated by carrying out an ANOVA with a group (PD, control) x construction type (SC, OC) design. A barely significant interaction was found (*p* = .0550), suggesting that although PD patients do not have more trouble with subject-clefts than control subjects, they do have a bit more trouble with object-clefts than control subjects (PDs: mean correct SC = 99.3%, *SD* = 2.49; mean correct OC = 84.7%, *SD* = 23.06; controls: mean correct SC = 100%, *SD* = 0.00; mean correct OC = 100%, *SD* = 0.00). These results are shown in Figure 44.

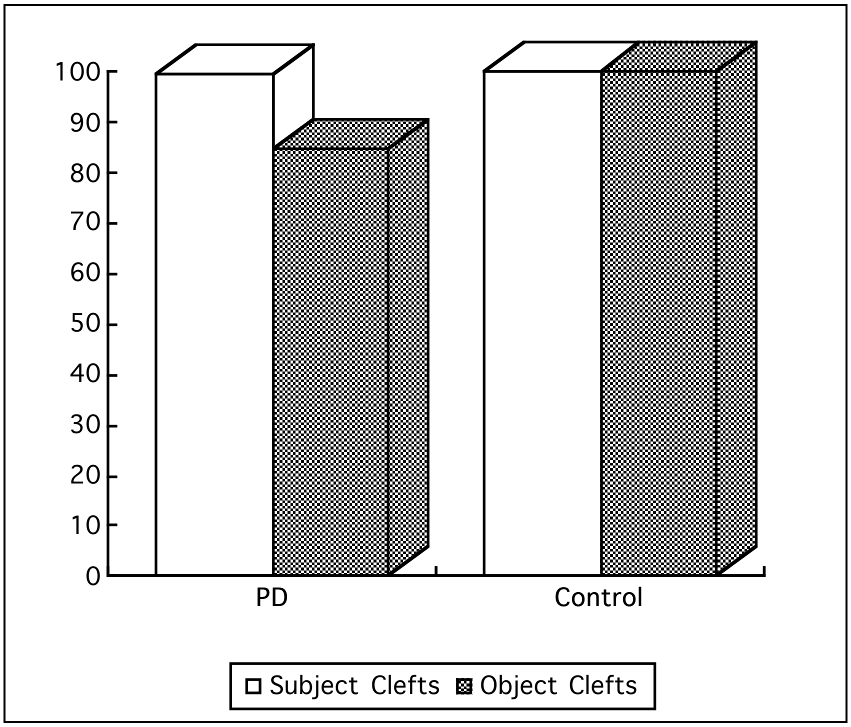

Figure 44: Comprehension of subject clefts and object clefts by PD patients

Again, close inspection of the individual patient profiles revealed that the patients divided into normal-like and non-normal subgroups. This time 10 patients fell into the normal-like subgroup (HG, AW, JE, JD, AD, RK, WP, JN, WS, and RD), and five patients fell into the non-normal subgroup (DJ, AK, CV, JS, and RZ). Three of the non-normal patients (CV, JS, and RZ) were also classified as non-normal on both SO and

OO relative clauses. Another non-normal patient (AK) was also classifed as non-normal on just the SO relatives. The final non-normal patient (DJ) was classifed as normal-like on both SO and OO relatives. With regard to the normal-like patients, all but one of them was also classified as normal-like on both SO and OO; the single exception (JN) was classified as non-normal on both of those constructions. An ANOVA with a group (normal-like, non-normal) x construction type (SC, OC) revealed a significant interaction (p = .0001), indicating that non-normal patients have intact comprehension of subject-clefts but impaired comprehension of object-clefts (normal-like subgroup: mean correct SC = 100%, *SD* = 0.00; mean correct OC = 100%, *SD* = 0.00; non-normal subgroup: mean correct SC = 98%, *SD* = 4.47; mean correct OC = 54%, *SD* = 15.17). These results are illustrated in Figure 45.

I turn now to the data for the active and passive undergoer-control sentences. An ANOVA with a group (PD, control) x construction type (UCa, UCp) design failed to reveal a significant interaction (p = .2428), which indicates that, overall, PD patients do not have greater difficulty understanding passive undergoer-control sentences than control subjects (PDs: mean correct UCa = 92.7%, *SD* = 17.69; mean correct UCp = 86%, *SD* = 17.81; controls: mean correct UCa = 100%, *SD* = 0.00; mean correct UCp = 96%, *SD* = 4.90). These results are shown in Figure 46. Despite the fact that a significant interaction was not found in the analysis of the group means, I should point out that two of the 15 patients did exhibit significant dissociations between good performance on the UCa sentences and poor performance on the UCp sentences (these patients are JE and AK). One of these patients (AK) also exhibited dissociations between SS and SO

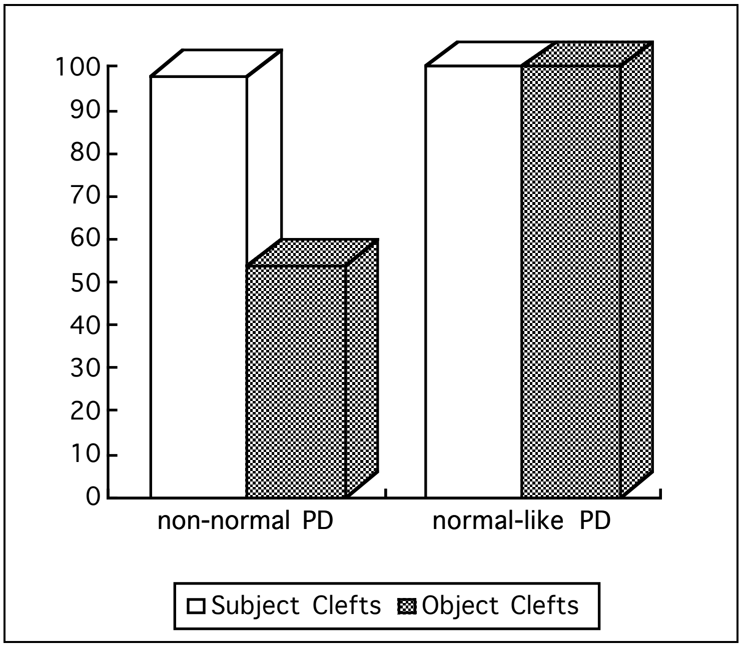

Figure 45: Comprehension of subject clefts and object clefts by non-normal and normal-like PD patients

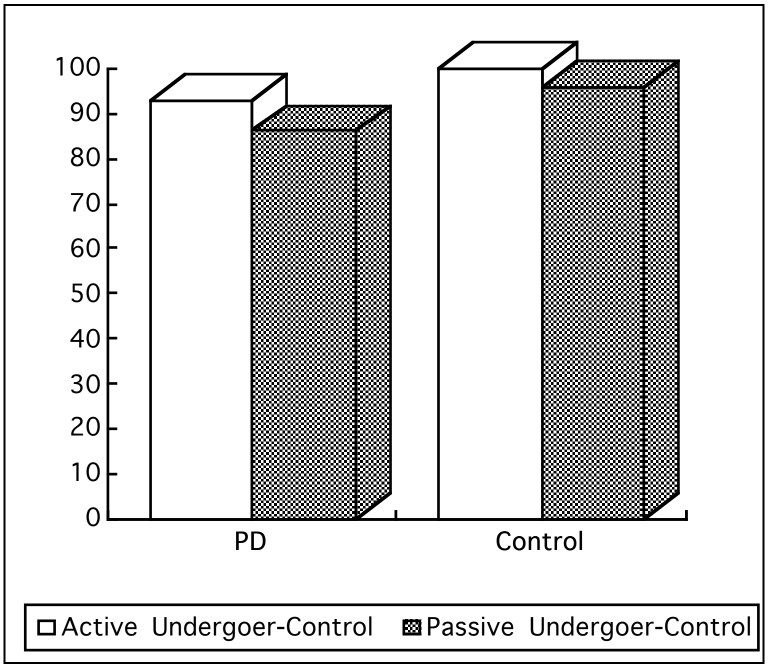

Figure 46: Comprehension of active and passive undergoer-control sentences by PD patients

relatives and between subject-clefts and object-clefts. The other patient (JE) did not exhibit dissociations for any of the other pairs of constructions. In addition, it is important to note that another patient (JS) performed poorly on both the UCa sentences and the UCp sentences. This patient exhibited dissociations for all of the other pairs of constructions.

The last set of constructions to be analyzed are those that were used to assess syntactic STM. An ANOVA with a group (PD, control) by construction type (syntactic STM required, syntactic STM not required) design did not reveal a significant interaction ($p = 1.0000$), indicating that PD patients perform just as well as control subjects on sentences that do and do not require syntactic STM (PDs: mean correct "syntactic STM not required" = 97.3%, *SD* = 9.98; mean correct "syntactic STM required" = 100%, *SD* = 0.00; controls: mean correct "syntactic STM not required" = 100%, *SD* = 0.00; mean correct "syntactic STM required" = 100%, *SD* = 0.00). These results are shown in Figure 47.

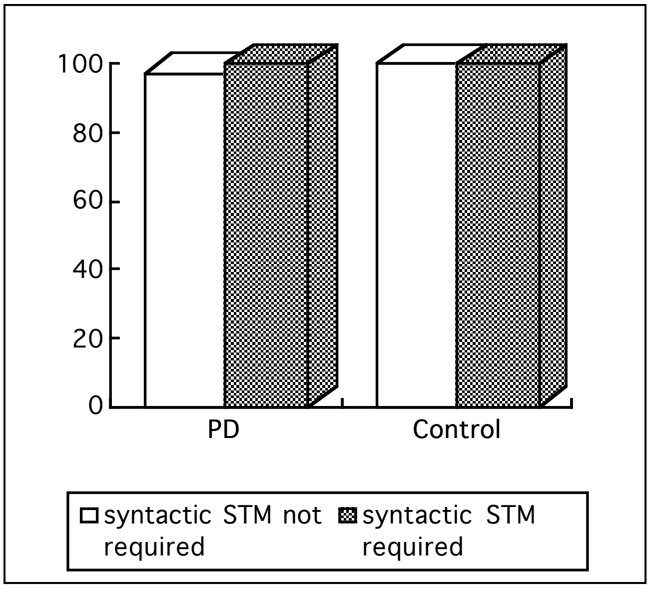

Figure 47: Comprehension of sentences that do and do not require syntactic STM by PD patients

In fact, only one patient (AK) diverged from 100% on either of the two constructions, and, strangely enough, he exhibited poor performance on the sentences that do not require syntactic STM and good performance on the sentences that do require this processing resource. I will offer a possible explanation for this behavior in the next section.

5.3.4 Discussion

In the introduction, I pointed out that the hypothesis that PD patients have an impairment of attentional control leads to a number of specific predictions about how they should perform on relative clause, cleft, and undergoer-control constructions. These predictions are as follows: good performance on SS relatives but poor performance on SO relatives; good performance on OS relatives but poor performance on OO relatives; good performance on subject-clefts but poor performance on object-clefts; and good performance on both active and passive undergoer-control sentences. I also pointed out that several alternative hypotheses make the same predictions, except that they all predict a dissociation between the two undergoer-control constructions. These hypotheses are, first, that PD patients have an impairment of complex parsing; second, that they have an impairment of noncanonical linking; and third, that they have an impairment of syntactic STM (note that SS relatives only require STM for main clause).

All of the predictions of the attention hypothesis were confirmed. The patients exhibited the expected dissociations between SS and SO relatives, between OS and OO relatives, and between subject-clefts and object-clefts; furthermore, they did not exhibit a significant dissociation between active and passive undergoer-control sentences. The results for the relative clause and cleft constructions are also consistent with all three of the alternative hypotheses; however, the results for the undergoer-control constructions are not. In addition, the hypothesis that PD patients have an impairment of syntactic

STM is inconsistent with another finding—namely, that the patients performed equally well on sentences that do and do not require syntactic STM.

It is interesting that the patients performed slightly better on the OO relatives than on the SO relatives. This pattern has been reported before in studies of aphasics (Caplan et al. 1985; Caplan & Hildebrandt 1988; Butler-Hinz et al. 1990) as well as in a recent study of how normal subjects perform on syntactic comprehension tasks in an RSVP paradigm (i.e., rapid serial visual presentation). It is likely that SO relatives elicit worse performance than OO relatives because in the former sentences the matrix clause is interrupted by the embedded clause, and two verbs must be processed in sequence.

