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AGRAMMATIC APHASIA AS A TIMING DEFICIT

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Agrammatic Aphasia as a Timing Deficit

AGRAMMATIC APHASIA AS A TIMING DEFICIT

Een wetenschappelijke proeve
op het gebied van de Sociale Wetenschappen
in het bijzonder de Psychologie

Proefschrift

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aan mijn ouders

voor Chris

Chapter 1

Introduction

"The dimensions of language patterns
are entirely of a temporal nature.
This seems logical enough, a priori,
since utterances progress through time;
however, it is difficult for our imagination
to carry this thought to its logical conclusion."

E.H. Lenneberg, 1967.

Imagine a computer programmer, a computational linguist for that matter, who has set himself to the task of developing a computer program that can understand as well as produce human sentences. Though by no means a trivial task, basically, what that programmer will do is the following. He will equip his program with knowledge about the linguistic units that are relevant to the task, in particular, knowledge about phonological, morphological, syntactic and semantic units. And then, he will proceed to implement the rules that specify the relationships among the linguistic units. Running the program, the rules will map input words to messages at the meaning level, and vice versa, messages at the meaning level to output words. A tacit assumption that the programmer will make is that at each stage during the running of the program the rules have access to the units to which they are applied. Indeed, an assumption that is usually met in all programming domains. Now, however, suppose that we make the task of the programmer more difficult by making the intermediate products of the computer program subject to a decay process, so that these products are not available indefinitely but only during a limited duration. In this situation, it is no longer guaranteed that the program will succeed in doing its job because the intermediate results of the computer program may disappear before the rules have had a chance to operate on them. In order to ensure that the program keeps working properly, the programmer may do one of two things. He may (1) increase the processing speed of the computer to such an extent that decay does not get a chance to become effective, or (2) decrease the decay rate in such a manner that the program still works given the computer's processing speed. Most likely, the programmer will try to find some optimal balance between the processing speed and the decay rate. Before this optimal balance is achieved, however, the programmer will have realized that even the slightest alteration in the temporal characteristics of the computer on which the program runs (i.e., the processing speed and the decay rate), will cause his program to fail. Applying this thought experiment to real humans, it seems an intriguing possibility that aphasic symptoms may be caused by a pathological alteration in the temporal processing characteristics of the brain. Indeed, this possibility formed the major motivation for the research that is reported in this thesis. In particular, the above logic will be applied to the syndrome of agrammatism, or Broca's aphasia, as it is also called. Why Broca's aphasia? As will be more clearly described below, Broca's aphasics typically have problems with syntactic processing in language production and, often, also in language reception. One of the theses defended in this dissertation is that, especially, syntactic processing is vulnerable to temporal changes because it involves hierarchical and, therefore, deep and time consuming processing.

In the remainder of this chapter, the symptoms of Broca's aphasia will be defined. Moreover, it will be argued that Broca's aphasia can be best characterized as a deficit in the processing of syntactic knowledge rather than a deficit in the representation of syntactic knowledge. After these preliminaries, Kolk and van Grunsven's timing deficit theory of Broca's aphasia, which formed the starting point of this dissertation, will be introduced. This will be done in the context of a framework which delineates the various theoretical possibilities with respect to the exact nature of the processing deficit as well as the linguistic elements affected by this processing deficit. From a review of the empirical research pertaining to these issues, it will become clear that relatively little research has been designed to probe into the exact nature of Broca's aphasia, a gap which the research reported in this dissertation was intended to fill. This introductory chapter will end with an overview of the research including a description of its goals and of the hypotheses tested.

1.1 BROCA'S APHASIA

Broca's aphasia is primarily caused by brain damage to the anterior parts of the left hemisphere. One of its clinically most striking features is the tremendous effort by which communication is achieved. Though communication is meaningful, the speech rate tends to be rather slow with long pauses between words and a poor sentence melody. Moreover, from a syntactic viewpoint, communication is achieved through simple means. Typically, the utterances of Broca's aphasics are short and show a lack of variety in syntactic structure with only simple structures being produced and with many function words and inflections being omitted, often resulting in speech with a telegraphic-like quality. In extreme cases, only one word utterances are produced, usually content words which emphasize the key elements of the message. Broca's aphasics' agrammatism in spontaneous speech is often contrasted with the paragrammatism of Wernicke's aphasics (Kleist's terminology, 1914), which is characterized by frequent substitutions of function words and inflections in the context of a fluent speech rate and more complex but sometimes erroneous (Heeschen, 1985) syntactic constructions containing embeddings and conjunctions. Both Broca's and Wernicke's show many phonemic paraphasias in their spontaneous speech, but only Wernicke's tend to also show semantic paraphasias and may also show semantically empty speech (Goodglass and Kaplan, 1983).

Part of the definition of the syndrome of Broca's aphasia is that auditory comprehension has to be relatively intact (Goodglass and Kaplan, 1983) contrary to what is the case for Wernicke's aphasics. Indeed in daily conversation, though speaking agrammatically and with a lot of effort, Broca's aphasics seem to have no severe problems in understanding what was said and tend to respond appropriately. Broca's aphasics' understanding, however, seems to rely predominantly on non-syntactic cues, such as lexical-semantic ones and cues provided by the discourse context. When the understanding of sentences hinges solely upon the correct analysis of syntactic structure, it often fails. This phenomenon is called agrammatic comprehension. Agrammatic comprehension has been known since the beginning of this century (Bonhoeffer, 1902; Salomon, 1914) and has been extensively investigated in carefully controled group studies starting from the seventies by means of the sentence-picture matching paradigm (Ansell and Flowers, 1982; Blumstein, Goodglass, Stadlender and Biber, 1983; Blumstein, Katz, Goodglass, Shrier, and Dworetzky, 1985; Caplan and Hildebrandt, 1988; Caramazza and Zurif, 1976; Friederici and Frazier, 1992; Goodglass et al., 1979; Heeschen, 1980; Heilman and Scholes, 1976; Kolk and Friederici, 1985; Kolk and van Grunsven, 1985; Naeser et al., 1987; Parisi and Pizzamiglio, 1970; Schwartz, Saffran, and Marin, 1980). In the sentence-picture matching paradigm, a subject is presented with a spoken or written sentence and has to choose from a set of picture alternatives that picture which depicts the correct meaning of the sentence, where sentence meaning refers to the thematic role relations among the major constituents (e.g., Actor, Theme, Experiencer, Source, Location). The syntactic problems of Broca's aphasics are apparent from the fact that they typically have many more problems with reversible than with irreversible sentences. Contrary to irreversible sentences, reversible sentences provide no lexical-semantic but only syntactic cues to assign thematic roles, so that, in the case of an inability to use the latter type of cues, the thematic roles may be reversed. Compare, for example, the passive sentences "the apple was seen by the man" and "the woman was seen by the man." In the first, irreversible sentence, the lexical semantics of the verb, namely, the selection restriction that "to see" requires an animate agent, provides a definite cue that "the man" must be the actor, since only "man" but not "apple" is animate. In the second, reversible sentence, there is no such definite cue to thematic role assignment, as both "the woman" and "the man" are animate. In the case where a Broca's aphasic fails to syntactically recognize this passive sentence, he may erroneously reverse the thematic roles, that is, assign the actor role to "the woman" and the theme role to "the man."

Two points about agrammatic comprehension must be made. First, agrammatic comprehension is not unique to Broca's aphasia. It has also been observed in Wernicke's and Conduction aphasia (Blumstein et al., 1983; Goodglass et al., 1979; Heeschen, 1980; Heilman and Scholes, 1976; Kolk and Friederici, 1985). Second, though in the majority of cases Broca's aphasics' agrammatism in production is paralleled in comprehension, this is not always the case. Several investigators (Kolk, van Grunsven, and Keyser, 1985; Miceli, Mazzucchi, Menn, and Goodglass, 1983; Nespoulos et al., 1988) have reported cases of Broca's aphasics which were agrammatic in production but not in comprehension. Though not the topic of this dissertation, both points will be addressed briefly in a speculative manner.

To begin with the first, the presence of agrammatic comprehension not only in Broca's, but also in Wernicke's and Conduction aphasics may be interpreted along the lines set out by Goldstein (1948). Goldstein attributed Conduction aphasia to a lesion involving the central language area, which he localized roughly in between Broca's and Wernicke's areas, and named Conduction aphasia accordingly "central aphasia." Goldstein speculated that lesions to the central language area resulted in problems with "the fundamental syntactical form of inner speech" (p. 98, see also p. 229). Goldstein attributed Broca's aphasia, which he named "central motor aphasia," to a lesion which encompassed the central language area and Broca's area and which was supposed to cause additional problems with the motor programming of words. Goldstein attributed Wernicke's aphasia, which he named "central sensory aphasia," to a lesion which encompassed the central language area and Wernicke's area and which was supposed to cause additional problems with the understanding of word phonology (i.e., in its extreme form causing word deafness). It could be that these additional problems are responsible for the specific way that Broca's and Wernicke's aphasics' syntactic problems manifest themselves, that is, as agrammatism and paragrammatism, respectively. However, it follows from Goldstein's view that the primary syntactic impairment in both patient types must be the same. Supporting evidence comes from a sentence-picture matching study by Kolk and Friederici (1985) and, as will be seen, from a CLOZE experiment that is reported in this dissertation in chapter five.

Let us now turn to the second point, the occurrence of cases of Broca's aphasia with agrammatic production but without agrammatic comprehension. This could imply that syntax instead of being represented centrally (Berndt and Caramazza, 1980) is represented for production and comprehension separately. However, for two reasons it might be premature to give up the notion of a centrally represented syntax.The first reason is a methodological one.

The number of grammatical morphemes omitted from spontaneous speech is usually interpreted as a reliable indicator of the severity of the syntactic impairment in production. However, as Kolk et al. (1985) suggest, this may not always be warranted. Omissions, instead of being the direct result of the underlying impairment, may be the indirect result of "preventive adaptation", that is, a patient's strategic use of elliptical utterances in order to prevent the negative consequences of the syntactic impairment (see below) and keep communication going. In most patients, the tendency to resort to preventive adaptation and the omission rate resulting from it is likely to be sensitive to the severity of the underlying syntactic impairment. However, in occasional patients, a high omission rate may be the result of a relatively strong tendency to resort to preventive adaptation in spite of the presence of only a mild syntactic impairment (for supporting evidence see Hofstede and Kolk, in press, and Kolk et al., 1985). Such a mild impairment may not be severe enough to lead to errors on sentence-picture matching tasks, giving the false impression of a patient who is agrammatic in production but not in comprehension. There is a second reason why it might be premature to give up the notion of a centrally represented syntax based on the occurrence of such patients. The real-time application of syntactic knowledge during production may simply be more difficult than during comprehension. In production, at least a subset of the conceptual elements forming the message to be conveyed is inputted simultaneously into the formulator (Kempen and Hoenkamp, 1987), while, in comprehension, the input of words into the parser proceeds completely serially, form left to right. Due to these differences in the timing of the input, there is probably more simultaneity of syntactic processing during production than during comprehension. This in turns might imply a heavier demand for syntactic resources during production than during comprehension, making production more vulnerable to brain damage than comprehenion.