The discovery that PD patients tend to perform well on passive undergoer-control sentences also deserves further comment. In particular, it is interesting that the patients are able to identify and respond appropriately to the semantic properties of control verbs, even though these semantic properties are completely implicit. This ability contrasts with their apparent inability to identify and respond appropriately to certain syntactic cues in relative clauses, clefts, and raising-to-subject sentences. The reason for this distinction may be, in part, that the semantic information is probably represented in the posterior portion of the left perisylvian cortex, which is not affected in PD, whereas the syntactic information is probably represented in the anterior portion of the left perisylvian cortex, which is affected in PD. It is also worth noting that the finding that PD patient are able to identify the semantic properties of controls verbs dovetails nicely with Grossman et al.'s (1993b) finding that PD patients are able to identify the semantic features of quantifiers, but have difficulty identifying the syntactic features of quantifiers. Finally, I should point out that the absence of a dissociation between active and passive undergoer-control sentences is only a group-level generalization; two of the patients (JE and AK) did manifest such a dissociation, and a third patient (JS) had trouble with both types of sentences[32] (I discuss these patients' individual performance profiles in more detail below). Nonetheless, it is still the case that the vast majority of patients did not exhibit differential comprehension of the two constructions.

I return now to the discussion of the patterns of results obtained in this study. Although significant dissociations were found at the group level between SS and SO relatives, between OS and OO relatives, and between subject-clefts and object-clefts, further analysis revealed that in each case the dissociation was restricted to less than half of the patients. For the SS and SO constructions, six patients (40%) fell into the non-normal subgroup (i.e., exhibited the expected dissociation); for the OS and OO constructions, four patients (27%) did so; and for the subject-clefts and object-clefts, five patients (33%) did so. It is somewhat surprising that such a small proportion of the patients displayed poor performance, given that Grossman and his colleagues have repeatedly found that roughly half of PD patients manifest syntactic comprehension deficits, and given that I found in Study 2 that *more* than half of the patients who were tested on SS and SO relatives exhibited a dissociation. Although there is no clear explanation for the comparatively low number of impaired patients, one possibility is that all of the patients who participated in this study were Hoehn and Yahr stage 2 or 2.5, whereas some of the patients who participated in Grossman et al.'s studies and in my first two studies were stage 3. Thus, it may be that few of the patients in this study performed poorly because their level of PD is fairly mild.[33]

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[32] It is worth noting, however, that on the day that JS was tested, he was feeling rather ill. This may have affected his motivation as well as his ability to concentrate on the experimental task. Indeed, I suspect that if I were to test him again on the same materials under more favorable conditions, his performance would improve.

[33] This may also explain why the patients in this study exhibited virtually no variation on the two con-structions that were used to assess syntactic STM, whereas the patients who Grossman et al. (1992b) tested on the same kinds of constructions displayed considerable variation (see Table 12, p. 192). Another reason for this difference may be that Grossman et al.'s patients actually had to perform two tasks for each sentence: first, make an acceptability judgement; and second, respond to the probe question. Thus,

At the level of individual patient profiles, a considerable amount of variability emerged; this is not so unusual, however, especially if the patients' syntactic comprehension deficits involve processing resources and not grammatical structures or operations. As can be seen in Table 26, patients CV, JS, and RZ have similar performance profiles: all of them exhibited significant dissociations between SS and SO relatives, between OS and OO relatives, and between subject-clefts and object-clefts. JS stands out from the other two patients, however, insofar as he also had some trouble with the SS and OS relatives and performed poorly on both types of undergoer-control constructions. Patients DJ and JN have performance profiles that are mirror images of each other: DJ exhibited a barely significant dissociation between subject-clefts and object-clefts, but performed well on all four types of relative clause constructions; by contrast, JN exhibited mild dissociations between SS and SO relatives and between OS and OO relatives, but performed well on both types of cleft constructions. Three other patients displayed syntactic comprehension deficits, and their performance profiles are all idiosyncratic. AW exhibited a large dissociation between SS and SO relatives, but performed perfectly on all of the other constructions. JE also exhibited only a single dissociation, but for him it was between active and passive undergoer-control sentences. While it is likely that these two patients performed as they did in part because of their PD, it is also possible that they were distracted, unmotivated, or even that their unusual profiles reflect some quirk in their syntactic comprehension systems that existed before the onset of PD (see §4.1, esp. pp. 152-3). Finally, AK exhibited dissociations between SS and SO relatives, between subject-clefts and object-clefts, and between active and passive undergoer-control sentences, but he did not exhibit a dissociation between OS and OO relatives. AK also displayed unexpectedly poor performance on the sentences

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these patients were, in a sense, involved in a dual-task situation, which imposes greater demands on attentional resources than a single-task situation.

that do not require syntactic STM. Although the underlying cause of this odd behavior is not clear, it may have been due to a primacy effect. Consider the examples below:

a. no syntactic STM required: *The boy chased the girl that is tall. Who is tall?*
b. syntactic STM required: *The boy that chased the girl is tall. Who is tall?*

For whatever reason, AK may have been frequently using a strategy of selecting the first NP as the argument of *tall*. Such a strategy would lead to the correct answer to the probe question for sentences like (b), but it would lead to the incorrect answer for sentences like (a). By way of concluding this discussion of the individual performance profiles of the patients, I should point out that some of the idiosyncrasies might vary if the patients were tested again on the same materials (recall that Grossman et al. (1992b) reported session-to-session variability when patients were tested twice on the same battery of sentences).

Finally, it is worthwhile to consider the "composite" performance of the patients who participated not only in this study but also in one or both of the previous two studies. These patients and their scores on the various constructions are shown in Table 27. Two main patterns stand out in this set of data. The first pattern is that three of the patients (WP, RD, and JD) performed extremely well on the entire battery of constructions. The second pattern is that the other four patients (AK, JS, CV, and RZ) have very similar performance profiles. They exhibited dissociations between SS and SO relatives, between OS and OO relatives (except for AK), between subject-clefts and object-clefts, between canonical and noncanonical SS raising sentences, and between canonical and noncanonical OS raising sentences. In addition, all but one of them (AK) performed well on both undergoer-control constructions and on all of the constructions that were used to evaluate syntactic STM. Thus, the general tendency for roughly half of PD patients to display syntactic comprehension deficits is borne out by this small group of patients. Moreover, it appears that for three of the four patients who manifested deficits—namely, JS, CV, and RZ—the most coherent explanation is that they have an impairment of attentional control. This hypothesis is consistent with the various dissociations that the patients exhibited as well as with the lack of a dissociation between active and passive undergoer-control sentences. By contrast, the hypothesis that the

	Patient							
Construction	AK	JS	CV	WP	RD	JD	RZ	*Mean*
SS*	90/100	100/80	80/90	90	100/100	100	100	*93.6*
SO*	40/40	30/50	20/40	90	100/100	100	50	*60*
OS	90	70	100	100	100	100	100	*94.3*
OO	90	30	60	90	100	100	40	*72.9*
SC	100	90	100	100	100	100	100	*98.6*
OC	60	30	50	100	100	100	60	*71.4*
SSc	100	100	100	100	100	100	92	*98.9*
SSn	50	58	58	100	100	100	92	*79.8*
OSc	100	100	75	100	100	100	100	*96.4*
OSn	50	58	42	75	100	75	17	*59.6*
UCa	100	30	80	100	100	100	100	*87.1*
UCp	60	40	80	90	100	100	90	*80*
OP (no STM)	100	100	100	-	100	-	-	*100*
ZA (STM)	60	100	80	-	100	-	-	*85*
Rel (no STM)	60	100	100	100	100	100	100	*94.3*
Rel (STM)	100	100	100	100	100	100	100	*100*

Table 2: Data for the PD patients who participated in Studies 1, 2, and 3. (Abbreviations: SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject-cleft, OC=object-cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa=active undergoer-control, UCp=passive undergoer-control, OV=overt pronoun, ZA=zero anaphora, Rel (no STM)=relative clause for which adjacent information is probed, Rel (STM)=relative clause for which nonadjacent information is probed. * = the first mean is from Study 2 and the second from Study 3; if only one mean is present, it is from Study 3.)

patients have an impairment of syntactic STM is falsified by their good performance on two types of constructions that require this processing resource. With regard to the other two hypotheses that are available—first, that the patients have an impairment of complex parsing, and second, that they have an impairment of noncanonical linking—while these hypotheses are compatible with the dissociations that the patients exhibited, they are not compatible with the fact that the patients performed well on passive undergoer-control sentences. As for patient AK, it does not seem to be possible to identify a single best explanation for his performance profile. He might have a disturbance of syntactic STM, since he performed poorly on the zero anaphora sentences and behaved idiosyncratically on the other pair of constructions that was used to assess syntactic STM. In addition, he might have an impairment of attentional control, complex parsing, or noncanonical linking, since he exhibited dissociations on all of the other pairs of constructions except for terminal relative clauses.

5.4 Study 4: Active, Passive, and Intransitive Constructions

5.4.1 Goals

This study was designed to test the predictions about how PD patients would perform with active, passive, and intransitive constructions. These constructions are exemplified below:

a. transitive active: *Harry saw Sally.*
b. passive:
    i. foregrounding: *Sally was seen.*
    ii. backgrounding: *Sally was seen by Harry.*
c. intransitive:
    i. actor-intransitive: *Harry applauded.*
    ii. undergoer-intransitive: *Harry drowned.*

For the sake of clarity, I will reiterate the specific predictions for these constructions.

The prediction for the transitive active construction is quite straightforward. This construction has a very simple constituent structure and a perfectly canonical linking pattern; hence, PD patients should not have difficulty comprehending sentences of this type. Several of the studies that I reviewed in Chapter 4 tested PD patients on transitive active sentences, so one might wonder why I decided to do this again. The reason is that although three of the previous studies found PD patients to have good comprehension of transitive actives (Lieberman et al. 1990, 1992; Grossman et al. 1992b), one of the studies found that PD patients perform better on transitive actives with "simple transitive" (ST) verbs than on transitive actives with "lexical causative" (LC) verbs (Geyer & Grossman 1995). I argued in my evaluation of this latter study that the patient's differential performance may have been due to the manner in which they were tested. Thus, one of the aims of the present study is to test PD patients on transitive active sentences containing these same two types of verbs, using a methodology which avoids these problems. My prediction is that the patients will perform well on all of the sentences, since transitive actives have canonical linking regardless of whether they contain ST or LC verbs (see p. 215).

I turn now to the predictions for the two passive constructions. Like the transitive active construction, both of these constructions involve simple constituent structures, but unlike the transitive active construction, their linking patterns are noncanonical. On the other hand, in both constructions the noncanonical linking pattern is signaled by multiple explicit cues—two in the foregrounding passive construction (the auxiliary verb and the perfect participial form of the main verb), and three in the backgrounding passive construction (the auxiliary verb, the perfect participial form of the main verb, and the preposition *by*). Because these cues are present, I suggested in Chapter 3 that attentional control is probably not needed to regulate template selection and linking during the on-line processing of these kinds of sentences. I also suggested that if attention is needed at all, it is needed more for foregrounding passives than for backgrouding passives, since the former sentences have fewer cues. Thus, if PD patients have an impairment of attentional control, they should still be able to comprehend both types of passive constructions, although they might have a bit more trouble with foregrounding passives than with backgrounding passives. By contrast, if PD patients have an impairment of noncanonical linking, they should perform poorly on both types of passive constructions. As with the transitive active construction, several of the studies that I reviewed in Chapter 4 have already tested PD patients on the backgrounding passive construction. Although most of these studies found that PD patients have intact comprehension of passives (Lieberman et al. 1990, 1992; Grossman et al. 1992b), one of the studies reported that PD patients perform better on passives with ST verbs than on passives with LC verbs (Geyer & Grossman 1995). I argued in my evaluation of this study, however, that the patients' performance may have been affected by the way in which comprehension was assessed. Hence, my aim here is to use a different methodology to test PD patients on passives containing the same two types of verbs. The prediction is still that the patients will perform well on all of the sentences, since passives have clearly marked noncanonical linking regardless of whether the verb is ST or LC.

Finally, I turn to the predictions for the two intransitive constructions. Both of these constructions have simple constituent structures, but they differ in their linking patterns. In the actor-intransitive construction, the pivot NP is associated with the actor macrorole, whereas in the undergoer-intransitive construction, it is associated with the undergoer macrorole. Since pivot NPs tend to be actors more frequently than undergoers, the linking pattern in the actor-intransitive construction can be considered canonical whereas the linking pattern in the undergoer-intransitive construction can be considered noncanonical. Furthermore, whether the linking pattern is canonical or noncanonical is not signaled by any explicit cues whatsoever; instead, it is determined solely by the implicit semantic structure of the verb. Specifically, according to RRG, activity verbs occur in the actor-intransitive construction, while state and achievement verbs occur in the undergoer-intransitive construction (see §3.1.1.2 for details regarding these two semantic classes of verbs; note also that activity verbs correspond to what Geyer and Grossman call ST verbs, while achievement verbs correspond, at least roughly, to what they call LC verbs). Given these facts, one might think that attentional control would be needed to regulate linking during the processing of undergoer-intransitives. However, I argued in Chapter 3 (§3.2.2.2, pp. 106-7) that special attention is not needed because, first, the constituent structure is very simple, and second, the relevant semantic properties of the verb are readily available, and they indicate that the most appropriate interpretation of the pivot NP is as an undergoer. Thus, the hypothesis that PD patients have an impairment of attentional control predicts that they should not have difficulty understanding either actor- or undergoer-intransitives. By contrast, the alternative hypothesis that PD patients have an impairment of noncanonical linking predicts that they should definitely exhibit a dissociation between good comprehension of actor-intransitives and poor comprehension of undergoer-intransitives.

5.4.2 Subjects

The same PD patients and control subjects who participated in Study 3 also participated in Study 4. The characteristics of the PD patients are provided in Table 25 (see p. 286).

5.2.3 Materials and Procedure

Ten instances of each of the constructions described above were used as linguistic stimuli. These sentences are listed below.

A. Transitive Actives

1. *The boy sketched the girl.*
2. *The girl applauded the boy.*
3. *The man observed the woman.*
4. *The boy followed the girl.*
5. *The woman called the man.*

6. *The bowl shattered the plate.*
7. *The woman drowned the man.*
8. *The man awakened the woman.*
9. *The saucer cracked the cup.*
10. *The girl turned the boy.*

B. Foregrounding Passives

1. *The boy was sketched.*
2. *The boy was applauded.*
3. *The man was observed.*
4. *The girl was followed.*
5. *The man was called.*

6. *The bowl was shattered.*
7. *The woman was drowned.*
8. *The woman was awakened.*
9. *The saucer was cracked.*
10. *The girl was turned.*

C. Backgrounding Passives

1. *The boy was sketched by the girl.*
2. *The girl was applauded by the boy.*
3. *The man was observed by the woman.*
4. *The girl was followed by the boy.*
5. *The woman was called by the man.*

6. *The plate was shattered by the bowl.*
7. *The man was drowned by the woman.*
8. *The woman was awakened by the man.*
9. *The saucer was cracked by the cup.*
10. *The boy was turned by the girl.*

These first three sets of sentences contain the same 10 verbs, the first five of which are activity verbs and the second five of which function here as accomplishment verbs. In each set of sentences, the verbs occur with the same NPs. For eight of the verbs, the NPs are male and female (*the man*/*the boy* and *the woman*/*the girl*), and in each set of sentences, the male NP is the pivot four times and the female NP is the pivot four times. In addition, across the three sets of sentences, there is variation regarding how frequently the participants associated with particular verbs serve as actor or undergoer. For three of the verbs (*sketch, observe,* and *crack*), the same participant serves as undergoer in both the foregrounding and backgrouding passive sentences. For three other verbs (*shatter, drown,* and *turn*), the same participant serves as undergoer in the transitive active and backgrounding passive sentences. For one verb (*applaud*), the same participant serves as undergoer in the transitive active and foregrounding passive sentences. And finally, for the remaining three verbs (*follow, call,* and *awaken*), the same participant serves as undergoer in all three sentences.

D. Actor-Intransitives

1. *The girl sketched.*
2. *The boy sketched.*
3. *The woman called.*
4. *The man called.*
5. *The girl applauded.*
6. *The boy applauded.*
7. *The girl followed.*
8. *The boy followed.*
9. *The woman observed.*
10. *The man observed.*

E. Undergoer-Intransitives

1. *The woman awakened.*
2. *The man awakened.*
3. *The cup cracked.*
4. *The saucer cracked.*
5. *The bowl shattered.*
6. *The plate shattered.*
7. *The woman drowned.*
8. *The man drowned.*
9. *The girl turned.*
10. *The boy turned.*

The set of actor-intransitive sentences contains the same activity verbs that appear in the active and passive sentences, and each of these verbs is associated with the same two participants that it is associated with in the actives and passives. Similarly, the set of undergoer-intransitive sentences contains the same verbs that have an accomplishment logical structure in the active and passive sentences; here these verbs have an achievement logical structure. Each of the verbs is associated with the same two participants that it is associated with in the actives and passives.

It should be clear from the five sets of sentences provided above that each of the ten verbs goes with two complementary "scenes." For example, the verb *applaud* goes with the following two scenes: first, a boy applauding a girl; and second, a girl applauding a boy. Likewise, the verb *drown* goes with the following two scenes: first, a man drowning a woman; and second, a woman drowning a man. An artist was hired to make ten line drawings representing the ten pairs of scenes associated with the verbs used in this study. Each drawing showed both scenes, side by side, with the only difference between them being the roles of the participants. These drawings are provided in the Appendix. Five copies of each drawing were made, one for each of the five sentences containing the verb that goes with the drawing. The 50 drawings were then placed in a ring binder in a quasi-random order corresponding to the order in which the sentences would be presented to the PD patients.

The procedure for the experiment was as follows. First, the patients were shown instances of each of the ten drawings in the binder, so that they could become familar with the content of the drawings. For each drawing, the examiner briefly described the two scenes using the verb and NPs that also appear in the test sentences. For example, the drawings for the verb *applaud* were described as follows: "Here's a boy applauding a girl, and here's a girl applauding a boy." Next, the patients were told that a list of sentences would be read aloud to them, one for each drawing, and that their task was to point to the scene which matched the meaning of the sentence. Alternatively, the patients could respond "A" or "B," since for each drawing the left-hand scene was labeled "A" and the right-hand scene was labeled "B." The 50 test sentences were then read aloud to the patients in a natural manner and in a quasi-random order (subject to the proviso that no more than two items of the same type could occur in sequence). There were no breaks, since the administration of the test only took about fifteen minutes.

5.2.4 Results

The results are shown in Table 28. It is clear from this table that the PD patients did not perform differently from the control subjects on either the active sentences or the two types of passive sentences. All of the subjects in both groups scored 100% on the actives. Only one PD patient (AW) made errors on the foregrouding passives, and this patient's score was still above chance. Similarly, only one PD patient (JS) made errors on the backgrounding passives, and again this patient's score was still well above chance. These results are illustrated in Figure 48.

	Construction Type				
PD Patients	Active	F-Passive	B-Passive	A-Intrans.	U-Intrans.
HG	100	100	100	100	100/100
DJ	100	100	100	100	100/100
AW	100	80	100	100	70/87.5
JE	100	100	100	100	90/100
JD	100	100	100	100	100/100
AK	100	100	100	100	90/100
AD	100	100	100	100	100/100
CV	100	100	100	100	60/75
RK	100	100	100	100	100/100
WP	100	100	100	90	100/100
JN	100	100	100	90	90/87.5
JS	100	100	90	100	80/100
WS	100	100	100	100	100/100
RZ	100	100	100	100	90/100
RD	100	100	100	100	100/100
Mean	*100*	*98.7*	*99.3*	*98.7*	*91.3/96.7*
Controls					
1	100	100	100	100	100/100

2	100	100	100	100	100/100
3	100	100	100	100	90/100
4	100	100	100	100	100/100
5	100	100	100	100	90/100
Mean	*100*	*100*	*100*	*100*	*96/100*

Table 28: Data for Study 4 on active, passive, and intransitive constructions. In the column for U-Intrans., the first mean is for all 10 sentences, and the second is for all of the sentences except for the two containing the verb *turn*. (Abbreviations: F-Passive=foregrounding passive, B-Passive=back-grounding passive, A-Intrans.=actor-intransitive, U-Intrans.=undergoer-intransitive.)

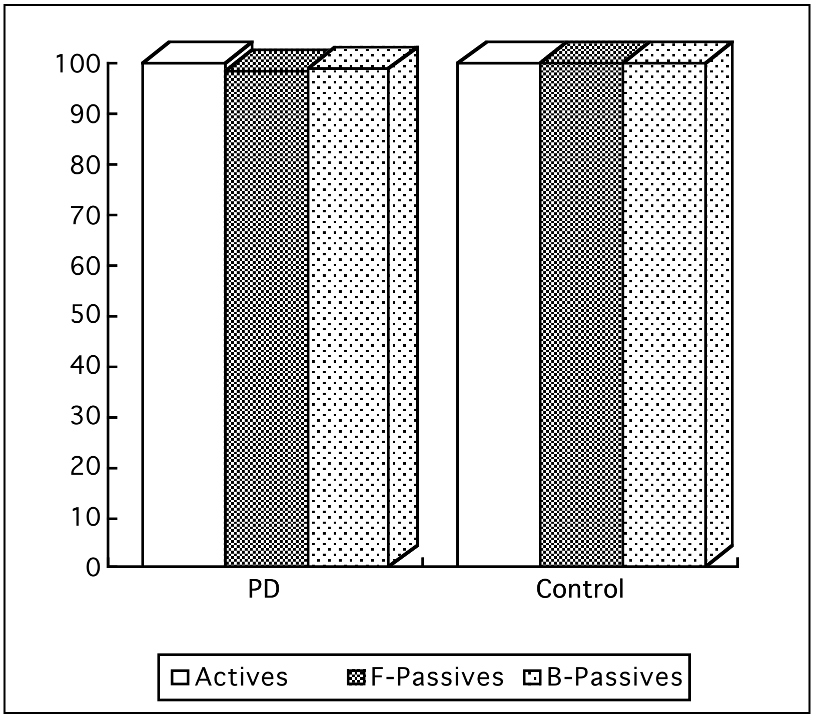

Figure 48: Comprehension of active and passive sentences by PD patients

With regard to the two intransitive constructions, the results were as follows. The PD patients performed extremely well on the actor-intransitives, achieving a group mean of 98.7%. Only two of the patients (WP and JN) made any mistakes, and both of these patients' scores were still well above chance. The results for the undergoer-intransitives are a bit more complicated. This is because six of the PD patients and two of the control subjects had particular difficulties with the two undergoer-intransitive sentences containing the verb *turn*.[34] In order to avoid biasing the results, Table 28 includes two means for each subject on the undergoer-intransitives—one for all 10 sentences, and the other for all of the sentences except the two with the verb *turn*. As can be seen, the group mean for the PD patients on all ten sentences is 91.3%, and that for the control subjects is 96%. Both of these means are lower than for any of the other constructions, although they are still very high in absolute terms and not substantially differently from each other. When the two sentences with *turn* are subtracted out, the means for both groups increase substantially: the mean for the PD patients is now 96.7%, and that for the control subjects is 100%. Thus, only two PD patients (CV and JN) made any mistakes on undergoer-intransitives apart from those with *turn,* and both of these patients' scores were still above chance. The results based on the scores without the *turn* sentences are shown in Figure 49.

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[34] There are two possible reasons for this finding. One is that the pictures representing the scenes associated with the verb *turn* were especially hard to process (recall that some PD patients have an impairment of visuospatial processing). The other is that the two undergoer-intransitive sentences with this verb—*The boy turned* and *The girl turned*—somehow led the patients to think that the pivot NP was better interpreted as an actor than as an undergoer. This latter possibility seems more likely than the first, since the two sentences can in fact mean that the turning was instigated by the boy/girl, and the pictures supported this interpretation by showing one participant causing the other to turn. In contrast, none of the other undergoer-intransitive sentences allowed such a reading; in all of them the pivot NP could only be properly construed as the undergoer of the event.

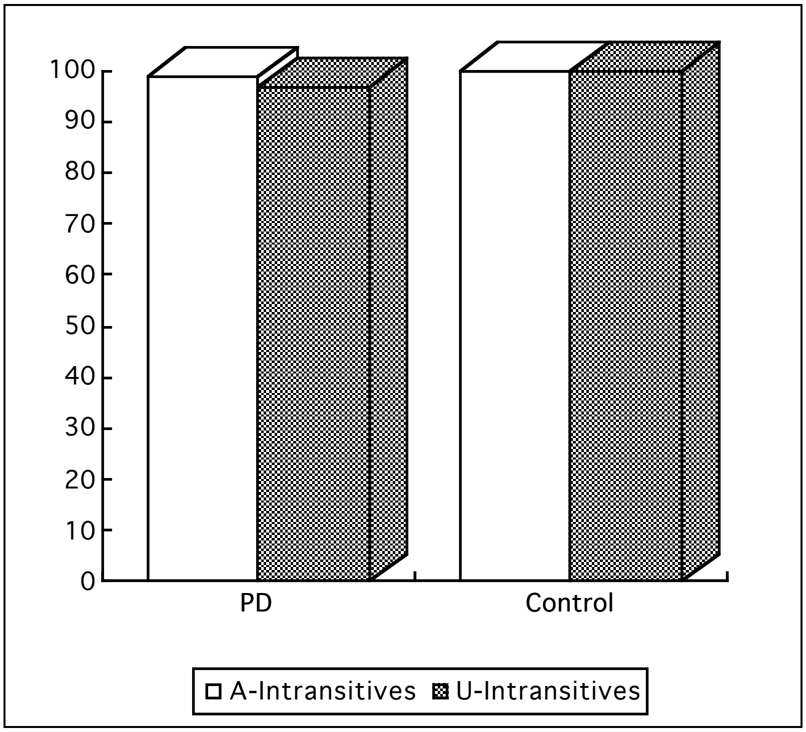

Figure 49: Comprehension of actor- and undergoer-intransitive sentences by PD patients

5.2.5 Discussion

Overall, the results support the predictions outlined earlier. The hypothesis that PD patients have an impairment of attentional control predicts that they should perform well on actives, both types of passives, and both types of intransitives, and this is exactly the pattern of performance that was found. On the other hand, the hypothesis that PD patients have an impairment of noncanonical linking cannot account for these results, since it predicts that PD patients should exhibit dissociations between active and passive sentences and between actor- and undergoer-intransitive sentences.