1.2 PRESERVATION OF SYNTACTIC KNOWLEDGE

A major contribution of modem psycholinguistic research on Broca's aphasia has been to show that patients afflicted with this syndrome do not suffer from a loss of structural, syntactic knowledge but instead have a problem in processing this type of knowledge. "Loss" is defined here as the permanent, functional unavailability of knowledge to the processor due either to the disappearance of that knowledge from memory or to a permanent access failure.

An often cited study demonstrating preservation of syntactic knowledge in Broca's aphasics stems from Linebarger, Schwartz, and Saffran (1983). In their study, four cases of Broca's aphasia appeared to be able to quite reliably (i.e., on average 82 % correct) distinguish syntactically well-formed sentences from ill-formed sentences in an acceptability judgement task involving a wide variety of violation types. This result came somewhat as a surprise, because the same four patients that were tested by Linebarger et al. had shown virtually no syntactic understanding of passive sentences or sentences with a locative preposition in a sentence-picture matching study by Schwartz et al. (1980). The observed inter-task variation seems to point to a processing deficit rather than a knowledge representational deficit. Depending on the task requirements it seems that syntactic knowledge can be brought into play to different degrees. One way to think of this is in terms of the trade-off hypothesis proposed by Linebarger et al.. According to this hypothesis, Broca's aphasics could suffer from a limitation in syntactic-semantic processing resources that goes unnoticed when mainly syntactic analysis is required as in syntactic judgement but that comes to the foreground when additional semantic analysis is required as in sentence-picture matching. An alternative explanation offered by Linebarger et al. is that the processing of syntactic knowledge itself is intact but that patients have a problem in mapping the products of this analysis onto semantics. The rationale for this so called mapping hypothesis (see Schwartz, Linebarger, Saffran, and Pate, 1987, for an extension) is that comprehension but not judgement requires syntactic-semantic mapping, that is, thematic-role assignment. However, the mapping hypothesis seems untenable for two major reasons. First, though Broca's aphasics perform relatively well on syntactic acceptability judgement tests, their performance is not near one hundred percent correct as in normal controls, suggesting that these patients do have a problem with syntactic analysis. To give an impression, Broca's aphasics made on average 18 percent of errors in the Linebarger et al. study, and, incidentally, also in a syntactic judgement study by Wulfeck (1988), while on average 25 percent of errors were made under on-line processing conditions (see below) in a syntactic judgement study by Shankweiler, Crain, Gorrell and Tuller (1989). Second, another result that the mapping hypothesis has difficulties in accommodating, is the finding by Baum (1988) and Blumstein et al. (1991) that Broca's aphasics show sensitivity to syntactic violations in an off-line agrammaticality judgement task but not in an on-line syntactic priming paradigm in which the same materials were used in the context of a lexical decision task. This type of inter-task variation again points to a syntactic processing deficit instead of a representational deficit and, moreover, cannot be accounted for by the mapping hypothesis because both tasks that were involved (i.e., syntactic judgement and syntactic priming) do not require correct thematic-role assignment.

Further evidence demonstrating preservation of syntactic knowledge comes from an on-line syntactic judgement study by Shankweiler et al. (1989). The major finding was that Broca's and normal controls showed nearly identical performance profiles both with respect to response latency and accuracy. This was most evident in the response latencies, which indicated similar effects of position and proximity. That is, for both groups, latencies were faster when the two lexical elements defining a grammatical anomaly occurred at later positions in the sentence and when the distance between them was close as opposed to far (i.e., no and more than two words intervening, respectively). In addition, though overall slower and less accurate, Broca's seemed to be able to give their responses without much conscious reflection as most responses were given either before or slighly after (i.e., 182 ms on average) the offset of the auditory sentence signal. As Shankweiler et al. discuss, the finding of similar on-line performance characteristics in Broca's aphasics and normal controls suggest a sparing of syntactic knowledge, while the overall lower reaction latencies suggest a processing problem. Also other on-line studies suggest preservation of syntactic knowledge. On-line sensitivity to syntactic violations in Broca's aphasics was obtained in a syntactic priming study by Blumstein et al. (1991) by Friederici and Kilborn (1989) and in monitoring studies by Baum (1989)(see also a case study by Tyler, 1985, 1989).

Still more evidence for the sparing of syntactic knowledge in Broca's aphasics stems from sentence-picture matching and sentence-order studies. As Kolk and van Grunsven (1985) have pointed out (see also the discussion of their arguments by Martin, Wetzel, Blossom-Stach, and Feher, 1989), patients' performance on these tasks shows three types of variation that are difficult to reconcile with the notion of a complete or partial loss of syntactic knowledge. To begin with, there is within-subject variation. On a given sentence type (e.g., a passive construction), a Broca's aphasic may perform above chance. It is not always possible to account for such above-chance performance in terms of a patient's use of non-syntactic, heuristic interpretation strategies (Kolk and Friederici, 1985). Instead, a patient's above-chance performance on a given sentence construction seems to suggest that a patient on occasion succeeds in parsing that construction and in utilizing the relevant syntactic knowledge. A second source of variation obtained in sentence-picture matching and sentence-order tasks is that between subjects. Between patients the number of errors for a given sentence type varies almost continuously (see for instance Kolk and van Grunsven, 1985). Moreover, subgroups of patients may perform at overall different average levels of severity (cf. for instance Schwartz et al., 1980, and Kolk and van Grunsven, also see Caplan and Hildebrandt, 1988). One could try to maintain that such between-subject variation reflects differences in the extent to which subjects use non-syntactic, heuristic interpretation strategies. However, Naeser et al. (1987) found patients' agrammatic comprehension scores to be highly correlated with measures that reflect the general severity of the aphasic disorder, that is, lesion size and performance on the well-known Token Test. This suggests that between-subject variation in agrammatic comprehension is a more or less direct reflection of different degrees of severity in underlying impairment. As Kolk and van Grunsven (1985) have pointed out, the notion of degrees of severity cannot be reconciled with the notion of a loss or partial loss of syntactic knowledge which only allows for chance level performance. Finally, there is a third type of variation on sentence-picture matching and sentence-order tasks that suggests syntactic knowledge has not been lost, namely, between-sentence variation. Typically, syntactically more complex sentences evoke more errors than more simple ones. For example, both Schwartz et al. (1980) and Kolk and van Grunsven (1985) found that Broca's aphasics had less problems with simple active declarative sentences than with syntactically more complex locative sentences and passive sentences, which were almost equally difficult. The differences between simple and complex sentences are not always all-or-none, that is, it is not always the case that a patient performs 100 percent correct for some simple sentence construction and at chance level for a syntactically more complex construction, as one would expect in the case of a loss of syntactic knowledge (e.g., the knowledge to use the information about the preposition "by" in the passive). Instead, different degrees of above chance level performance result for simple and more complex sentences, with the more complex sentences evoking the most errors. As a group, the Broca's aphasics in the studies by Schwartz et al. (1980) and Kolk and van Grunsven (1985) performed at different average levels of severity. They showed, however, the same qualitative sentence-complexity effect described above (for similar evidence see Caplan and Hildebrandt (1988). The occurrence of the same performance profiles at different levels of severity strongly suggests that Broca's aphasics are not suffering from a loss of syntactic knowledge but rather from some processing deficit which, in a rather general sense, can be best described in terms of a reduction in the amount of processing resources available for parsing (Caplan and Hildebrandt, 1988; cf. Frazier and Friederici, 1991).

1.3 TOWARDS A PROCESSING THEORY

The evidence presented in the previous section made clear that the syntactic deficit of Broca's aphasics can be best characterized as a deficit in processing rather than representing syntactic knowledge. Specifically, the finding that Broca's aphasics may show similar performance profiles at different average levels of severity suggests that this processing deficit can be best characterized as a pathological limitation in processing resources which can affect subjects in a qualitatively similar manner but to different degrees. The concept of processing resources is rather vague, however, and in need of specification. In the context of research on the effects of ageing, Salthouse (1988) maintains that "the bulk of references to the concept of processing resources could be encompassed within three categories organized around the metaphors of energy, space and time" (p. 258). What is the situation with respect to resource limitation accounts of Broca's aphasics' syntactic deficit? As it turns out, all metaphors have figured in recent accounts.

Let us begin with the time metaphor of processing resources, in particular, its application by Kolk and van Grunsven, as their theory is central to this dissertation. Kolk and van Grunsven (1985) have proposed that Broca's syntactic problems may be due to a timing deficit, in particular, a pathological slowing of the activation rate (see also Kolk et al., 1985) or a pathological increase in the decay rate of sentence representational elements (i.e., lexical and/or syntactical elements). The starting point for their proposal is the observation that there is context dependency in sentence processing, that is, the specific form and position of certain sentence elements often determine the way other sentence elements have to be interpreted in comprehension and realized in production. To give an example from comprehension, compare the sentences "the woman smoked a cigarette" and "the man that greeted the woman smoked a cigarette." Because of the structural context, the noun "woman" will only be interpreted as the person who is doing the smoking (i.e., the actor of "to smoke") in the first but not in the second sentence. An example of context dependency in production is the position of the subject NP and main verb in Dutch sentences with an adverb of time. This order is subject NP followed by the main verb (e.g., "Hij komt morgen" ["He comes tomorrow"]), unless the sentence starts with the adverb. In that case the order between subject NP and main verb is reversed (e.g., "Morgen komt hij" ["Tomorrow comes he"]). As Kolk and van Grunsven (1985) point out, the context-dependent nature of sentence processing requires certain sentence representational elements to be co-active during sentence processing in real-time. They furthermore point out that both a slowing down in the activation rate and an increase in the decay rate may disturb co-activation. Because of a too slow activation rate, certain sentence elements may get activated in parsing memory too late, that is, at a moment in time when earlier activated sentence elements have already decayed away naturally below some critical threshold. One might find fault with this logic because a delay in activation might be expected to equally affect all sentence elements and therefore to not change co-activation among them. One of the contributions of this dissertation, however, will be to show that this is not necessarily the case (see chapter two). Also a too fast decay rate may disturb co-activation between sentence elements. Due to fast decay early activated elements may have already disappeared from parsing memory when later arriving elements become activated at their normal rate. Within this overall framework, Kolk and van Grunsven conceptualize degrees of severity in terms of quantitative differences in the activation and/or decay rate. The sentence-complexity effect according to Kolk and van Grunsven follows from the longer time it takes to construct complex sentences. Kolk (1987) reports a model of sentence production, called PROZIN, in which both a selective delay in syntactic processing speed and a selective increase in the decay rate cause more problems with the production of syntactically complex sentences than with the production of simple ones.