The results of this study are also relevant to the question, originally raised by Geyer and Grossman (1995), of whether PD patients have greater difficulty understanding active and passive sentences with LC verbs than active and passive sentences with ST verbs. Geyer and Grossman found this to be the case; however, I argued that the patients' performance may have been influenced by the probe verification task that was used to measure comprehension. In the present study, it was found that when PD patients are tested on the same kinds of sentences but in a sentence-picture matching paradigm, their comprehension of both kinds of sentences is extremely good. This lends support to the possibility that Geyer and Grossman's patients were indeed affected by the manner in which they were tested. Moreover, the good performance of the patients in the present study can easily be explained by the fact that the linking patterns of active and passive sentences are the same regardless of whether the verb is LC or ST.

Finally, it is important to note that all of the patients who participated in this study also participated in Study 3. Thus, the finding that all of these patients performed well on foregrounding passives, backgrounding passives, and undergoer-intransitives indicates that their poor performance on several of the constructions in Study 3 that require noncanonical linking cannot be due to an impairment of the ability to execute noncanonical linking (these constructions are as follows: SO relatives, OO relatives, and object-clefts). Seven of the patients who participated in this study and in Study 3 also participated in Studies 1 and 2. The "composite" results for these patients are shown in Table 29 (this is the same as Table 28, except that the data for actives, passives, and intransitives have been added). As expected, the three patients who performed well on all of the constructions in Studies 1, 2 and 3 also performed well on all of the constructions in the present study. What is more interesting is that the four patients who exhibited multiple dissociations on the constructions in Studies 1, 2, and 3 did not exhibit dissociations between actives and passives or between actor- and undergoer-intransitives in the present study. This implies that the dissociations that these patients did exhibit cannot be due to an impairment of noncanonical linking. As I argued in the discussion section of Study 3, the most coherent explanation for these patients' syntactic comprehension deficits is that that they are due to an impairment of attentional control (this applies especially to JS, CV, and RZ; AK may have other impairments as well).

	Patient							
Construction	AK	JS	CV	WP	RD	JD	RZ	*Mean*
Active	100	100	100	100	100	100	100	*100*
F-Passive	100	100	100	100	100	100	100	*100*
B-Passive	100	90	100	100	100	100	100	*100*
SS	90/100	100/80	80/90	90	100/100	100	100	*93.6*
SO	40/40	30/50	20/40	90	100/100	100	50	*60*
OS	90	70	100	100	100	100	100	*94.3*
OO	90	30	60	90	100	100	40	*72.9*
SC	100	90	100	100	100	100	100	*98.6*
OC	60	30	50	100	100	100	60	*71.4*
SSc	100	100	100	100	100	100	92	*98.9*

SSn	50	58	58	100	100	100	92	*79.8*
OSc	100	100	75	100	100	100	100	*96.4*
OSn	50	58	42	75	100	75	17	*59.6*
UCa	100	30	80	100	100	100	100	*87.1*
UCp	60	40	80	90	100	100	90	*80*
A-Intrans.	100	100	100	90	100	100	100	*98.6*
U-Intrans.	90/100	80/100	60/80	100/100	100/100	100/100	90/100	*88.6/97.1*
OP (no STM)	100	100	100	-	100	-	-	*100*
ZA (STM)	60	100	80	-	100	-	-	*85*
Rel (no STM)	60	100	100	100	100	100	100	*94.3*
Rel (STM)	100	100	100	100	100	100	100	*100*

Table 29: Data for the PD patients who also participated in Studies 1, 2, and 3. In the SS and SO rows, the first mean is from Study 2 and the second from Study 3; if only one mean is present, it is from Study 3. In the U-Intrans row, the first mean is for all ten sentences, and the second is for all of the sentences except those with the verb *turn*. (Abbreviations: F-Passive=foregrounding passive, B-Passive=backgrounding passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject-cleft, OC=object-cleft, SSc=canonical subject-to-subject raising, SSn=non-canonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa=active undergoer-control, UCp=passive undergoer-control, A-Intrans.= actor-intransitive, U-Intrans.=undergoer-intransitive, OV=overt pronoun, ZA=zero anaphora, Rel (no STM)= relative clause for which adjacent information is probed, Rel (STM)=relative clause for which nonadjacent information is probed.)

5.5 Summary

The studies described in this chapter were conducted with two main goals in mind. The first goal was to test PD patients on a variety of constructions which they have not been tested on before. This goal has been satisfied, since I have shown that PD patients tend to exhibit the following kinds of dissociations: between canonical and noncanonical SS raising sentences; between canonical and noncanonical OS raising sentences;

between OS and OO relatives; and between subject-clefts and object-clefts. I have also shown that PD patients do not tend to exhibit other kinds of dissociations: between overt pronoun and zero anaphora sentences; between active and passive undergoer-control sentences; between backgrounding and foregrounding passive sentences; and between actor- and undergoer-intransitive sentences. All of this information is new and can help us to better understand the nature of syntactic comprehension deficits in PD.

The second goal was to test the hypothesis that the underlying cause of syntactic comprehension deficits in PD is an impairment of attentional control. In the introduction to this chapter, I presented a table showing which sentence processing factors are implicated in which constructions, together with predictions about which constructions should pose comprehension difficulties for PD patients if they have an impairment of attentional control. This table is reproduced below, except that two more rows have been added showing the mean scores for the PD patients I tested. The first row shows the overall means, and the second row shows the means for the non-normal subgroups, where these are applicable.[35]

	Construction Type															
Processing Factor	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Complex parsing			x	xx	x	xx	x	xx	x	xx	x	xx	x	xx		
Noncanonical linking		x		x		x		x		x		x		x		x
Syntactic STM			x	x		x		x		x		x		x		

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[35] The score in the cell for "overall P mean" represents the mean of the means for foregrounding and backgrounding passives. The scores in the cells for "overall SS mean" and "overall SO mean" represent the combined means from Studies 2 and 3. The scores in the cells for "non-normal subgroup SS" and "non-normal subgroup SO" represent the combined means for just those patients in Studies 2 and 3 who exhibited dissociations.

Attentional control				x		x		x		x		x				
Prediction for PD				x		x		x		x		x				
Overall mean	100	99	96.2	66.3	97.3	82.7	99.3	84.7	97.3	76.5	96.7	60.5	92.7	86	98.6	97.1
Non-normal subgroup	-	-	94.5	47.7	92.5	50	98	54	98.7	56.7	96.3	46.2	-	-	-	-

Table 30: Construction-Specific Predictions for PD Patients (Abbreviations: A=active, P=passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa=active undergoer control, UCp=passive undergoer-control, AI=actor-intransitive, UI=undergoer-intransitive.)

It is clear from this table that all of the predictions of the attention hypothesis were confirmed. The hypothesis predicts that PD patients should perform well on actives and passives, and this was found to be the case. The hypothesis also predicts that PD patients should exhibit dissociations between SS and SO relatives, between OS and OO relatives, and between object-clefts and subject-clefts. At the group level, only the first of these dissociations was clearly manifested; however, at the level of subgroups, the other two dissociations also appeared. That is to say, a substantial proportion of the patients who were tested (between 30% and 50%) exhibited the expected dissociations for terminal relatives and clefts. A third prediction of the attention hypothesis is that PD patients should perform well on both active and passive undergoer-control sentences; this prediction was also borne out. Finally, the attention hypothesis predicts that PD patients should not exhibit a dissociation between actor- and undergoer-intransitive sentences, and this was strongly confirmed. In no case did a dissociation go in opposite direction from what was predicted.

In this chapter, I have also considered three alternative hypotheses regarding the underlying cause of syntactic comprehension deficits in PD: first, that PD patients have an impairment of complex parsing; second, that they have an impairment of noncanonical linking; and third, that they have an impairment of syntactic STM. The parsing hypothesis is consistent with all of the dissociations reported in Table 30 (note that good performance could be achieved on the various complex constructions with canonical linking patterns by resorting to heuristics). This hypothesis is also consistent with the lack of dissociations between actives and passives and between actor- and undergoer-intransitives. However, it does not seem to be able to account for the finding that PD patients generally perform well on passive undergoer-control sentences. In addition, this hypothesis is incompatible with Grossman et al.'s (1992b) discovery that PD patients display variable comprehension of the same materials when tested on different occasions. This is because if PD patients had a disorder of the operations necessary to assemble complex constituent structures, one would expect them to experience fairly regular sentence processing difficulties and hence display stable performance across testing sessions. The second hypothesis—that PD patients have an impairment of noncanonical linking—is consistent with all of the dissociations reported in Table 30, but it is falsified by the demonstration that PD patients perform well on foregrouding passives, backgrounding passives, undergoer-intransitives, and passive undergoer-control sentences. Finally, the third hypothesis—that PD patients have an impairment of syntactic STM—is consistent with all of the dissociations that do and do not occur for the constructions in Table 30. However, it is disconfirmed by the results of Studies 2 and 3 which show that PD patients perform equally well on sentences that differ only with respect to whether they require syntactic STM.

According to Table 30, all of the constructions on which PD patients performed well are marked for zero or only one processing factor; the only exception is the UCp construction, which is marked as having three factors. By contrast, all of the constructions on which they performed poorly are marked as having four processing factors. Thus, it is conceivable that the various processing factors have an additive effect on the comprehension difficulty of constructions. One might think that the fact that the patients performed well on the UCp construction refutes such a possibility; however, it is important to note that three of the patients performed at chance on these sentences, and also that other researchers have found various kinds of additive effects on the syntactic comprehension abilities of brain-damaged patients other than PD patients (Caplan 1992). Nonetheless, it still appears that the single most important processing factor affecting the performance of PD patients is attentional control. My overall conclusion, then, is that the most coherent explanation for the syntactic comprehension deficits exhibited by PD patients is that they are due to an impairment of attentional control.

This view is supported by the relation between the neuropathology of PD and the putative neural substrates of the major components of the syntactic comprehension system. PD directly affects the basal ganglia and indirectly affects the prefrontal cortex. In Chapter 3, I argued that parsing tends to be implemented in the anterior portion of the left perisylvian cortex, perhaps in the anterior third of the superior temporal cortex. Since this area is spared in PD, it makes sense that the vast majority of patients do not appear to have a parsing impairment. I also argued that interpretation tends to be carried out in the posterior third of the left perisylvian cortex. Again, because this area is not affected in PD, it is not surprising that patients do not have difficulty executing non-canonical linking operations. With regard to syntactic STM, I argued that it tends to be implemented in the vicinity of Broca's area. I raised the possibility that this area might interact with the basal ganglia via a reciprocal circuit, and hence that it might be affected in PD. I also suggested that this area might receive a heavy dopaminergic innervation from the mesocortical projection system, which would provide another way in which it could be affected in PD. In Studies 2 and 3, it was shown that PD patients do not appear to have trouble with syntactic STM, and this finding casts doubt on the reality of a ventrolateral circuit and dopaminergic innervation. However, as I pointed out at the end of Chapter 4, it is possible that the neural pathways do exist and are affected in PD, and that the reason most patients seem to have intact syntactic STM is that the tests were not demanding enough. Further research is needed to investigate this issue. Turning to the last component of the syntactic comprehension system—namely, attention control—I argued that its implementation may be distributed among several brain areas: the anterior cingulate cortex, the basal ganglia, and perhaps the ventrolateral prefrontal cortex. Since the basal ganglia and the anterior cingulate cortex are known to be affected in PD, it makes sense that the syntactic comprehension deficits exhibited by patients appear to be due to an impairment of attentional control.

A final issue that deserves consideration is whether PD patients' syntactic comprehension abilities correlate with any demographic factors. It is not possible to conduct a statistical analysis to investigate this issue because different groups of patients participated in each study. However, it is still possible to see if any demographic factors appear to cluster more with patients who have good comprehension than with patients who have poor comprehension. In Table 31, all of the patients who were tested in studies 1 through 4 are ranked from highest to lowest in terms of their overall mean score on the constructions that require attentional control. There were five such constructions in total: the two noncanonical raising-to-subject constructions (study 1); the two object-gap relative clause constructions (study 2 [just SO] and study 3 [both SO and OO]); and the object-cleft construction (study 3). The numbers in parentheses after each patient's initials indicate which studies he participated in, and hence which constructions are reflected in his mean score. The demographic characteristics of each patient are shown in the other columns of the table (medication data is only available for the patients who participated in studies 3 and 4). The table breaks the patients down into five groups according to their scores on the constructions requiring attentional control: 90-100%, 80-89%, 70-79%, 50-69%, and 29-49%.