Kolk and van Grunsven furthermore suggested that the overt behavior of Broca's aphasics may be seen as an outcome of compensatory reactions that reduce the negative consequences of a timing problem. These compensatory reactions work by influencing the input to the syntactic analyser in one of two ways. One way is to feed the same input more than once to the syntactic analyzer. Kolk and van Grunsven call this reaction "corrective adaptation." Corrective adaptation increases the chances that co-activation between sentence-representational elements is achieved because during each re-input cycle the syntactic analyser may make use of rest-activation left from the previous cycle. In comprehension, corrective adaptation may be achieved by re-inputting the input words. This in turn may be achieved by selectively attending to the trace of the representations of the input words that is kept in verbal short term memory. Of course, this strategy will only work if the patient has no additional short term memory deficit. In production, corrective adaptation may be achieved by re-inputting the message to be formulated. This can account for the many overt restarts of syntactic constructions that can often be observed in Broca's aphasics' spontaneous speech. The typical pauses in the speech output of Broca's aphasics could be the result of covert repairs, that is, restarts without overt speech already being produced. Another compensatory way to reduce the negative consequences of a timing problem is to give the syntactic analyser the kind of input that reduces the complexity of the syntactic representations, as especially complex representations are affected by a timing problem. Kolk and van Grunsven have termed this reaction "preventive adaptation." In comprehension, preventive adaptation may be achieved by not syntactically analyzing a sentence completely, but instead by limiting syntactic analysis to the beginning of a sentence, and integrating the remainder of the input words on a non-syntactic, lexical-semantic basis (Kolk and Friederici, 1985). In production preventive adaptation may be achieved by inputting only simple message representations into the formulator which will tend to correspond to utterances with a simple syntactic structure. Kolk and van Grunsven suggest that preventive adaptation is going on when Broca's aphasics speak in telegraphic utterances. Supporting evidence is presented in a recent dissertation by Hofstede (1992). Hofstede found that the telegraphic style of Broca's aphasics shows most of the linguistic regularities of elliptical utterances in normals, suggesting that the formulator of Broca's aphasics is able to realize telegraphic messages in a normal way in spite of a timing deficit. Hofstede moreover found that the quality of Broca's speech output changes from telegraphic to paragrammatic when the task was changed from spontaneous conversation to picture discription (see also Heeschen, 1985 and Kolk and Heeschen, in press). This supports the notion that telegraphic style is not a mandatory outcome of the primary syntactic deficit of Broca's aphasics, but instead the result of a compensatory reaction that may be given up depending on the task conditions. According to Kolk and van Grunsven, paragrammatism results when the patient does not adapt the primary syntactic deficit. In that case, there is an incomplete basis for sentence production as the timing deficit will have caused a premature disintegration of the sentence representation and both paragrammatic errors and broken-off sentences will be the result. It should be pointed out that though Kolk and van Grunsven's ideas about adaptation are consistent with the hypothesis of a timing deficit, these ideas do not by necessity point to such a deficit. They are congruent with any processing theory that can account for syntactic complexity effects and that allows for improvement in syntactic computation after re-inputting.

Also others have considered the time metaphor in their accounts of Broca's aphasic syntactic problems. To begin with, several investigators have stressed that a slowing down in the retrieval rate of lexical information may disrupt the real-time integration of that information with the ongoing structural and semantic analysis (Friederici, 1988; Gigley, 1982, 1983; Grodzinsky, Swinney, and Zurif, 1985; Hagoort, 1990; Swinney et al., 1989). In a theoretical paper, Friederici (1988) has hypothesized that especially a slower access to structural information associated with closed class elements may be responsible for Broca's aphasics' syntactic problems (see also Huber, Cholewa, Wilbertz, and Friederici, 1990, and Hagoort, 1990, chapter five). Friederici left open the possibility that also access to content words may be slowed down. Gigley (1982, 1983) simulated problems with thematic role assignment in sentence comprehension as the outcome of a slowing in the retieval time of syntactic information associated with both function and content words. Grodzinsky et al. (1985) speculate that in Broca's aphasics lexical access is slowed down. On the basis of a series of experiments (discussed below), Hagoort (1990) suggests that Broca's aphasics are slowed down not so much in accessing lexical information as well as in integrating this type of information into a higher-level message representation. What about fast decay? Besides Kolk and van Grunsven (1985), also Gigley (1982, 1983), Hagoort (1989) and Friederici and Kilborn (1989) have mentioned the possibility that Broca's aphasics might suffer from fast decay. Specifically, Gigley (1982, 1983) simulated agrammatic comprehension as the outcome of a too fast decay of lexical-semantic information, while Hagoort (1989) and Friederici and Kilborn (1989) have postulated a too fast decay of higher order syntactic information and syntactic information associated with function words, respectively. The empirical data on which Hagoort and Friederici and Kilborn have based their proposals are discussed in the next section (i.e., 1.4).

Not only Broca's syntactic problems, but also other aphasic symptoms have been explained by resorting to the use of the time metaphor of processing resouces. It has been proposed that the left hemisphere is specialized in rapid temporal analysis (Bradshaw and Nettleton, 1981; Tallal and Newcombe, 1978). An interference with this function due to focal brain damage has been hypothesized to be the source of aphasics' problems with speech perception (Tallal and Newcombe, 1978). Supporting evidence came from studies which showed that aphasics have difficulties in judging the temporal order between two sound stimuli (i.e., tones) that are separated by short time intervals (Efron, 1963; Tallal and Newcombe, 1978). Also aphasics' speech production problems have been explained in temporal terms. In the context of Dell's speech production model (1986), a less efficient spread of activation (i.e., reduced activation rate) has been postulated as the primary cause for the abnormally high incidence of perseverations in the speech output of two cases of Jargon aphasia (Bloch and Schwartz, 1989, and Schwartz, Saffran, and Dell, 1990). Furthermore, in the context of the same model, the semantic and phonemic paraphasias that were observed in a case of deep dysphasia have been attributed to a pathologically rapid decay (Martin and Saffran, 1991). From the foregoing review it should have become clear that the use of time as an explanatory factor in theories of aphasia is now becoming more widespread. In fact, the temporal approach has strong roots in the "chronogenetic" tradition in neuropsychology, with such spokesmen as Grashey (1885), Von Monakow (1914), Luria (1970), and Lenneberg (1967)(see Kolk and van Grunsven, 1985, for an overview). Lenneberg (1967), who was quoted at the beginning of this chapter, was the most radical in calling time "the most significant dimension of language physiology" suggesting that "almost all of the central nervous system disorders of speech and language may be characterized as disorders of timing mechanisms" (p. 218).

The other two metaphors of processing resources, those of space and energy, have been also used to account for Broca's syntactic problems. Both Kolk and van Grunsven (1985) and Caplan and Hildebrandt (1988) have proposed that Broca's aphasics might suffer from a spatial limitation in the capacity of parsing working memory. The reason to locate this spatial limitation in a special parsing working memory is that a reduction in auditory-verbal short term memory does not necessarily lead to agrammatism in production (Shallice and Butterworth, 1977) or comprehension (Martin, 1987). Kolk and van Grunsven point out that a reduced syntactic buffer capacity, much like a decrease in activation rate, or an increase in decay rate, may disturb the co-activation of sentence-representational elements because such a resource restriction limits the number of elements that can be retained together. LaPointe (1985) has explained Broca's aphasics' use of verb forms by assuming a reduction in available energy. The energy metaphor of processing resources seems to have also been used by Linebarger et al. (1983). These researchers suggested the trade-off hypothesis as an alternative to the mapping hypothesis (see above) in order to account for their finding of preserved grammaticality judgements in combination with severely impaired sentence-picture matching. According to the trade-off hypothesis, Broca's suffer from a reduction in the computational resources that are shared (by hypothesis) for syntactic and semantic analysis and will, depending on the task requirements place emphasis on one type of analysis at the expense of the other. Sentence-picture matching is more vulnerable to a reduction in computational resources than grammaticality judgement because it requires not only syntactic analysis but in addition also semantic analysis (i.e., thematic role mapping). It is not entirely clear to what extent Linebarger et al. interpret a reduction in processing resources in terms of the energy metaphor. Their conjecture that syntactic and semantic analysis draw from the same resources seems to imply that some energetic quantity is distributed for processing. On the other hand, however, Linebarger et al. associate a reduction in processing resources with a reduction in the efficiency by which parsing operations are executed. Specifically, they suggest that such a reduction could be the result of a lack of a special fast access routine for function words as has been proposed by Bradley and colleagues (Bradley, 1978, Bradley, Garrett, and Zurif, 1980). This would imply the use of the time metaphor of processing resources.

Recently, Hagoort (1990) seems to have linked the time and energy metaphors of processing resources together in his account of Broca's aphasics' processing deficit. Based on a series of associative priming studies (discussed below), Hagoort suggested that Broca's aphasics suffer from a pathological slow down not so much in the rate by which lexical information is accessed from the mental lexicon, but more in the rate by which this information is integrated into a higher-level message representation after it has been accessed. The slow down in the rate of lexical integration Hagoort attributes to a pathological reduction in processing resources. Hagoort argues that such a resource reduction will affect lexical integration more than lexical access because the former process is probably more resource demanding than the latter. He points out that lexical access requires computational resources to retrieve information from the lexicon, whereas lexical integration requires computational resources both to maintain a context representation and to integrate the retrieved lexical information into this context representation. Just as is the case for Linebarger et al.'s trade-off hypothesis, it is not entirely clear whether Hagoort views computational resources in terms of the energy metaphor. As he writes, "The amount of processing resources determines the number of computational operations that can be accomplished per time unit. To illustrate this, one can use the metaphor of the internal computer clock. In general, the speed of processing increases with a higher clock rate. Conversely, decreasing the clock rate reduces the computational power of the system. A slower clock rate will affect complex computational operations more severely than relatively simple ones (the complexity effect)" (p. 177, parentheses are his). This clearly seems to imply the time rather than energy metaphor of processing resources.

Any processing theory of Broca's aphasics requires that two kinds of assumptions are made. On the one hand, assumptions need to be made about the nature of the processing deficit (i.e., the How-aspect of the processing deficit). As discussed above, slow activation, fast decay, reduced memory capacity, and reduced energy to carry out parsing operations have all been considered as reflecting the true nature of Broca's aphasics' processing deficit. On the other hand, assumptions need to be made about which linguistic elements are primarily affected by the processing deficit (i.e., the What-aspect of the processing deficit). The proposals with respect to this latter aspect will be discussed next.

To begin with, the presence of problems with the processing of function words in spontaneous language production is one of the defining characteristics of Broca's aphasia (Goodglass and Kaplan, 1983). Several researchers have accordingly suggested that Broca's aphasics' syntactic problems can be understood in terms of their difficulties in processing function words. An early version of a function word hypothesis was proposed by Kean (1977). Adopting the phonological theory of Chomsky and Halle (1968), Kean suggested that Broca's aphasics omit those elements from the structure of a sentence which cannot be lexically construed as phonological words, that is, function words and inflections. Grodzinsky (1990) has recently criticized Kean's theory for making the wrong predictions for languages like Russian and Hebrew in which the omission of an inflection may result in a nonword stem. Instead of omitting the inflection and producing a nonword in such cases, as Kean's phonological hypothesis would predict, Broca's aphasics appear to substitute a word with the wrong inflection. Bradley and colleagues (Bradley, 1978; Bradley et al, 1980) suggested that Broca's aphasics suffer from the loss of a special fast access routine for the retrieval of function words. Bradley et al. obtained supporting evidence for their view that the retrieval of function words had lost its privileged status in Broca's aphasics, in a series of lexical decision experiments. In normal controls, the access to content words was guided by two access principles, that is, frequency sensitivity and left-to-right scanning order. Frequency sensitivity was indicated by faster lexical decision times for words with a more frequent appearance in the language than for words with a less frequent appearance, and left-to-right scanning order was indicated by the finding that the rejection of nonwords was interfered with when these nonwords started with words. Normals' access to function words, however, did not seem to be guided by these two access principles but instead seemed to be frequency insensitive and holistic (i.e., showing no left-to-right scanning order). Broca's aphasics differed from normal controls in that they showed both access principles (i.e., frequency insensitivity and left-to-right scanning order) not only for content words but also for function words. More carefully controlled follow-up studies, however, revealed that frequency sensitivity (Gordon and Caramazza, 1982; Segui, Mehler, and Morton, 1982) and left-to-right scanning order (Kolk and Blomert, 1985) were principles that guided the access of function words not only in Broca's aphasics, but also in normal controls, casting doubt on the validity of the normal baseline condition in the experiments of Bradley et al.. Moreover, as Kolk and van Grunsven (1985) have pointed out, Bradley et al.'s hypothesis cannot account for degrees of severity because the loss of the special function word retrieval system is supposed to be all-or-none. Contrary to Bradley et al., Friederici (1982, 1983) has proposed that Broca's aphasics do not have a problem with the processing of function words as such, but only in sofar that these words play a syntactic role in the sentence. In support of this hypothesis, Friederici found that in both production (1982) and comprehension (1983) Broca's aphasics have more problems in retrieving prepositions that mainly carry syntactic information (i.e., syntactically obligatory prepositions such as the "by" preposition in the passive) than prepositions which carry additional lexical meaning content (e.g., a preposition indicating a location such as "in"). In comprehension, these problems are indicated by the slower recognition times for syntactic as opposed to lexical prepositions of the same word form. According to Friederici (1988), this suggests that the syntactic information associated with the former type of function word is not available fast enough to structure the incoming input words. The disruptive effect this can have on thematic-role assignment was simulated by Gigley (1982, 1983). In her simulations, Gigley assumed also that the structural information associated with content words was accessed at a slower than normal rate. A possibility which is also considered by Friederici (1988), but left open in the absence of empirical evidence.

It seems possible that Broca's slower recognition of syntactic prepositions in sentences (Friederici, 1983) does not so much reflect a slow down in the lexical access to the structural information associated with function words, but rather reflects a slower than normal integration of this structural information into an abstract phrase-structure representation of the sentence (i.e., a representation describing the hierarchical relations among the constituents of a sentence). Such a problem in turn could be the result of difficulties in constructing abstract phrase-structure representations beyond the level of lexical syntactic categories as has been suggested by Caplan (Caplan, 1983; Caplan and Futter 1986). Under such an account of Broca's aphasia it is possible that the processing deficit affects phrasal categories, that is, the non-lexical categories of constituents such as NP (noun phrase), VP (verb phrase) and PP (prepositional phrase). Another account which locates Broca's aphasics' deficit at the level of a phrase-structure representation has been offered by Grodzinsky (1986, 1990). Following Government and Binding theory (GB theory, Chomsky, 1981), Grodzinsky proposed that in comprehension Broca's aphasics construct incomplete phrase-structure representations from which so-called traces are deleted. Without traces a patient is no longer able to assign thematic roles to constituents which have been moved into a different position when transforming D-structure to S-structure. For example, patients' problems with the understanding of passives is supposed to arise from an inability to link (i.e., via a co-indexation of the moved constituent and the trace) the subject NP in S-structure to its post-verbal direct-object position in D-structure, due to the deletion of the trace in this latter position. A problem with Grodzinsky's trace-deletion hypothesis is that it cannot account for the finding that Broca's aphasics may also show agrammatic comprehension for sentences not containing a trace in S-structure, such as the reversible active subject-verb-object (SVO) sentences that were included in the studies of Schwartz et al. (1980) and Kolk and van Grunsven (1985), albeit that these sentences evoked less errors than their passive counterparts. This does not imply that Broca's aphasics have no difficulties in representing traces. It does, however, imply that a deficit theory which attempts to account for between-sentence variation by looking for distinguishing features in the linguistic representation of sentences (e.g., traces present versus absent) is incomplete. Such a theory must by necessity be supplemented by a processing theory which explains why the absence of those features causes less, rather than no problems, for comprehension (for a concrete proposal see the discussion in chapter two). For further criticism of Grodzinsky's trace-deletion hypothesis see Martin et al. (1989).

To sum, a processing theory of Broca's syntactic deficit should not only make assumptions about what linguistic elements are affected (e.g., function words or phrasal categories) but also how these linguistic elements are affected. Several researchers have suggested that the syntactic deficit of Broca's aphasics could involve a timing deficit, in particular, a too-slow activation or too-fast decay rate. However, other conceptualizations of the deficit, involving spatial storage limitations in a syntactic buffer or a reduction in computational energy, seem possible as well. It should be stressed that most proposals with respect to Broca's syntactic processing deficit are of a speculative nature and, as discussed in the next section, empirical evidence distinguishing between them is not decisive.

1.4 EMPIRICAL EVIDENCE

Research on the exact nature of the syntactic deficit in Broca's aphasia reveals an enormous gap. Hardly any studies have explicitly been designed to find direct empirical evidence for and distinguish between the various possible resource restrictions that were mentioned in the last paragraph as possible characterizations of Broca's aphasics' syntactic processing deficit (i.e., slow activation, fast decay, reduced memory capacity, and reduced energy). There are several studies whose data seem to point towards one type of resource restriction, but when looked at more closely, also seem to be consistent with another type of resource restriction (Baum, 1988; Blumstein et al., 1991; Hagoort , 1989; Shankweiler et al., 1989). Other studies that do not suffer from this flaw and seem to allow a more definite conclusion about the particular resource restriction from which Broca's aphasics might or might not suffer, have to be interpreted with caution because of the types of materials that were used (Baum, 1989; Friederici and Kilborn, 1989; Hagoort, 1990). These studies are now discussed in more detail.

As already mentioned above, both Baum (1988) and Blumstein et al. (1991) failed to find syntactic priming for Broca's aphasics in an on-line lexical decision task for materials whose grammaticality was judged rather well by the same patients under off-line conditions, suggesting a processing, rather than a knowledge deficit. These data seem difficult to reconcile with the reduced-memory-capacity hypothesis. Because the same materials were used in both tasks, a spatial limitation in the storage capacity of a syntactic buffer should have influenced sensitivity to syntactic violations in the same manner in both tasks. Sensitivity to syntactic violations should either have been present or absent in both tasks, depending on whether the syntactic complexity of the materials succeeded the buffer capacity or not. The results of Baum's and Blumstein et al. 's studies seem to be consistent, however, with both the slow activation and fast decay hypothesis. Both Baum and Blumstein et al. suggested that the lack of syntactic priming could reflect a loss of automaticity in the access to syntactic representations (cf. case study by Tyler, 1985). In order to be able to account for degrees of severity, loss of automaticity can not be taken as reflecting a loss of the procedures that are used for automatic syntactic access. Instead, loss of automaticity could be taken as implying a slow-down in parsing speed or syntactic activation rate (cf. Hagoort, 1990, p.170). The reason is that the concept of automaticity has speed as one of its defining characteristics. However, we cannot be completely certain that Broca's aphasics' lack of syntactic priming in Baum's and Blumstein et al.'s studies reflects a pathological slowing in the syntactic activation rate. The reason is that both studies only included a medium-sized stimulus onset asynchrony (SOA) between prime fragment and lexical decision target (i.e., 500 ms). A wider range of SOAs would have to be used in order to uniquely establish whether Broca's are suffering from too slow activation and/or too fast decay. In such an experiment, normal controls can be expected to show syntactic priming at a wide range of SOAs. Broca's aphasics, however, might show several priming patterns depending on the nature of the timing deficit: (1) earlier disappearance of priming (i.e., only priming at short SOAs), (2) later appearance of priming (i.e. only priming at long SOAs) and (3) both later appearance and earlier disappearance of priming (i.e. priming starts at longer SOAs and remains present less longer than in normal controls). In order, the first, second, and third priming pattern would point towards too fast decay, too slow activation, and a combination of both.