Patient	Score	Age	Dur.	H&Y	MMSE	HRSD	Edu.	Medication
HG (3,4)	100	65	4	2	29	5	18	E, A, Pro
RD (1-4)	100	66	6	2	29	0	12	Sin, Sel, D
RK (3,4)	100	45	9	2	29	3	14	Sin, A, T, B, F
WS (3,4)	100	72	12	2	30	1	21	I, V
JE (3,4)	96.7	70	6	-	-	-	8	-
JD (1,3,4)	95	71	3	2	30	4	18	Sin, Sel
AD (3,4)	93.3	72	14	2.5	27	2	12	Sin, Sel, Per
WP (1,3,4)	91	72	2	2	30	1	14	Sel, A
BU (1)	83	71	3	3	28	7	12	
AW (3,4)	80	73	7	2	30	3	13	Sin, Sel, B, Elo
ML (1)	79	78	2	3	28	5	12	
DJ (3,4)	76.7	72	6	2.5	30	1	16	Sin, D, Z, L, N, Par, Pen
JN (3,4)	76.7	68	16	2.5	27	2	16	Sin, Sel, T
JR (1,2)	76	72	6	2	26	9	16	
CM (1,2)	72.7	61	7	3	24	2	12	
TH (1)	70.5	80	8	3	28	4	9	
PH (2)	70	74	9	3	27	4	12	
DB (1,2)	64.7	75	4	2	26	5	14	
PP (1)	58	77	3	3	28	6	12	
AK (1-4)	58	68	8	2	29	9	12	Sin, Sel, D, Per, Ph
RZ (1,3,4)	51.8	72	2	2	28	9	14	Sin, Sel
TS (2)	50	59	9	3	28	3	12	
CV (1-4)	48	65	10	2	30	4	12	Sin, Sel, Vas
JS (1-4)	43.2	61	6	2.5	29	3	14	Sin, Per, Am, Cim
LS (1)	29.5	76	10	3	29	4	8	

Table 31: Scores for constructions requiring attentional control together with demographic factors. Abbreviations: Dur=duration of PD, H&Y=Hoehn and Yahr rating scale for PD, MMSE=Mini-Mental State Exam, HRSD=Hamilton rating scale for depression, Edu=years of education. Medications: E=eldepryl, A=amantadine, Pro=propanolol, Sin=sinemet, Sel=selegiline, D=docusate, T-trihexyphenidyl, B= bromocriptine, F=fludricortisone, I=inderol, V=verapamil, Per=pergolide, Elo=elonozepam, Z=zoloft, L=lerothyroxine, N=nifedipine, Par=parlodel, Pen=pentoxifylline, Ph=phenytoin, Vas=vasotec, Am= amlodipine, Cim=cimetidine.

Focusing first on the medications, several of them are present throughout the different groups: sinemet, selegiline, pergolide, and docusate. Hence, there is no evidence that any of these drugs had a strong influence, either positive or negative, on the patients' comprehension of constructions requiring attentional control. As for the other medications, most are restricted to particular groups. However, it is not clear at this time whether any of them had a significant effect on the patients' syntactic comprehension abilities.

In order to bring out any relations that may exist between the comprhension scores for the five groups and their other demographic features, the mean values of the demographic features for each group are shown in Table 32:

	Age	Duration	H&Y	MMSE	HRSD	Education
90-100%	58.6	6.5	2.07	29.1	2.3	14.6
80-89%	81.5	5.0	2.50	29.0	5.0	12.5
70-79%	72.1	7.7	2.71	27.1	3.9	13.3
50-69%	70.2	5.2	2.40	27.8	6.4	12.8
29-49%	67.3	8.6	2.50	29.3	3.7	11.3

Table 32: Mean values of demographic features for five groups of patients

With regard to the factor of age, the 90-100% group is by far the youngest; however, the remaining four groups do not show a trend of decreasing comprehension scores correlating with increasing age. In fact, the second best group (80-89%) is the oldest, and the worst group (29-49%) is the second youngest. Comprehension does not appear to interact with duration of PD in any systematic way, although it is noteworthy that the worst group (29-49%) has the longest duration of PD. The third factor, Hoehn and Yahr stage, seems to pattern like the age factor, since the 90-100% group has by far the lowest value, but the other four groups do not exhibit a progression of decreasing comprehension scores correlating with increasing severity of PD. Comprehension scores do not interact with Mini-Mental State scores. As for depression, the best group (90-100%) has the lowest value; however, the comprehension scores for the remaining four groups do not pattern with this factor. Finally, the best group (90-100%) has the most education and the worst group (29-49%) has the least education, but the difference is only 3.3 years and the education column of Table 31 indicates that values were scattered fairly evenly across the five groups. In sum, this brief consideration of how comprehension interacts with demographic factors suggests that the most influential factors are age and severity of PD (as measured by the Hoehn and Yahr scale): on average, younger, early-stage patients tend to have better comprehension of constructions that require attentional control than older, later-stage patients.

Chapter 6: Conclusion

The goal of this thesis has been to gain a better understanding of the functional and neuropathological bases of syntactic comprehension deficits in PD. In this final chapter, I will summarize the approach that I have taken to achieve this goal and the conclusions that I have reached. I will also discuss a number of open questions that remain topics for future research.

In the first part of the thesis, which consists of Chapters 2 and 3, I presented the background information that is necessary for carrying out both theoretical and empirical research on the syntactic comprehension abilities of PD patients. Chapter 2 was devoted to reviewing the neuropathology and neuropsychology of PD. The main points that were made there are as follows. PD is a progressive neurodegenerative disorder that involves deterioration of the two dopaminergic projection systems in the basal ganglia. The nigrostriatal system is affected most strongly, causing severe dysfunction in the putamen in 100% of patients and less severe dysfunction in the caudate in roughly 50% of patients. The reduction of dopamine in these striatal nuclei prevents them from accurately recognizing behaviorally significant contexts in their massive input from the cortex and thalamus. As a result, the basal ganglia are no longer able to relay appropriate recommendations for thought or action to the frontal lobes via multiple specialized circuits. This lack of "biasing input" to certain regions of the frontal lobes leads to what DuBois et al. (1991) call "cortical demodulation." Since the putamen participates in a circuit with the motor cortices, all PD patients develop characteristic movement disorders; and since the caudate participates in circuits with the dorsolateral and orbital (and perhaps also ventrolateral) prefrontal cortices, about half of PD patients develop cognitive and emotional disorders as well. The mesocor-tical dopaminergic projection system is also affected in PD, albeit less severely than the nigrostriatal system. This leads to moderate dopamine depletion not only in the ventral striatum, which participates in a circuit with the

anterior cingulate cortex, but also directly in the frontal lobes. Hence, the degeneration of the mesocortical system contributes to
the mental dysfunction of PD patients. Overall, without the influence of either the basal ganglia-thalamocortical circuitry or the direct mesocortical dopaminergic innervation, the prefrontal cortex is forced to "reason through" challenging cognitive problems that are normally handled much more quickly and easily. Indeed, a plethora of neuropsychological studies have shown that about half of PD patients exhibit cognitive deficits that are similar to those found in patients who have suffered lesions in the frontal lobes. These patients generally perform well on visuospatial, memory, and attentional tasks that provide clear environmental guidelines for response formation or selection, but perform poorly on tasks that require them to rely entirely on internal cognitive resources. In particular, they have difficulty regulating mental "sets" by either shifting from one to another or by maintaining one despite interference from others.

The focus of Chapter 3 was on constructing a model of the normal syntactic comprehension system that could be used as a frame of reference for specifying and testing predictions about the nature of syntactic comprehension deficits in PD. Following current methodological practice in cognitive neuroscience, the model that I offered contains three different levels of analysisùstructure, processing, and neurobiology. The first level characterizes, from the point of view of RRG, the kind of syntactic and semantic structures that occur in various linguistic constructions, as well as the way in which the syntactic structure is mapped onto the semantic structure. The second level addresses the processing operations and resources that are dedicated to assembling syntactic and semantic structures and linking the former to the latter during the course of on-line sentence processing. More precisely, on the basis of both computational analyses and empirical psycholinguistic studies, I postulated a set of fairly specific parsing and linking operations as well as two processing resourcesùnamely, syntactic STM and attentional control. Finally, the third level is concerned with the brain areas that physically implement the major components of the syntactic comprehension system. I argued that the left perisylvian cortex is dominant for syntactic comprehension in the vast majority of the population (over 90%), but that it is difficult to find more narrowly defined cortical areas that are reliably associated with specific aspects of syntactic comprehension. Nonetheless, I suggested the following localization trends: parsing is typically implemented in the anterior perisylvian cortex, perhaps in the anterior third of the superior temporal cortex; interpretation is typically implemented in the posterior perisylvian cortex; syntactic STM is typically implemented in the pars opercularis of Broca's area; and attentional control is typically implemented in the anterior cingulate cortex, ventrolateral prefrontal cortex, and basal ganglia.

By combining this multilevel model of the normal syntactic comprehension system with the review of the neuropathology and neuropsychology of PD in the previous chapter, I was able to formulate a general hypothesis about the syntactic comprehension abilities of PD patients. I proposed that roughly 50% of PD patients should have difficulty under-standing constructions that depend on attentional control for regulating template selection and linking in a top-down manner. Such constructions often have complex constituent structure together with noncanonical linking which is signaled by few or no explicit mor-phosyntactic cues; hence, they require shifting from a routine processing strategy to a non-routine processing strategy and maintaining the latter in the face of interference from the former. The prediction that PD patients should have trouble with constructions of this type is motivated by two main considerations: first, attentional control for syntactic comprehen-sion is implemented in brain areas that are known to be affected in PD; and second, neuro-psychological studies of PD patients have shown that one of their major cognitive deficits involves an inability to regulate various kinds of mental "sets" in a top-down manner, espe-cially when there is little or no guidance from the environment. In addition to proposing that PD patients should have trouble with constructions that require attentional control, I also suggested that they should *not* have trouble with constructions in which the only com-plex processing factor is parsing, or with constructions that require noncanonical linking but provide multiple explicit cues for this. With regard to the processing resource of syn-tactic STM, I pointed out that a firm prediction as to whether it is impaired in PD patients cannot be made, because it is not known whether a circuit exists that relates the basal ganglia to the ventrolateral prefrontal cortex (where Broca's area resides), or whether this cortical region receives a heavy dopamineric innervation via the mesocortical projection system.

The second part of the thesis, which consists of Chapters 4 and 5, was devoted to testing the predictions set forth at the end of Chapter 3. In Chapter 4, I summarized and critically evaluated ten previous studies that have focused on syntactic comprehension deficits in PD. I argued that many of these studies suffer from problems involving experimental design, data analysis, and/or the explanation of performance profiles. However, I also showed that of the seven studies that are directly relevant to my predictions, all of them provide results that largely support the predictions. Not only do these studies demon-strate that roughly half of PD patients exhibit syntactic comprehension deficits, but they also indicate that the kinds of constructions that cause trouble for PD patients are precisely the ones that should do so, according to the hypothesis that the patients have an impairment of attentional control. For instance, Grossman et al. (1992b) found that PD patients per-formed significantly worse on center-embedded object-relatives than on center-embedded subject-relatives. In itself, this result is consistent with several hypotheses about the nature of the underlying deficitùit could involve complex parsing, noncanonical linking, syntactic STM, or attentional control. Other findings, however, appear to rule out all but the last possibility. Thus, the patients displayed variable performance when tested on the same materials in different sessions, which is hard to reconcile with the view that they have a parsing impairment. They also performed well on passive sentences, which is incom-patible with the view that they have an impairment of noncanonical linking. Furthermore, they performed well on an independent test of syntactic STM, which raises doubt about the possibility that they have an impairment of this processing resource. The most coherent explanation of the overall pattern of data, then, is that PD patients have an impairment of attentional control. With respect to neurobiological issues, the finding that syntactic STM appears to be intact suggests the absence of either a circuit relating the basal ganglia to the ventrolateral prefrontal cortex or a heavy dopaminergic innervation of the ventrolateral prefrontal cortex. However, this is by no means definitive, since it could be that Grossman et al.'s test of syntactic STM was not demanding enough to reveal a disturbance.

In Chapter 5, I presented four new studies that were designed to test PD patients on a variety of constructions which they have not been tested on before, and also to further explore the predictions of the hypothesis that such patients have an impairment of attentional control. These studies show that around half of PD patients exhibit the following dissociations: canonical subject-to-subject raising sentences (good) vs. noncanonical subject-to-subject raising sentences (bad); canonical object-to-subject raising sentences (good) vs. noncanonical object-to-subject raising sentences (bad); center-embedded subject-relatives (good) vs. center-embedded object-relatives (bad); terminal subject-relatives (good) vs. terminal object-relatives (bad); and subject-clefts (good) vs. object-clefts (bad). In addition, the studies show that PD patients typically do *not* exhibit dissociations between the following other constructions: transitive active sentences vs. passive sentences (foregrounding and backgrounding); active undergoer-control sentences vs. passive undergoer-control sentences; and actor-intransitive sentences vs. undergoer-intransitive sentences. Finally, the studies indicate that very few PD patients manifest problems on pairs of constructions that differ only with respect to whether they require syntactic STM. As I argued in Chapter 5, this entire set of results is consistent with the hypothesis that PD patients have an impairment of attentional control. By contrast, certain aspects of the results are inconsistent with three alternative hypotheses. First, the finding that PD patients generally do not perform significantly worse on passive undergoer-control sentences than on active undergoer-control sentences disconfirms the hypothesis that they have an impairment of complex parsing. Second, the finding that PD patients have good comprehension of foregrounding and backgrounding passive sentences, undergoer-intran-sitive sentences, and passive undergoer-control sentences disconfirms the hypothesis that they have an impairment of noncanonical linking. And third, the finding that PD patients tend to perform well on independent tests of syntactic STM disconfirms the hypothesis that they have an impairment of this processing resource (although, as noted earlier, it should be kept in mind that such patients might exhibit a decrement in performance if tested with more demanding measures of syntactic STM).

As this terse summary of the thesis has revealed, there is a substantial amount of support for the notion that the underlying cause of syntactic comprehension deficits in PD is an impairment of attentional control. Nonetheless, there are still a number of issues that I have not fully addressed or have not dealt with at all. I will conclude by mentioning several of them.

In developing a model of the normal syntactic comprehension system in Chapter 3, I did not elaborate the processing resource of attentional control in very much detail, even though in the second part of the thesis I used this component of the system as the foundation for characterizing the nature of the disorder in PD. As I pointed out in Chapter 3, very little research has been done on the role that attention plays in on-line sentence proces-sing. Carpenter and her colleagues have conducted a few interesting studies, but these studies are of limited value for two main reasons. First, although Just and Carpenter (1992) designed a computer model that simulates many effects of attentional demands on sentence processing, this model treats attentional control and short-term memory as a single computational resource with a common pool of activational capacity. Other researchers have also neglected to distinguish between the different processing tasks of these two resourcesùe.g, Caplan and Hildebrandt (1988) posit a highly general resource called the "syntactic comprehension workspace," and Frazier and Friederici (1991) posit a similarly general resource called "computational capacity." I have tried to go beyond this level of analysis by arguing on both engineering and neurobiological grounds that attentional control and syntactic short-term memory are functionally distinct processing resources which are implemented in distinct brain areas. The second limitation of the studies that Carpenter and her colleagues have done is that they have focused primarily on only one pair of constructionsùcenter-embedded subject-relatives and object-relatives. Extrapolating from these studies, I offered some suggestions about which other constructions do and do not require attentional control. These suggestions, however, need to be tested through psycholinguistic and neurolinguistic experimentation. Psycholinguistic paradigms that could be used include the following: measurement of reaction times, pupil dilation, or backward saccades during reading, and measurement of reaction times in dual-task situations. Several powerful neurolinguistic methodologies are also available: event-related potentials, functional MRI, MEG (i.e., magnetoencephalography), and PET.

Continuing with the topic of attentional control for syntactic comprehension, an interesting question which I did not discuss is whether this processing resource is specialized for the domain of language or applicable to other domains as well. Support for the view that attentional control is a general-purpose resource comes from Seidl et al.'s (1995) dual-task study in which sentence processing was the primary task and verbal or visuospatial processing was the secondary task (see º 4.3.4, pp. 210-13). The results showed that performance decreased for both PD patients and control subjects as both kinds of task became increasingly more challenging. This suggests the existence of a single executive attentional resource which has limited capacity and can be allocated to multiple domains simultaneously (see also Posner et al. 1987). Additional support for the general-purpose view of attentional control comes from the fact that the anterior cingulate gyrus, which is a well-established anatomical substrate for this processing resource, is activated in attention-demanding tasks regardless of the content domain (Devinsky et al. 1995; Frith & Grasby 1995). On the other hand, there is also evidence for the view that attentional control is not a completely general-purpose processing resource but is instead fractionated into a number of domain-specific components. Grossman et al. (1992b) provided some behavioral support for domain-specificity, since they found that some PD patients exhibited dissocia-tions between syntactic comprehension tests and neuropsychological tests of executive functioning. This finding must be interpreted cautiously, however, because as I argued in my evaluation of this study, none of the neuropsychological tests that Grossman et al. used focused on set-regulation, which is the aspect of attentional control that I suggested is most important for syntactic comprehension. Neurobiological support for multiple domain-specific attentional systems comes from the finding that even though the anterior cingulate gyrus is reliably activated in different kinds of attention-demanding tasks, distinct subareas of this brain region tend to be activated for visuospatial and linguistic tasks (Frith & Grasby 1995). Moreover, at a finer anatomical level of analysis, researchers have found distinct sets of cortical columns in the anterior cingulate gyrus of monkeys such that some columns are connected with the parietal lobeùa region that is involved in visuospatial processingù while other columns are connected with the ventrolateral prefrontal cortexùa region that is involved in linguistic processing (Vogt et al. 1992; Posner & Raichle 1994). Further support for the view that attentional control is domain-specific comes from computational considerations. If it is the case that the function of attentional control for syntactic comprehension is to influence the selection of templates and associated linking strategies in a top-down manner, the attentional component must contain a considerable amount of know-ledge about the grammar of the language. For example, it must know that for subject-object relative clauses like *The boy that the girl chased knows me*, the correct template and linking strategy is the one that maps the head NP onto the undergoer macrorole and the preverbal NP onto the actor macrorole. This kind of knowledge is necessarily domain-specific, and there does not appear to be any way in which attentional control could accom-plish its task without such knowledge. I conclude, therefore, that although attentional control for syntactic comprehension is in many respects functionally and neurobiologically similar to attentional control for other domains, it is nonetheless specialized for dealing with the domain of sentence processing.

This view leads directly to a series of very difficult questions about the nature of this processing resource: Exactly what sort of knowledge does it contain? How is this knowledge organized and applied? How does it develop during the course of language acquisition? I will not attempt to answer any of these questions in detail now, but I will suggest some directions that future research could take. Grafman (1995) has developed a represen-tational theory of the prefrontal cortex which states that this enormous part of the brain stores high-level representations called "managerial knowledge units" (MKUs) and "struc-tured event complexes" (SECs), analogous to the frames, schemas, scripts, story gram-mars, etc. that have been discussed in the cognitive science and artificial intelligence litera-ture. MKUs and SECs are organized in a hierarchical, domain-specific fashion. For instance, there are domains for social behavior, appetitive behavior, linguistic behavior, mechanical behavior, and so on. Each of these domains is further subdivided, so that, for instance, the social domain consists of subdomains for mating, status-striving and reputa-tion maintenance, reciprocal exchange of favors, etc. The subdomain of mating itself consists into collections of MKUs and SECs for dating behavior, marriage behavior, seduction behavior, sexual behavior, etc. Grafman describes how MKUs and SECs are structured, how they are processed, how they interact with one another, how they develop, and how they are impaired following brain damage. This general theory of prefrontal cortical function leads to the possibility that the knowledge contained in the attentional component of the syntactic comprehension system is organized in terms of "packets" of information about the structural and processing requirements of not only hierarchically arranged categories of grammatical constructions (e.g., relative clauses, raising construc-tions), but also very specific constructions (e.g., subject-object relatives). These packets of information may develop during language acquisition through a process of "redescrip-tion" and "explicitation" of regularities that are identified in the grammar of the language (Karmiloff-Smith 1992).

Shifting to other topics, another issue that warrants further investigation is the status of syntactic STM in PD patients who exhibit syntactic comprehension deficits. Two different tests of this processing resource have been used. First, both Grossman et al. (1992b) and I (in Study 3) evaluated the ability of PD patients to answer probe questions that focus on either adjacent or nonadjacent portions of target sentencesùe.g., adjacent (syntactic STM not required): *The girl pushed the boy that is tall. Who is tall?;* nonadjacent (syntactic STM required): *The girl that pushed the boy is tall. Who is tall?* Only three of the 20 patients in Grossman et al.'s study performed significantly worse on the latter construction than on the former, and none of the 15 patients in my study did so. Second, in Study 2 I evaluated the ability of PD patients to answer probe questions for overt pronoun and zero anaphora sentencesùe.g., overt pronoun (syntactic STM not required): *The boy helped the girl and then he watched TV. Who watched TV?;* zero anaphora (syntactic STM required): *The boy helped the girl and then watched TV. Who watched TV?* Only two of the nine patients performed significantly worse on the latter construction than on the for-mer. These results suggest that syntactic STM is not affected in the vast majority of PD patients. However, as I have pointed out several times, neither of these tests places heavy demands on syntactic STM. Thus, it could be that further experimental work using more challenging materials will uncover at least a mild deficit. The normal syntactic comprehen-sion system is designed to handle even very long-distance dependencies in sentences, as illustrated in the following examples where the underlined stretch of words represents the portion of the sentence over which syntactic STM is required: *The girl wondered who John believed that Mary claimed that the baby* *saw; Reverse the clamp that the stainless steel hex-head bolt extending upward from the seatpost yoke holds in place* (from Pinker 1994: 220-1). It would certainly be interesting to find out whether PD patient have the syntactic STM capacity necessary to process sentences like these.

Yet another issue that constitutes a topic for future research involves the relation between cognitive deficits and syntactic comprehension deficits in PD. Lieberman et al. (1992), Grossman et al. (1992b), and McNamara et al. (in press) included in their studies linguistic tests as well as standardized neuropsychological tests. Lieberman et al. found significant correlations between, on the one hand, deficits in speech production and syntactic comprehension and, on the other hand, deficits on tests of set maintenance (the Odd Man Out Test) and concentration (the backward part of the Digit Span Test) on the other hand. Such a correlation is exactly what one would expect, given the neuropathology and neuropsychology of PD; however, as I pointed out in my evaluation of Lieberman et al.'s study, the results are of limited value because the test of syntactic comprehension was not designed to isolate any specific processing factors, such as complex parsing, noncanonical linking, syntactic STM, or attentional control. Grossman et al. (1992b) administered a large battery of neuropsychological tests to their patients, but found very few correlations between the patients' performance on these tests and their performance on the tests of syntactic comprehension. The problem with this study is the opposite of the problem with Lieberman et al.'s: the test of syntactic comprehension was, for the most part, well designed, but none of the neuropsychological tests were designed specifically to measure the ability to use internal attention control for set regulation. If such tests had been used, significant correlations might have appeared. Finally, McNamara et al. (in press) compared the performance of PD patients on both sentence processing tests and the Wisconsin Card Sort Test, which is an excellent measure of working memory and attentional control. However, the researchers found only marginal correlations, most likely because, as I argued in Chapter 4, their tests of sentence processing did not really

tap the processing resources of memory and attention. In planning my own Study 3, I originally intended to include a version of the Stroop test similar to the version that Brown and Marsden (1988b) used (see º2.2.3, pp. 37-8), the reason being that this test places a heavy load on internal attentional control for inhibiting a routine processing strategy and promoting a nonroutine processing strategyùthe same kind of attentional control that I suggested is required for understanding certain kinds of grammatical constructions. Ultimately, however, I was
not able to administer this test to the PD patients who participated in the study. Thus, it remains for future research to determine the extent to which the performance of PD patients on syntactic comprehension tests correlates with their performance on tests of prefrontal function, especially attentional control.

Another issue has to do with the kinds of methodologies that have been used to evaluate the syntactic comprehension abilties of PD patients. All of the studies that have been done so far, with the possible exception of Seidl et al. (1995), have employed off-line paradigms such as requiring patients to respond to probes or match sentences with pictures. These studies have revealed deficits that can be accounted for best in terms of an impairment of attentional control. However, it is conceivable that the deficits do not exist at the level of on-line sentence processing, but rather at the level of so-called "post-interpretive proces-sing," that is, the level at which attentional resources must be allocated over the final repre-sentation of a sentence in order to carry out the task of responding to a probe or matching the sentence with the appropriate picture. In a series of detailed case studies of aphasic patients, Tyler (1992) found dissociations of precisely this sortùnamely, intact on-line processing but impaired off-line processing. She did not provide any lesion data about her patients, however, which makes it impossible to know whether the brain areas that are affected in these patients are similar to those that are affected in PD patients. Nonetheless, the fact that some brain-damaged patients exhibit such dissociations indicates that it is very important for future investigations of the sentence processing abilities of PD patients to use on-line paradigms. Several paradigms of this kind are available. Most of them involve reaction times for button-presses, however, and this might present a problem for PD patients, since they have movement disorders that include slowness of execution. The ideal on-line paradigm for investigating PD patients is probably event-related potentials, since this approach does not require any motor response whatsoever. In fact, it would be very interesting to measure ERPs in PD patients as they process center-embedded subject-relatives and object-relatives, and then compare the results with the study of these same constructions that King and Kutas (1995) conducted. The prediction is that if PD patients have an impairment of the on-line application of attentional control, they should exhibit ERP profiles similar to, but more exaggerated than, the profiles exhibited by the "low capacity" subjects in King and Kutas's study (see º3.2.2.2, p. 102, and º3.3.2.5, pp. 138-9). On-line techniques such as ERPs could also be used to explore another possible cause of syntactic comprehension deficits in PDùnamely, slowed information processing. The final issue that I will discuss is about how PD patients who speak other languages might perform on syntactic comprehension tests. In particular, it is important to note that in many other languages, raising constructions and relative clause constructions often provide explicit cues that signal the appropriate linking pattern. Consider, for example, the following two raising sentences from Icelandic (Van Valin & LaPolla, in press):

a. Harald-ur virthist haf-a far-ith heim.
Harold-MsgNOM seem.3sgPRES have-INF go-PSTP home
'Harold seems to have gone home.'

b. Peim virthist hafa pott Olaf-ur leithinleg-ur.
3plDAT seem.3sgPRES have.INF think.PSTP Olaf-MsgNOM boring-MsgNOM
'They seem to have found Olaf boring.'