Recent findings of an on-line syntactic judgment study by Shankweiler et al. (1989) and a word monitoring study by Hagoort (1989) also do not uniquely point to a particular resource restriction. In both studies, Broca's aphasics' sensitivity to violations of grammaticality appeared to decrease as a function of the distance between two sentence elements (e.g. "two customer") that caused these violations. Distance was defined in terms of the number of intervening words and could be either short or long. Shankweiler et al. used different violation types involving determiners, prepositions, particles and auxiliary-verb agreement, while Hagoort concentrated on violations of agreement between a subject noun phrase (NP) and a finite verb. For both Broca's aphasics and normal controls in the Shankweiler et al. study, on-line syntactic judgment took more time in the long than in the short distance condition. According to Shankweiler et al. (1989), "It is presumbly more difficult to relate two items if other items intervene than if they are adjacent because the grammatical features of the first item must be retained in working memory" (p. 22). The more remote dependencies seem to have stressed especially the working memory of Broca's aphasics. Broca's aphasics made significantly more errors in the short than in the long condition, whereas no such difference was found for the normal control group. Hagoort (1989) found the word *monitoring times of the normal controls to be negatively influenced by subject-verb agreement* violations in both the short and long distance condition. For Broca's aphasics, on the other hand, this was only the case in the short condition. Hagoort suggests fast decay of syntactic information, which would especially have a negative effect in the long distance condition, as a possible explanation for his results. The distance effect obtained in the Shankweiler et al. study might be explained in a similar way. The support for the fast decay hypothesis is not undisputable since a distance effect may also result from the two other resource restrictions that were mentioned above. First, a reduced storage capacity would especially interfere with retention (and thus disturb co-activation) in the long condition, since the two words that cause the violation are separated by more intervening words. Second, slow activation would especially delay parsing in the long condition or, alternatively, could have especially disturbed co-activation, since more words have to be integrated syntactically in the long condition. In the case where co-activation is disturbed, there is neither a syntactic basis for a syntactic acceptability judgment nor for delaying word monitoring times in the ungrammatical condition. In case of a delayed parse, the monitoring response may already have been given by the time the parse is completed.

Other studies seem to allow a more definite conclusion about the particular resource restriction from which Broca's aphasics might or might not suffer (Baum, 1989; Friederici and Kilborn, 1989; Hagoort, 1990). As previously stated, however, they have to be interpreted with caution because of the types of materials that were used. Using a word monitoring paradigm, Baum (1989) recently found that normal controls showed sensitivity to grammaticality violations (i.e., slower word monitoring times in the ungrammatical than grammatical condition) for both local and global syntactic dependencies, while Broca's aphasics only showed sensitivity to grammaticality violations for local but not for global dependencies. Local dependencies all occurred within a clause boundary and involved, verb sub-categorization, auxiliary agreement, and the use of reflexives. Global dependencies, on the other hand, all occurred across a clause boundary and involved, the coordinate structure constraint, the filling of question and relative clause gaps. Baum's results seem to argue against the slow activation hypothesis. In Baum's study the monitoring target immediately followed the grammaticality violation or completed it. The presence of a grammaticality effect for Broca's aphasics in the local condition under such circumstances seems to indicate that syntactic processing is still relatively fast in these patients, at least for simple syntactic constructions that are contained within a clause. The question, however, is to what particular kind of syntactic processing this conclusion pertains. In Baum's study, all local dependencies could be processed based on syntactic knowledge that is stored in the lexicon (e.g., subcategorization information about the verb). It is therefore still possible that non-lexical (i.e., phrasal) syntax is processed at a slower rate in Broca's aphasics than in normals.

The results of a recent cross-modal syntactic priming study with Dutch Broca's aphasics by Friederici and Kilborn (1989) must be interpreted with similar caution. Their results suggested that Broca's aphasics suffer from both fast decay and slow activation. Fast decay was indicated by the finding that Broca's, contrary to normal controls, only showed syntactic priming at a short SOA of 0 ms, but not at a longer SOA of 200 ms. Slow activation was indicated by the finding that Broca's responded slower to lexical decision targets preceded by a prime fragment than to lexical decision targets presented in isolation, contrary to normal controls who showed the opposite trend. As was the case for Baum's study, the question is for what particular kind of syntactic processing this conclusion holds. Friederici and Kilborn's critical materials contained two kinds of grammaticality violations, violations of the transitiveness of the past partciple verb as is required for the passive (e.g., *"he was slept") and violations of the perfect auxiliary that is demanded by the past participle verb in Dutch (e.g., *"hij heeft gekomen" ["he has come"]). As was the case for the materials in Baum's study, these grammatical violations can be processed based on grammatical knowledge that is stored in the lexicon. It is therefore an open question to what extent non-lexical (i.e., phrasal) syntax is affected by a timing deficit in Broca's aphasics (for further discussion of Friederici and Kilborn's study, see chapters three and four).

Another relevant study involving a syntactic disambiguation paradigm and testing Dutch Broca's aphasics and normal controls was carried out by Hagoort (1990, chapter five). In these experiments, subjects had to listen to a triplet consisting of an introductory sentence fragment, an ambiguous sentence final word with an independent noun and verb reading, and a target word presented for lexical decision after an inter-stimulus interval (ISI) of 100 or 700 ms. The syntactic structure of the sentence fragment selectively biased interpretation towards either the noun or the verb reading of the ambiguous word. The target word, however, could be a semantic associate to either reading of the ambiguous word. For normal controls, the pattern of associative priming indicated a fast syntactic disambiguation effect and, thus, seemed to reflect a fast buildup of syntactic structure. Already at the 100 ms ISI and also at the 700 ms ISI, normal controls only showed associative priming when the syntactic structure was congruent with the meaning of the ambiguous word that was associatively related to the target (e.g., a noun-biasing sentence context and a noun related target). No associative priming was observed in normal controls when the syntactic structure was incongruent with the meaning of the ambiguous word that was associatively related to the target (e.g., a noun-biasing sentence context and a verb-related target) (see Seidenberg et al., 1982, for similar results in the context of a naming task). For Broca's aphasics the results were different in that the time-course of syntactic disambiguation depended on whether the syntactic context was noun or verb biasing. For verb-biasing sentences, syntactic disambiguation was evident at both the 100 and 700 ms ISI. For noun-biasing sentences, syntactic disambiguation became evident only at the 700 ms ISI. At the 100 ms ISI, Broca's showed associative priming for both noun and verb readings despite the fact that only the noun readings fit the syntactic context.

Hagoort's results seem to be inconsistent with the hypothesis that Broca's aphasics suffer from slow activation of phrasal syntax. As Hagoort points out, this hypothesis would have predicted that Broca's aphasics show later (i.e., not at 100 ms ISI, but only at the 700 ms ISI) syntactic disambiguation for both noun- and verb-biasing sentences, not just for noun-biasing sentences. Nevertheless, it seems premature to reject the slow-phrasal-activation hypothesis on the basis of Hagoort's results. As was the case for the studies of Baum (1989) and Friederici and Kilborn (1989), Hagoort's results also have to be interpreted with caution because of the materials used.To begin with, the slow-phrasal-activation hypothesis predicts problems with the construction of phrase-structure representations, especially when they are syntactically complex (for an explanation see section 2.2.6). However, noun disambiguation in Hagoort's materials could always be based on the analysis of a rather local and simple syntactic string, that is, a determiner or an adjective immediately preceding a noun, whereas verb disambiguation could in many cases also be based on the analysis of a rather local and simple syntactic string, that is, the Dutch particle "te" (i.e., "to") or a modal verb immediately preceding an infinitive verb. It seems very plausible that patients can still analyze such simple syntactic structures even when suffering from a slower-than-normal phrasal activation. Thus, Hagoort's materials did not really allow for a test of the slow-phrasal-activation hypothesis.

Furthermore, the presence of an early syntactic disambiguation effect for verb-biasing sentences could have been due to the fact that Hagoort's list of target words may have biased subjects towards the verb reading of the ambiguous words. With the exception of one adjective, this target list contained only nouns and verbs. Target nouns were always singular and target verbs were always plural. Thus, subjects could have applied the rule that a plural target implies a verb. This together with the fact that all ambiguous words occurred in plural form might have biased subjects towards the verb reading of the ambiguous words. It is interesting to point out in this context that at the 100 ms SOA not only Broca's aphasics but also normal controls showed a tendency (although not significant) towards associative priming (i.e., 29 ms) in the incongruent condition in which ambiguous words were preceded by noun-biasing sentences and followed by verb-related targets. Hagoort himself suggests a different explanation for his results. His account also utilizes the fact that ambiguous words always ended in "-en", that is, the plural, marked form for Dutch nouns and the infinitive, unmarked form for verbs. Therefore, disambiguation of nouns, but not of verbs, requires morphosyntactic processing of the "-en" ending. And, consequently, as Hagoort himself suggests, Broca's later than normal disambiguation in noun-biasing sentences could reflect a delay in the activation of closed-class morphology. However, this seems an unlikely possibility because the plural noun ending is typically the ending most spared in Broca's aphasics language production (Goodglass and Berko, 1960, this dissertation, chapter five).

Milberg, Blumstein, and Dworetzky (1987) have claimed that Broca's aphasics show a selective impairment in automatic lexical access. This claim was based on the results of a series of semantic priming studies by Milberg and colleagues themselves (Blumstein, Milberg, and Shrier, 1982; Milberg and Blumstein, 1981; Milberg, Blumstein, and Dworetzky, 1987) and by others (Katz, 1986; Swinney, Zurif, Rosenberg, and Nicol, 1986; see also Katz, 1988, and Swinney, Zurif, and Nicol, 1989). In some of these studies, Broca's aphasics showed semantic priming (i.e., faster lexical decision times for target words that are preceded by semantically related as opposed to semantically unrelated prime words), that is, when auditorily presented word pairs were used (Blumstein et al., 1982; Katz, 1988), or under cross-modal auditory-visual presentation conditions, when the target word was related to the most frequent meaning of an ambiguous prime word (Swinney et al., 1989). A non-significant trend towards semantic priming was obtained by Milberg and Blumstein (1981) using visually presented prime-target pairs. The same researchers, however, failed to obtain semantic priming under more difficult processing conditions, that is, when auditory word triples instead of word pairs were used (Blumstein et al., 1987), or when the target word was not related to the most frequent meaning of an ambiguous prime word but instead to a less frequent one (Swinney et al., 1989). Blumstein and colleagues attributed the lack of semantic priming under these processing conditions to a selective impairment with automatic lexical access. However, the type of priming that these researchers investigated was of a non-syntactic, semantic nature. Therefore, as these researchers point out themselves, the question of whether a deficit in automatic lexical access contributes in any significant way to the syntactic impairments of Broca's aphasics is left open. Swinney and colleagues seem to suggest that this is indeed the case. Based on their finding that semantic priming in Broca's occurs only for the most frequent meaning of the prime word, they suggest that a selective impairment in automatic lexical access could indicate a slower-than-normal lexical access (for support see a case study by Prather, Zurif, Stern, and Rosen, 1990). Slower-than-normal lexical access in turn could disrupt comprehension by delivering lexical information to other components of the comprehension device (e.g., the syntactic parser) at the wrong temporal point in the comprehension sequence. This immediately raises another question. As pointed out above, in comprehension, Broca's aphasics typically have problems with reversible sentences in which syntactic structure is crucial for thematic-role assignment. They have, however, much lesser problems with irreversible sentences in which thematic-role assignment can be achieved solely on the basis of the semantic integration of lexical items (e.g., Kolk and Friederici, 1985). This raises the question why a slow down in lexical access has a more disruptive effect on syntactic than on lexical-semantic integration of lexical information. This question was not addressed by Swinney and colleagues. It was, however, addressed in Hagoort's recent dissertation (1990).

Hagoort (1990) has challenged the hypothesis that lexical access is slowed down in Broca's aphasics. Unlike Blumstein et al. (1987), Hagoort (his chapter three, experiment 1) did obtain semantic priming for Broca's aphasics when auditorily presented word triplets were used. The fact that overall lexical decision latencies were much faster in Hagoort's study than in Blumstein et al.'s study suggested that the discrepancy in priming results might have been due to the fact that the patients in Hagoort's study were suffering from a less severe impairment. Hagoort reasoned that a deficit in automatic lexical access should show up even in his mildly impaired patients under temporally more constrained processing conditions in which the ISI between the words is reduced from 500 ms to 100 ms (Hagoort, chapter three, experiment 2). However, under those conditions, Broca's aphasics still appeared to show semantic priming, suggesting that fast, automatic lexical access was still present in Hagoort's patients.

Additional findings led Hagoort to suggest that Broca's aphasics suffer not so much from a slow-down in lexical access, but rather from a slow-down in the lexical integration of the accessed information into a higher-level message representation. To begin with, using the same paradigm, Hagoort (his chapter three, experiment 3) failed to obtain semantic priming in

Broca's aphasics but not in normal controls when a rather large ISI of 1250 ms was used. This according to Hagoort could suggest a faster-than-normal decay of lexically accessed information in Broca's aphasics, but also a slower than normal integration of this information into a higher-level message representation. The rationale for this latter interpretation is that semantic priming at large ISIs in normals is supposed to be largely due to a post-lexical process of meaning integration (De Groot, 1990). Further support for a slow down in lexical-meaning integration came from an additional study in which Hagoort used a paradigm similar to the one used in his syntactic disambiguation experiment described above (Hagoort, chapter four). In this study, subjects had to listen to a sentence biasing either the dominant or subordinate noun meaning of an ambiguous sentence-final prime word followed after an ISI of 100 ms by a lexical decision target. Normal controls showed semantic priming for dominant prime meanings irrespective of whether the sentence introducing the prime word biased interpretation towards its dominant meaning or not (Hagoort's chapter four, experiment 1b). For subordinate prime meanings, however, normal controls showed an early context selection effect, that is, semantic priming was only obtained when the sentence introducing the prime word biased interpretation towards the subordinate meaning of the prime word. Broca's aphasics, on the other hand, showed significant and marginally significant semantic priming for dominant and subordinate prime meanings, respectively, regardless of the contextual bias. Thus, contrary to normal controls, there was no evidence of an early context selection effect for subordinate prime meanings in Broca's aphasics. When the ISI was increased from 100 ms to 750 ms (Hagoort's chapter four, experiment 2b), both normal controls and Broca's aphasics showed a context selection effect for dominant and subordinate prime meanings, that is, semantic priming was only obtained when the sentence biased the interpretation of the prime word towards the same meaning as the one related to the target word. To summarize Hagoort's results, contrary to normal controls, Broca's aphasics show semantic priming for subordinate prime meanings regardless of contextual bias when the ISI is 100 ms and an effect of context selection only when the ISI is increased to 750 ms. These findings according to Hagoort provide evidence against the hypothesis that Broca's aphasics suffer from slow lexical access, rather they seem to suffer from a slower-than-normal integration of this lexical information into a higher-level message representation, once this information has been accessed. According to Hagoort, such a problem will have especially disruptive effects in processing domains that require correct temporal sequencing, such as syntactic processing. With the exception of reversible sentences, separate lexical meanings can be integrated into a higher-level message representation even when they are not delivered in the right order. This according to Hagoort might explain the common finding that Broca's have less comprehension problems with irreversible than reversible sentences in which interpretation critically depends on syntactic information. As will become clear from the final chapter of the present dissertation, the same explanation will be defended here.

To sum, the results of studies investigating Broca's on-line syntactic processing are consistent with more than one view of their deficit (i.e., both with regard to the What- and How-aspect of the syntactic impairment). Hagoort's (1990) findings on Broca's on-line processing of lexical-semantics suggest that these patients suffer from a slower than normal post-lexical integration, which by definition would also encompass syntactic processing. However, because of the material problems in his syntactic disambiguation experiments it remains to be seen whether Hagoort's results can indeed be generalized towards the domain of syntactic processing.

1.5 OVERVIEW

The central goal of the research reported in this thesis was to test Kolk and van Grunsven's (1985) processing theory of the underlying deficit in agrammatism, namely, that it involves either a too slow activation or a too fast decay of sentence representational elements. Except for the final chapter, which ties all the reported research together, each chapter (i.e., two to five) has been written as a research article (see list of publications) that can be read independently from the other chapters. The content of each chapter is as follows.

In chapter two, a computer simulation study of agrammatic comprehension is presented. This study was conducted in order to refine Kolk and van Grunsven's processing theory of agrammatic comprehension in a more formal mannner and represents the first quantitative simulation of agrammatic comprehension that has been reported in the literature. In order to conduct this study, a new computer model, SYNCHRON, was developed. The data that were being simulated came from the sentence-picture matching studies of Schwartz et al. (1980) and Kolk and van Grunsven (1985) that were discussed above. Recall that in these studies the same syntactic complexity effect was obtained at two different average levels of severity. The goal of the computer model was to simulate the combined complexity-severity effects, while testing which hypothesis about the what (i.e., linguistic unit affected by the deficit) and how (i.e., nature of the processing deficit) would yield the best fit to the data. In particular, based on the previous literature, two hypotheses about the what and how of the processing deficit were tested. It was hypothesized that the linguistic unit affected is either the syntactic information associated with function words (e.g., "by" belongs to the lexical-syntactic class of prepositions) (Bradley et al., 1980; Friederici, 1983, 1988; Zurif, 1982, 1984) or the syntactic information associated with constituent phrases as a whole (e.g., "sees the man" is a VP or verb phrase constituent) (Caplan, 1983; Caplan and Futter, 1986). In line with Kolk and van Grunsven's (1985) proposal, it was furthermore hypothesized that this syntactic information was either subject to a too slow activation rate or a too fast decay rate.

As the results of the computer simulation study showed, the sentence-picture matching data could only be simulated when the timing disorder minimally affected phrasal categories. It did not matter much to the fit whether the timing disorder was assumed to involve a too fast decay rate or a too slow activation rate. In order to find out from which of these two temporal changes Broca's aphasics actually suffer, a syntactic priming study involving Broca's aphasics and age-matched controls was conducted. This study is reported in chapter three. Unlike Friederici and Kilborn's study (1989), this study included not only grammaticality violations involving lexical syntax but also syntactic violations that could be claimed to involve non-lexical, phrasal syntax. The critical manipulation in syntactic priming experiment involved the SOA (stimulus onset asynchrony: 300, 700 and 1100 ms) between a two-word sentence fragment and a target letter string presented for lexical decision. Of special interest were the response times to word targets. Target words formed either a grammatically appropriate or inappropriate continuation of the preceding prime fragment. With normal, healthy subjects, one typically observes syntactic priming, that is, lexical decision times are significantly faster in the grammatical condition than in the ungrammatical condition. It is important to realize, however, that syntactic priming only occurs if the syntactic representation of the prime fragment can be integrated with that of the target fragment before the target is responded to. This in turn will only happen if the syntactic representation of the prime fragment is available at the right moment in time. Both slow activation and fast decay can change the moment of availability of the syntactic representation of the prime fragment so that no syntactic priming occurs. Specifically it was predicted that slow activation would result in a late appearance of syntactic priming (i.e., at a larger SOA than in control subjects), while fast decay would result in an early disappearance of syntactic priming (at a smaller SOA than in normal controls). Moreover, it was predicted that a pathologically reduced syntactic buffer size (Caplan and Hildebrandt, 1988) would result in either the same priming pattern as obtained in normal controls, or in case the syntactic complexity of the material surpassed the capacity of the buffer, in no syntactic priming at all. Any sensitivity of Broca's syntactic priming to temporal factors cannot be accommodated by the reduced-buffer-size hypothesis, because this hypothesis postulates a spatial processing limitation.

In chapter four, two nearly identical word monitoring experiments with Broca's aphasics and age-matched controls are presented. In both experiments subjects' on-line sensitivity to subject-verb agreement violations was assessed as a function of the syntactic complexity of the sentence frames that these agreement violations were couched in. In the first experiment, these syntactic frames were immediately followed by the noun phrase containing the target. In the second experiment, there was a 750 ms separation. In accordance with a previous word monitoring study (Baum, 1989), it was expected that Broca's would still show sensitivity to agreement violations (i.e., significantly larger monitoring times in the non-agreeing than agreeing condition) in syntactically simple sentences. For syntactically complex sentences, however, no such sensitivity was expected. This prediction follows from the SYNCHRON model which predicts that larger syntactic complexity (i.e., roughly defined as the number of nodes in a constituent structure) results in an increased difficulty in building phrase-structure representations. As will be shown in chapter two, this effect is due to the larger accumulation of retrieval time delays in syntactic branches of greater depth. Unlike what was the case in most previous studies, it was made sure that the syntactic complexity manipulation was not confounded by differences in sentence length or propositional meaning content. Moreover, by noting the effect of syntactic complexity on a morpho-syntactic operation (i.e., the computation of subject-verb agreement), we tried to control for potential problems in syntactic-semantic mapping. For the second experiment the following predictions were made. In the case of slow activation, it was predicted that the agreement effect for complex sentences, which was expected to be absent in the first experiment, would appear in the second experiment. In the case of fast decay, it was predicted that the agreement effect for simple sentences in the first experiment would disappear in the second experiment for the Broca's, but not for the age-matched controls. Thus, like the syntactic priming study reported in chapter three, the two word monitoring experiments in chapter four were conducted in order to contrast the slow activation and fast decay hypothesis. Especially, in view of the fact that hardly any research has been conducted to trace the time course of syntactic activation in Broca's aphasics (see Hagoort, 1990, chapter five, for an exception), it seemed important to explore the use of different experimental paradigms to assess this time course.The results of the syntactic priming (chapter three) and the monitoring study (chapter four) will prove to be partially contradictory. In the discussion section of chapter four, Just and Carpenter's (1992) CC READER model of sentence comprehension is introduced in order to reconcile these seemingly contradictory results. The issue is readdressed in the final chapter (six).