In (a) the pivot NP receives nominative case, which is the default. As a result, it is not immediately clear what semantic role this NP will have in the dependent core. The proper interpretation can only be determined when the relevant material in the dependent core is encountered. Thus, in order to process Icelandic raising sentences that have normal case-marking in the matrix core and noncanonical linking in the dependent core, attentional control might be needed to regulate the selection of the appropriate template and linking strategy. One would therefore expect PD patients to have difficulty understanding such sentences. By contrast, in (b) the pivot NP is "quirky" case-marked as dative, since the verb *pott* requires this. As a result, it is clear from the outset what semantic role the NP will play in the dependent core, and hence attentional control is not needed, even when the linking pattern in the dependent core is noncanonical. PD patients should therefore not have trouble comprehending such sentences. Other languages, especially those that have rich inflectional systems, provide explicit morphological cues for parsing and interpretation. For instance, in German all relative clauses begin with a pronoun which codes for the role that the head NP plays in the relative clauseùnominative, accusative, dative, or gen-itive. Such cues make on-line processing easier for the listener and hence diminish the need for top-down attentional intervention. An important direction for future research is to investigate whether PD patients are able to understand such constructions despite having an attentional impairment.

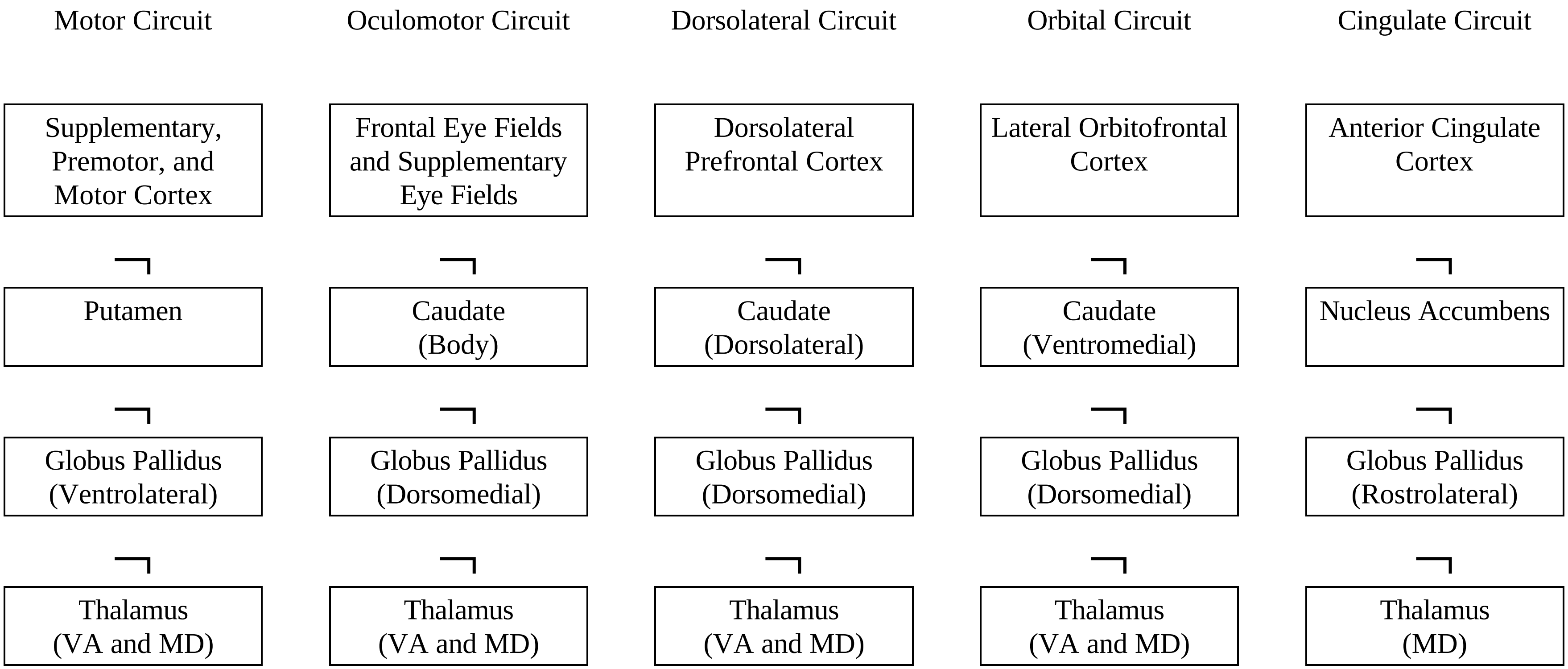

Figure 6A: Organization of the five basal ganglia-thalamocortical circuits that have been identified. VA indicates ventral anterior; MD, medial dorsal. (Adapted from Cummings 1993)

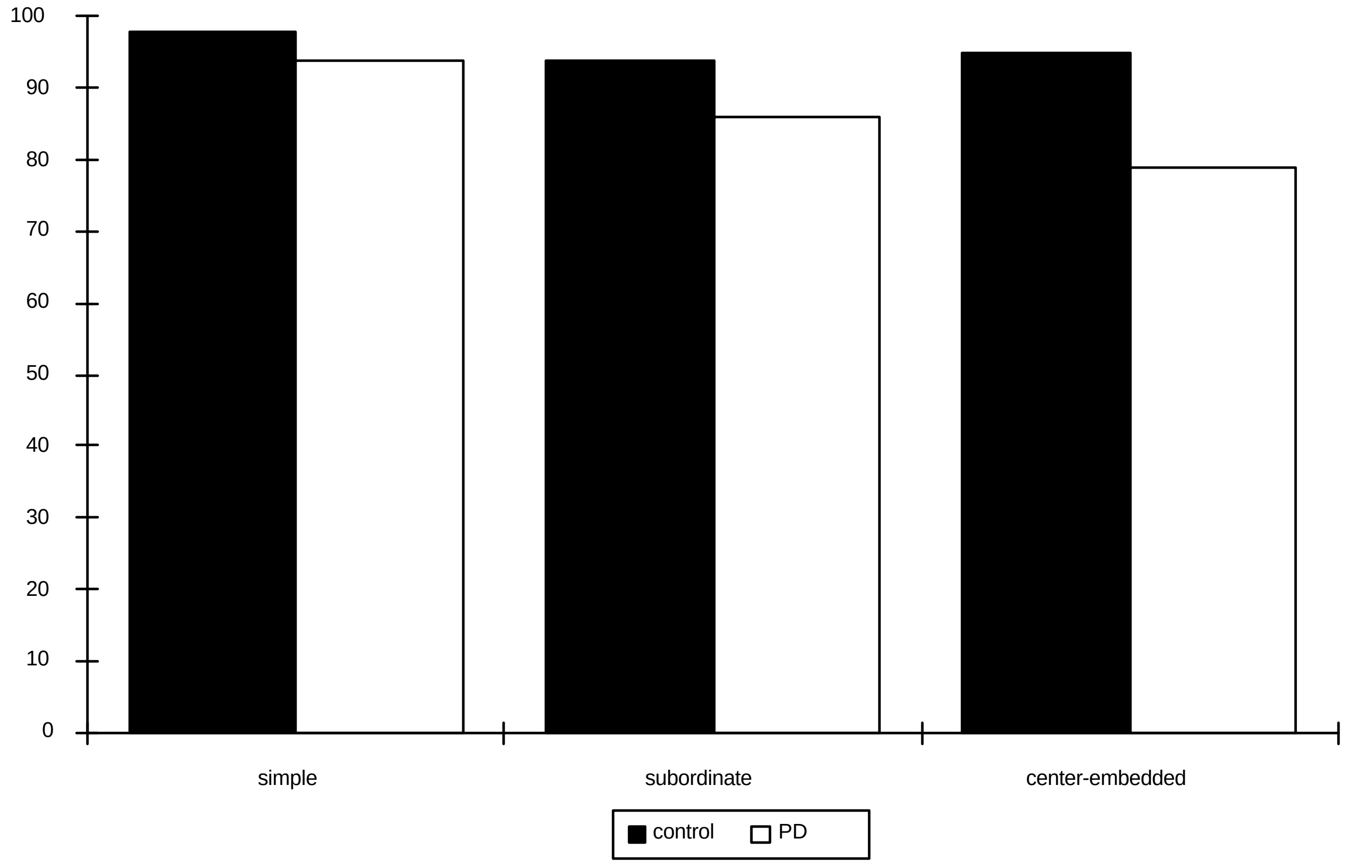

Figure 24: Comprehension of sentences that vary in grammatical complexity (Grossman et al. 1992b)

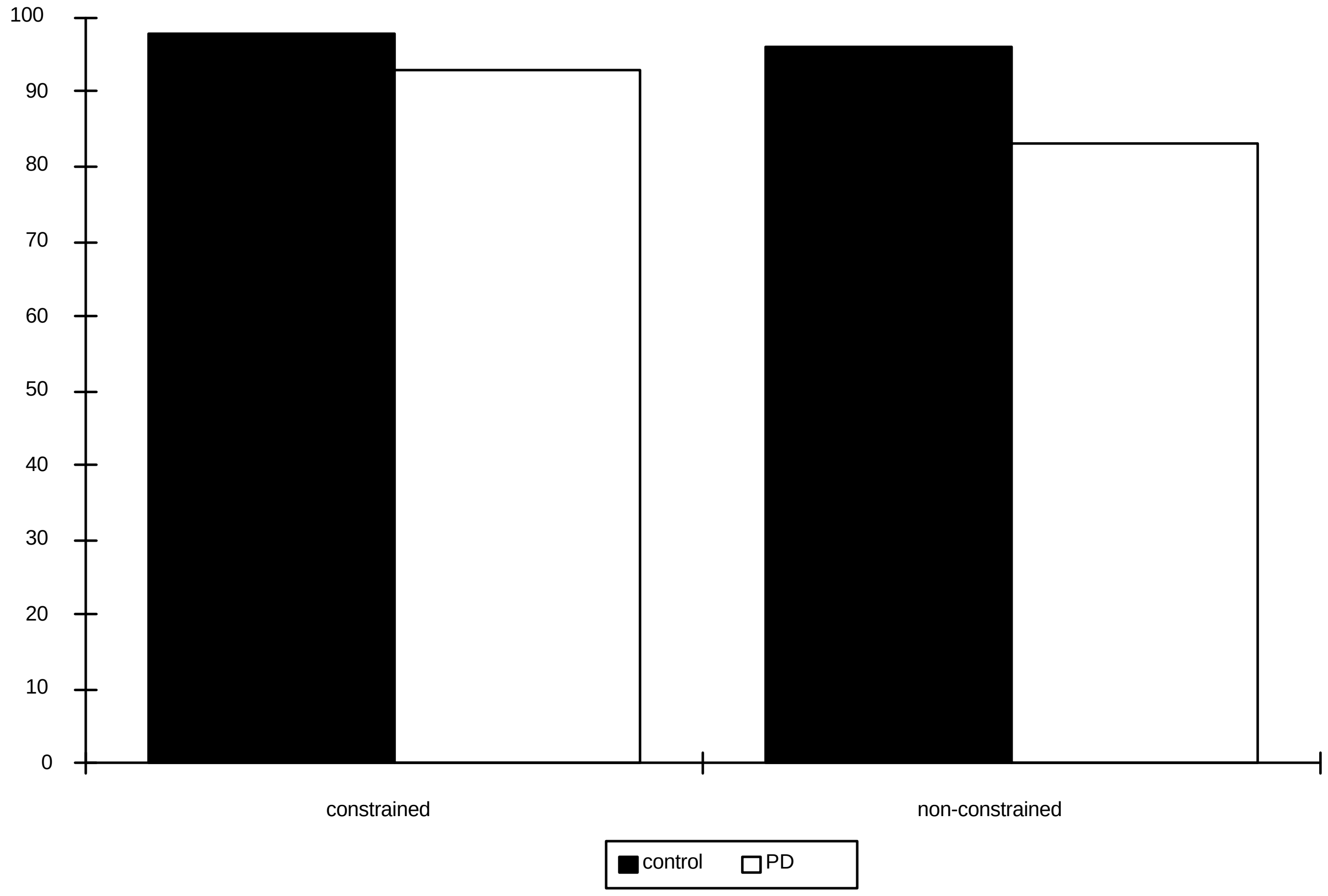

Figure 25: Comprehension of sentences that vary in semantic constraint (Grossman et al. 1992b)

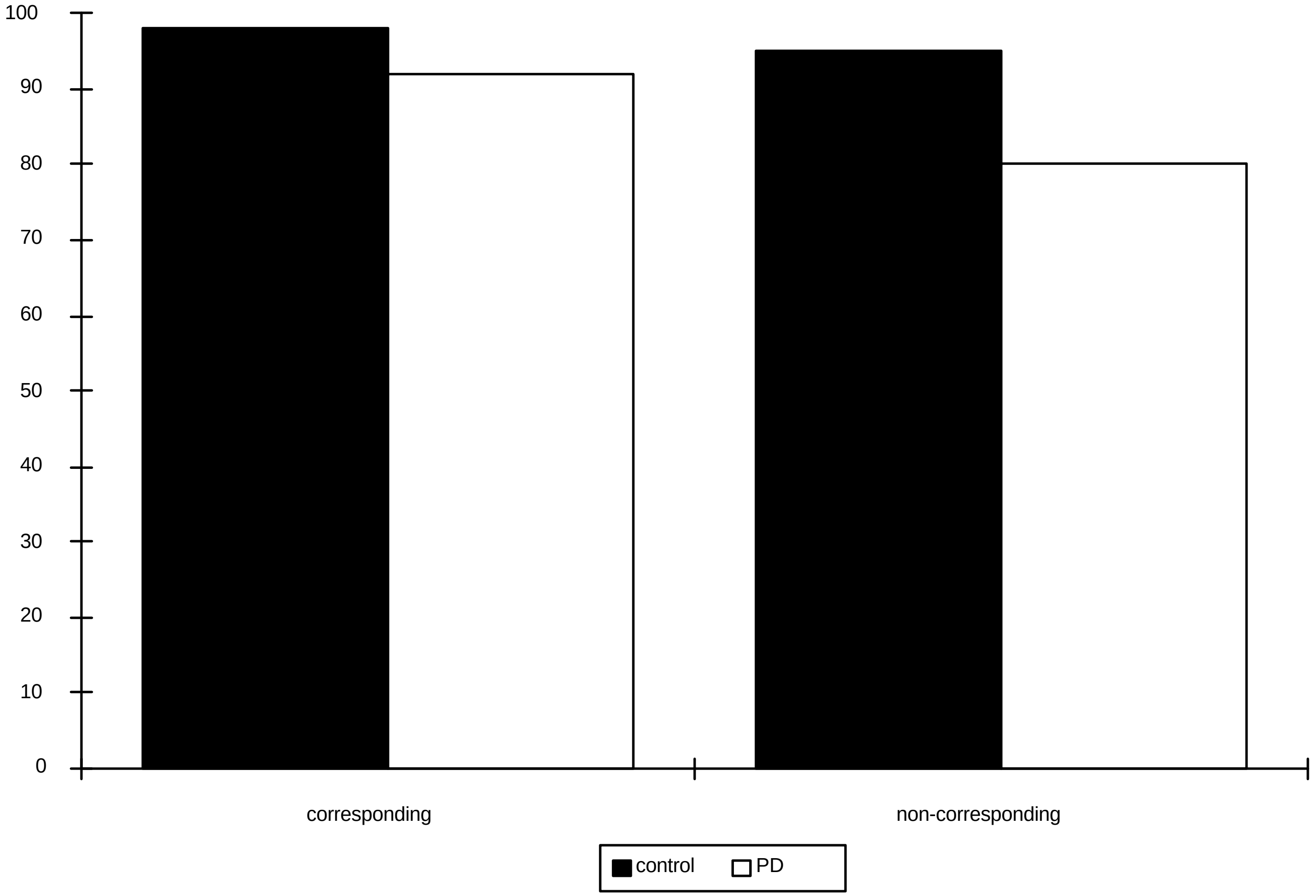
100
90
80
70
60
50
40
30
20
10
0
corresponding
non-corresponding
control
PD

Figure 26: Comprehension of sentences that vary in voice correspondence with probes (Grossman et al. 1992b)

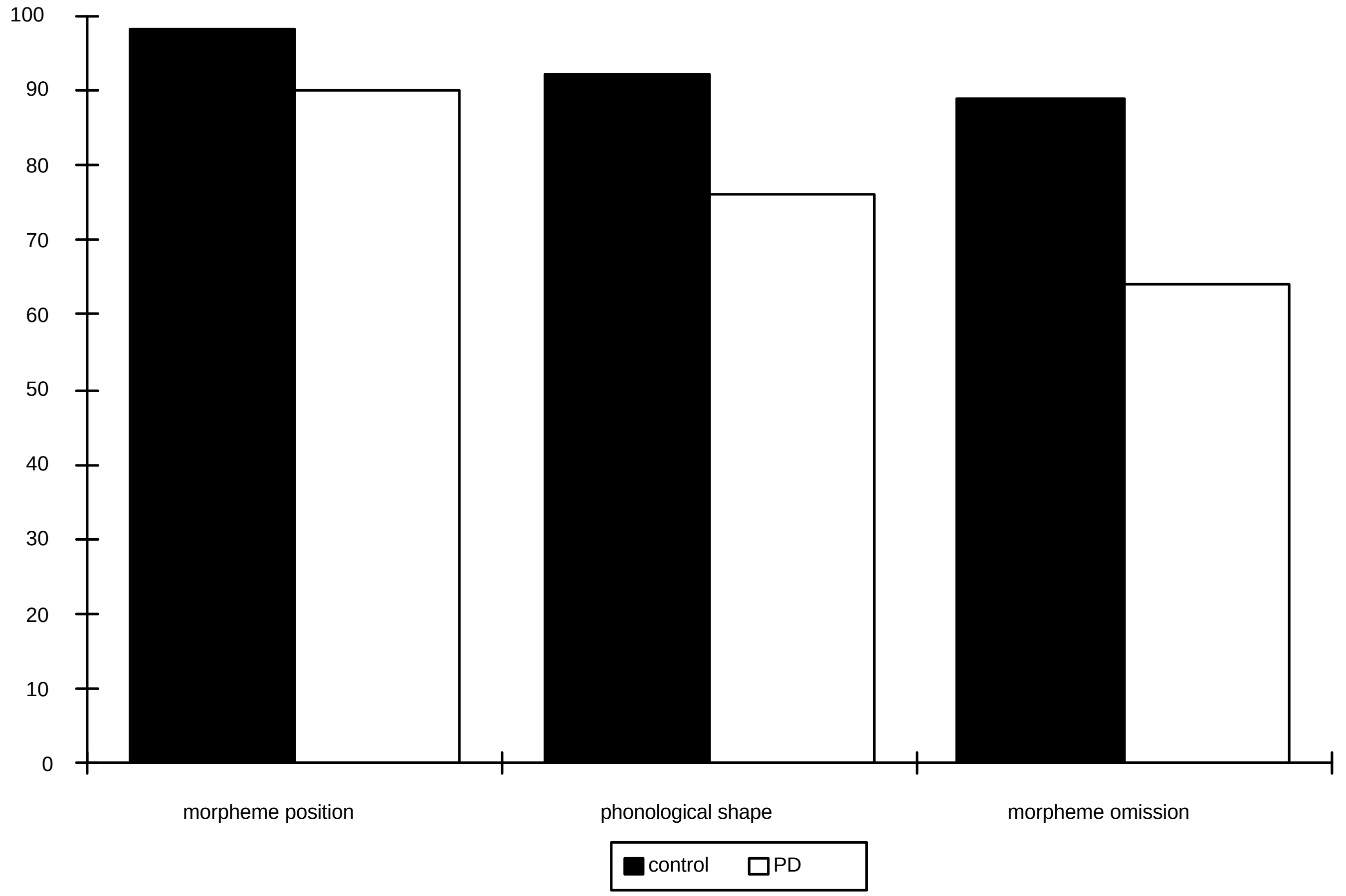
100
90
80
70
60
50
40
30
20
10
0
morpheme position
phonological shape
morpheme omission
■ control
□ PD

Figure 27: Detection of errors in sentences (Grossman et al. 1992b)

Table 13: Individual patients profiles (Grossman et al. 1993b)

Figure 35: Sentence comprehension performance "on" and "off" dopamine supplementation (Grossman, in press)

	Construction Type									
PD pts.	SS	SO	OS	OO	SC	OC	UCa	UCp	no STM	STM
HG	100	100	100	100	100	100	100	90	100	100
DJ	100	80	100	80	100	70	100	100	100	100
AW	100	40	100	100	100	100	100	100	100	100
JE	100	100	100	90	100	100	100	60	100	100
JD	100	100	100	100	100	100	100	100	100	100
AK	100	40	90	90	100	60	100	60	60	100
AD	100	90	100	90	100	100	90	90	100	100
CV	90	40	100	60	100	50	80	80	100	100
RK	100	100	100	100	100	100	100	100	100	100
WP	90	90	100	90	100	100	100	90	100	100
JN	90	60	100	70	100	100	90	90	100	100
JS	80	50	70	30	90	30	30	40	100	100
WS	100	100	100	100	100	100	100	100	100	100
RZ	100	50	100	40	100	60	100	90	100	100

RD	100	100	100	100	100	100	100	100	100	100
Mean	*96.7*	*76*	*97.3*	*82.7*	*99.3*	*84.7*	*92.7*	*86*	*97.3*	*100*
Controls										
1	100	100	100	100	100	100	100	90	100	100
2	100	100	100	100	100	100	100	100	100	100
3	100	90	100	90	100	100	100	100	100	100
4	100	100	100	100	100	100	100	90	100	100
5	100	100	100	100	100	100	100	100	100	100
Mean	*100*	*98*	*100*	*98*	*100*	*100*	*100*	*96*	*100*	*100*

Attentional Control

Syntactic STM Parsing Interpretation

	Construction Type															
Interpretive Operation	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Canonical linking	x		x		x		x		x		x		x		x	
Noncanonical linking		x		x		x		x		x		x		x		x
Cross-core linking: link NP in matrix core to macrorole associated with LS of predicate in dependent core										x		x	x	x		
Cross-core linking when matrix core NP has already been linked to macrorole associated with LS of matrix core predicate													x	x		
Cross-core linking guided by semantic properties of predicate in matrix core ("theory of control")													x	x		
Cross-core linking when matrix core NP cannot be linked to macrorole associated with LS of matrix core predicate										x		x				
On basis of [0MR] feature, override normal process of linking pivot NP to macrorole associated with LS of predicate in matrix core									x	x						
Cross-clausal linking: link NP in matrix clause to macrorole associated with LS of predicate in peripheral clause			x	x	x	x	x	x								
Cross-clausal linking when matrix clause NP has already been linked to macrorole associated with LS of predicate in matrix clause					x	x	x	x								
Cross-clausal linking when matrix clause NP has not yet been linked to macrorole associated with LS of matrix clause predicate			x	x												

Table 2: Interpretive Operations for Constructions (Abbreviations: A=active, P=passive, SS=subject-subject

relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc= canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa=active undergoer control, UCp=passive undergoer control, AI=actor intransitive, UI=undergoer intransitive)

	Construction Type															
Operation/Resource	A	P	SS	SO	OS	OO	SC	OC	SSc	SSn	OSc	OSn	UCa	UCp	AI	UI
Assemble simple constituent structure	x	x													x	x
Assemble complex constituent structure			x	x	x	x	x	x	x	x	x	x	x	x		
Canonical linking	x		x		x		x		x		x		x		x	
Noncanonical linking		x		x		x		x		x		x		x		x
Cross-core linking: link NP in matrix core to macrorole associated with LS of predicate in dependent core										x		x	x	x		
Cross-core linking when matrix core NP has already been linked to macrorole associated with LS of matrix core predicate													x	x		
Cross-core linking guided by semantic properties of predicate in matrix core ("theory of control")													x	x		
Cross-core linking when matrix core NP cannot be linked to macrorole associated with LS of matrix core predicate										x		x				
On basis of [0MR] feature, override normal process of linking pivot NP to macrorole associated with LS of predicate in matrix core									x	x						
Cross-clausal linking: link NP in matrix clause to macrorole associated with LS of predicate in peripheral clause			x	x	x	x	x	x								
Cross-clausal linking when matrix clause NP has already been linked to macrorole associated with																

LS of predicate in matrix clause					x	x	x	x								
Cross-clausal linking when matrix clause NP has not yet been linked to macrorole associated with LS of matrix clause predicate			x	x												
Syntactic STM			x	x		x		x		x		x		x		
Attentional control				x		x		x		x		x				

Table 5: Operations and Resources for Constructions (Abbreviations: A=active, P=passive, SS=subject-subject relative, SO=subject-object relative, OS=object-subject relative, OO=object-object relative, SC=subject cleft, OC=object cleft, SSc=canonical subject-to-subject raising, SSn=noncanonical subject-to-subject raising, OSc=canonical object-to-subject raising, OSn=noncanonical object-to-subject raising, UCa=active undergoer control, UCp=passive undergoer control, AI=actor intransitive, UI=undergoer intransitive)

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