In chapter five, the focus of attention is switched from Broca's language reception to Broca's language production. As pointed out above, Broca's aphasics' agrammatic spontaneous speech output is often contrasted with Wernicke's aphasics' paragrammatic spontaneous speech output. Whereas Broca's tend to omit grammatical morphemes in the context of non-fluent speech production, Wernicke's aphasics tend to substitute grammatical morphemes in the context of more fluent speech production. Because of these qualitative differences, it is tempting to assume that Broca's and Wernicke's have a different underlying grammatical impairment. Heeschen (1985), however, recently challenged this commonly held assumption. He observed that Broca's who show very few paragrammatic errors in their spontaneous speech, do make these errors in a more constrained picture description task. He reasoned that at least part of the differences between Broca's and Wernicke's problems in sentence production stem from the fact that Broca's avoid the production of grammatical morphology and Wernicke's do not (see also Kolk and Heeschen, in press). This raises the possibility that the underlying grammatical impairment is the same in Broca's and Wernicke's (see Goodglass and Menn, 1985 for a similar suggestion). In chapter five, an experiment is reported that was designed as a direct test of the same-grammatical-impairment hypothesis. In order to counter the possibility of avoidance behavior, that is, in order to insure that all subjects have to construct the same underlying syntactic representation for each sentence, a CLOZE experiment was conducted which required Dutch Broca's and Wernicke's to speak aloud various types of grammatical morphemes that were missing from a sentence. By comparing the response profiles of Broca's and Wernicke's aphasics on both error and response time measures an attempt was made to obtain a more precise test of the same-grammatical-impairment hypothesis. In the discussion of the CLOZE data, Bison's (1990) recent model of paragrammatism is used to explain the obtained order of difficulty for bound morphemes. There are two characteristics of Bison's model that make it the production analogue of the theory of Broca's receptive syntactic processing that is advocated in this thesis, namely, (1) that errors arise as a consequence of a pathological change in the temporal availability of syntactic information, and (2) that the difficulty of a particular morpheme is dependent on the complexity of the syntactic context that this morpheme requires for its agreement computation.

Chapter six, finally, provides a general discussion of the research presented in chapters two to five. To begin with, the methodological and theoretical implications for research on Broca's aphasia will be discussed. Moreover, some of the limitations of the reported research will be addressed in an attempt to delineate new lines for future research.

Chapter 2

A Computer Model of the Temporal Course of Agrammatic Sentence Understanding: The Effects of Variation in Severity and Sentence Complexity[1]

ABSTRACT

In this chapter, we present SYNCHRON, a computer model of Kolk and van Grunsven's (1985) hypothesis of agrammatic comprehension deficits. According to this hypothesis, parsing fails in agrammatic aphasics since syntactic representational elements that need to be active simultaneously are often not co-active because of disturbances in timing due to brain damage. SYNCHRON has been especially designed to account for two neglected aspects of agrammatic comprehension: degrees of severity and the sentence-complexity effect. We report an attempt to simulate data from two sentence-picture matching studies in which a qualitatively similar sentence-complexity effect was found at two different average levels of severity. This pattern was reproduced when the timing disorder was assumed to affect syntactic phrasal categories but not when it was assumed to affect function word categories. When phrasal categories were affected, it did not matter much to fit whether the damage was assumed to slow down the time for an element to be retrieved, or to decrease the time for an element to remain available.

2.1 INTRODUCTION

Aphasics belonging to major syndrome types, in particular Broca's aphasics, are known to suffer from problems with the syntactic understanding of sentences. (see for instance Tyler, 1985 and Caplan & Hildebrandt, 1988 for an overview of research and theories). When

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[1] Haarmann, H.J., & Kolk, H.H.J. (1991). *Cognitive Science, 15*, 49-87. Slightly changed version with addendum

presented with a sentence whose interpretation critically depends on syntactic form, patients often fail to choose the picture-alternative that depicts the meaning of the sentence. The focus thus far has been to only determine the locus of the problem. For example, theories have proposed that asyntactic understanding involves a problem with function words (Bradley, Garrett & Zurif, 1980; Zurif, 1984), with word-order (Schwartz, Saffran & Marin, 1980), with hierarchical phrase-structure (Caplan, 1985) and with the mapping of syntactic onto semantic relations (Linebarger, Schwartz & Saffran, 1983). However, two basic characteristics of asyntactic understanding, degrees of severity and the sentence complexity effect, have evoked very litte theoretical interest. The question is how can these two characteristics arise given a certain specification of the locus of impairment.

2.1.1 DEGREES OF SEVERITY

It is a well-established clinical phenomenon that asyntactic understanding is a disorder that exhibits degrees of severity. Of the studies employing a sentence-picture matching task some have shown subjects to perform near chance level (Caramazza & Zurif, 1976; Heilman & Scholes, 1977; Blumstein, Goodglass, Stadlender & Biber, 1983) and others above chance-level (Goodglass et al., 1979; Caplan, Matthei & Gigley, 1981; Ansell & Flowers, 1982; Kolk & Friederici, 1985). Kolk and van Grunsven (1985) repeated a study of Schwartz, Saffran and Marin (1980) in which agrammatic aphasics had to perform two tasks, a sentence-picture matching task and a sentence order (anagram) task. In both studies, patients were presented with the same three sentence types: Simple active sentences of the form subject-verb-object, their passive counterparts and locative sentences, i.e. active sentences with a prepositional phrase indicating a location. The sentence order task in Schwartz et al., however, did not include passive sentences. In both studies, the order of difficulty between tasks and between sentence types was the same. Sentence-picture matching was easier than sentence ordering and locative and passive sentences were more difficult than active sentences. At the same time, overall performance on both tasks was better for the aphasics in Kolk and van Grunsven than for those in Schwartz et al.. From these results, Kolk and van Grunsven concluded that their patients were suffering from the same underlying syntactic disorder as the patients in Schwartz et al., but to a lesser degree. The same result, differences in degree but not in order of difficulty observed, was obtained by Naeser et al. (1987) who tested nine aphasia groups for their syntactic understanding of a set of 10 syntactic contrasts. Naeser et al. also found that performance on this test was highly correlated both with performance on the well-known Token Test and with patient lesion size. The last two measures can be interpreted as reflecting the general severity of the aphasic disorder. Caplan and Hildebrandt (1988) made a similar observation as Kolk and van Grunsven (1985). Across groups of aphasic patients with different average severity, complex sentences were more difficult to understand than simple ones.

At first glance, the observation that syntactic understanding problems can occur with degrees of severity seems quite trivial. Quantitative variation is to be expected, since aphasics' brain damage varies in degree. For example, lesions vary in depth and extent and in proximity to areas that are believed to be involved in syntactic understanding (Naeser et al., 1987). Nevertheless, it was only in 1985 that Kolk and van Grunsven proposed an explicit information processing account of how degrees of severity in aphasics' asyntactic understanding could be caused. As will be explained below, Kolk and van Grunsven assume that the representations of sentence elements are still intact in agrammatic aphasics but that their availability in time is disturbed to different degrees. An alternative to this approach would be to assume that the representations of sentence elements are no longer intact but degraded to different degrees. Connectionist models offer a possibility to degrade distributed knowledge representations to different degrees (Rumelhart & McClelland, 1986) by varying the number of lost connections or units or by adding noise (McClelland, 1986). This concept of 'graceful degradation' has not yet been applied to the problem of severity in asyntactic understanding.

Kolk and van Grunsven (1985) criticized previous theories of asyntactic understanding for not being able to account for degrees of severity. Typically, theories of asyntactic understanding state that some ability is lost or impaired. This can be interpreted in two different ways. First, the ability is completely lost. Kolk and van Grunsven argued that this interpretation cannot explain above-chance performance, even if one takes into account that aphasics use strategies to cope with their syntactic understanding problem. Second, the ability functions less efficiently. Kolk and van Grunsven argued that this interpretation is underspecified as to how degrees of severity in asyntactic understanding are caused. Therefore, they proposed the following theory.

To begin with, the authors point out certain processing restrictions to which syntactic understanding is subject. Syntactic understanding requires that a sentence representation is constructed over time. Construction proceeds as a series of activations of lexical and syntactic elements and is subject to two important processing restrictions. First, a representational element is only available for processing if its activity is above a certain critical value. The activation rate of an element determines how long it takes the element to build up enough activity to surpass the critical value. Then, the decay rate of an element determines how long it takes the element's activity to drop below the critical value. Second, a certain amount of synchrony between elements is required. The context-dependent nature of language requires certain elements to be active above threshold at the same time (e.g. the gender of an article and noun). Kolk and van Grunsven call the latter processing restriction the requirement of 'computational simultaneity.'

Assuming the above processing restrictions, Kolk and van Grunsven point out how problems with syntactic understanding could arise and how such problems could arise to different degrees. The requirement of computational simultaneity of two or more elements is violated if the first activated element is no longer available in memory when the last activated element rises above critical value. Three pathological changes might be responsible for this. First, a memory capacity limitation of some specialized memory store makes it impossible to hold enough elements. Second, a too-fast decay rate makes the first activated element drop below critical value, and thus unavailable, before the last activated element arrives. Third, a too-slow activation rate causes the last activated element to arrive too late, since the first activated element will already have decayed naturally below critical value. Degrees of severity correspond to between-subject differences in degree of pathological change, i.e. degree of memory capacity restriction, amount of increase in decay rate or amount of decrease in activation rate. The more a patient suffers from these pathological changes, the more likely he will fail to understand sentences correctly.

Caplan and Hildebrandt (1988) have taken the first option, a memory capacity limitation, to account for degrees of severity. They speak of 'decrease in available parsing work space.' However, they have not attempted to make this term more explicit, since its formal quantification would require the detailing of which elementary operations are carried out in a specified period of time. Caplan and Hildebrandt argue that such a specification would be too much dependent on which of several implemented instantiations of a particular parser is chosen. In this article, a computer simulation of degrees of severity is reported that works out the two hypotheses on temporal restriction: the 'slow-activation' hypothesis and the 'fast-decay' hypothesis. An attempt was made to minimize the effect of choice of parser and implementational details on the simulation of temporal restrictions as much as possible.

Kolk and van Grunsven place themselves within the "chronogenetic" tradition in neuropsychology, with such spokesmen as Von Monakow (1914), Luria (1970) and Lenneberg (1967), all of whom stressed that units of movement and language have to be activated at the proper moment in time. Lenneberg (1967) takes the radical view that "almost all of the central nervous system disorders of speech and language may be characterized as disorders of timing mechanisms" (p. 218). More recently, Grodzinsky, Swinney and Zurif, (1985) and Friederici (1988) have stressed the importance of the temporal integration of different types of information that are involved in the on-line construction of a sentence representation. Gigley (1982, 1983) was the first to simulate sentence understanding problems as a function of an increase in decay rate and a decrease in activation rate, by means of a computer model. These authors have not, however, applied their insights specifically to the problem of degrees of severity.

Having characterized asyntactic understanding as a disturbance of the synchrony between representational elements, the question arises as to which type of element is impaired in its processing. Where agrammatic aphasics are concerned, the processing of two types of elements could be impaired. First, the processing of syntactic category information that is associated with function words (e.g., determiner, preposition) could be impaired. Several researchers have suggested that agrammatic patients cannot use function words for the on-line construction of phrase structures (Bradley et al., 1980; Zurif 1982, 1984; Friederici 1983, 1988). A second logical possibility, however, is that it is the processing of higher order syntactic information that is impaired, in particular, the syntactic category information associated with phrases (e.g. noun-phrase, prepositional-phrase). Both function word and phrasal categories enter into representations of phrase-structure. Therefore, a processing problem with both types of elements could cause asyntactic understanding.

It is now possible to specify four different hypotheses regarding degrees of severity in asyntactic understanding. These hypotheses differ with respect to the type of pathological change (decreased activation rate vs increased decay rate) and the type of element affected (function word category vs phrasal category).

Hypothesis 1: Degrees of severity correspond to different decreases in the activation rate of function word categories.

Hypothesis 2: Degrees of severity correspond to different increases in the decay rate of function word categories.

Hypothesis 3: Degrees of severity correspond to different decreases in the activation rate of phrasal categories.

Hypothesis 4: Degrees of severity correspond to different increases in the decay rate of phrasal categories.

2.1.2 THE SENTENCE-COMPLEXITY EFFECT

Besides degrees of severity, there is another basic characteristic of asyntactic understanding for which explicit information processing accounts are notably lacking: the sentence-complexity effect. Schwartz et al. and Kolk and van Grunsven (discussed above) found that locative and passive sentences were more difficult to process than simple active sentences containing no prepositional phrase. Other researchers have also observed that aphasic patients fail to understand syntactically complex sentences more often than simpler ones (see for instance, Caramazza & Zurif, 1976; Goodglass et al., 1980 and Caplan and Hildebrandt, 1988).

Kolk and van Grunsven have explained the sentence-complexity effect in terms of their earlier mentioned theory of asyntactic understanding which assumes that agrammatic aphasics suffer from one of three pathological changes: a capacity reduction of a specialized syntactic short term memory store, a decrease in the activation rate or an increase in the decay rate of sentence-representational elements. Such changes can be expected to affect syntactically complex sentences more than simple ones, since complex sentences have more elements and take more time to process than simple ones. Recently, also Caplan and Hildebrandt (1988) suggested that the complexity effect could arise as a consequence of storage limitations internal to the parsing system.

A minimal requirement for a theory of the sentence-complexity effect in asyntactic understanding is that it explains why a certain complex sentence is more difficult to process than a simpler one. A more demanding requirement would be to explain why a particular difference in error score between complex and simple sentences is obtained. To our knowledge, an attempt to account for the size of the relative differences between the error percentages of complex and simple sentences has never been undertaken. This article reports a computer simulation study that is based on an implemented version of Kolk and van Grunsven's temporal hypothesis, in which we tried to simulate the relative differences in error percentages between active, locative and passive sentences as were obtained in the comprehension studies of Schwartz et al. and Kolk and van Grunsven.

In summary, we tried to simulate two effects at once: degree of severity and sentence complexity. The question, of course, was whether both effects could be simulated in a single model. Of particular interest was to determine under which of the four hypotheses given above would this be possible. Since the studies of Schwartz et al. and Kolk and van Grunsven included only agrammatic aphasics, the conclusions of the simulation study are necessarily restricted to this type of patient. A computer model, SYNCHRON, was designed to keep track of the complex interactions in time, that are implied by the above proposal. The development of such a computer model is in line with the recent call by researchers in aphasia for more explicit models of cognitive dysfunction (Arbib & Caplan, 1979; Caplan & Hildebrandt, 1988; Tyler, 1988). The next section describes the computer model, SYNCHRON.

2.2 SYNCHRON: A SIMULATION MODEL OF THE TIME-COURSE OF PARSING

The area of artificial aphasia (terminology borrowed from Gigley, 1982), though still in its infancy, is rapidly expanding. Lavorel (1982) and Marcus (1982) were among the first to suggest the potential value of using computer models as a means to develop and test theories about aphasic symptoms. Lavorel's (1982) JARGONAUT model is intended as a computational architecture within which different hypotheses about the speech deficit of Wernicke's aphasics could be simulated. Marcus (1982) indicates how agrammatic comprehension could be simulated by removing the closed-class lexicon from an implemented parser. His all-or-none loss approach, however, does not allow to define degrees of severity (cfr. Kolk and van Grunsven). During the last decade, several researchers have made an attempt to actually simulate aphasic symptoms. Gordon (1982) simulated confrontation naming by cutting connections in an associative network. It is interesting to note that several computer models have postulated slow activation and fast decay as explanatory factors of aphasic symptoms. In the context of Dell's speech production model (1986), a less efficient spread of activation (i.e., reduced activation rate) has been postulated as the primary cause for the abnormally high incidence of perseverations in the speech output of two cases of Jargon aphasia (Bloch and Schwartz, 1989 and Schwartz, Saffran and Dell, 1990). Furthermore, in the context of the same model, the semantic and phonemic paraphasias that were observed in a case of deep dysphasia have been attributed to a pathologically rapid decay (Martin and Saffran, 1991). Gigley (1982, 1983) used her HOPE model to simulate problems with the derivation of thematic roles either by slowing down the feed forward of syntactic information or by increasing the rate by which lexical information decays. A major drawback of the HOPE model was its limited computational power. In order to parse even simple active subject-verb-object sentences, HOPE had to resort to the use of non-syntactic information, i.e. phonological information about the sentence end (Gigley, 1983). Another limitation of the HOPE model was that it did not yield quantitative results (i.e., error percentages for different sentence types) which could be compared to actual data. One of the goals of the present simulation study was to overcome this latter limitation. Finally, inspired by a previous version of this chapter, Kempen and Vosse (1989) also carried out a quantitative simulation of agrammatic comprehension. As will be discussed in an addendum to this chapter (section 2.5), their "Unification Space" model provides an alternative way for implementing Kolk and van Grunsven's temporal deficit theory.

In this section, we describe a new computational model of aphasic language breakdown, SYNCHRON. The model is socalled because it simulates agrammatic sentence understanding as the outcome of a lack of synchrony during the processing of a sentence (cfr. Gigley above) SYNCHRON represents a further specification of Kolk and van Grunsven's theory of degrees of severity and the sentence complexity effect in agrammatic sentence understanding. It should be stressed at the outset of the model's description that the parsing process itself, i.e. determining which phrase-structure representation can be assigned to a sentence, is not simulated. The model is supplied with a pre-specified phrase-structure representation and computes whether its complete build-up would have possible given certain assumptions about the time-course of activation of its constituting elements. In other words, SYNCHRON is not a model of the parsing process itself but of the assumed time-course of parsing. Only one qualitative assumption about the parsing process itself is made, the "No Incomplete Nodes principle." Frazier and Fodor (1978) formulated this principle to describe a bottom-up parsing scheme. It states that a node is only entered into a phrase marker when all of its daughter categories have been established.

Below, we will briefly discuss why a phrase-structure representation is important in syntactic understanding, how it looks and which assumed temporal constraints determine its buildup. These constraints include the "simultaneity requirement" which represents a temporal specification of the "No Incomplete Nodes Principle". A step-by-step processing example is added to illustrate SYNCHRON's mechanism of comprehension failure. Finally, it is explained how degrees of severity are conceptualized and how the sentence-complexity effect arises. In appendix A, an outline is given of the algorithm that implements the model assumptions described in this section. The algorithm specifies one run of a sentence.

2.2.1 PHRASE-STRUCTURE REPRESENTATION

This simulation attempts to simulate experimental data from two studies by Schwartz et al. and Kolk and van Grunsven that both employed a sentence-picture matching task. In such a task, the subject is presented with a sentence and must choose from a set of picture alternatives the one that depicts the meaning of the sentence. To choose the correct picture, the subject has to determine which phrases occupy what 'thematic roles'. For example, in the sentence "The man who greeted the woman smiled", the noun phrase "the man" occupies the Agent role (Who/What did it?) both of the verb "greeted" and of the verb "smiled" and the noun phrase "the woman" occupies the Theme role (To whom/what was it done?) of the verb "greeted". Thematic roles can be uniquely determined by reference to a hierarchical phrase-structure representation of a sentence. For example, in the foregoing sentence, the noun phrase "the woman" is not mistaken as the Agent of the verb "smiled" because "the woman" is embedded in a relative clause. The consequence of the dependency of thematic roles on hierarchical phrase-structure is that a failure to complete the build-up of a phrase-structure representation causes problems with syntactic understanding in a sentence-picture matching paradigm. If other sources of information to determine thematic roles, such as verb-selection restrictions (e.g. The agent of the verb "to see" has to be Animate), are eliminated or controlled for (Berndt & Caramazza, 1980; Blumstein et al., 1983), the subject is left with guessing the correct picture alternative or applying a failing strategy.

SYNCHRON represents the phrase-structure of a sentence as a set of hierarchically ordered nodes at three different representational levels. The lowest level represents the surface form of input words. The next level represents the syntactic categories that are associated with these word forms, lexical categories. (See Kempen & Huybers, 1983 and Garrett, 1980 for arguments for a dual representation of words). The highest level represents the syntactic categories that are associated with phrases, phrasal categories. The distinction between lexical and phrasal categories is illustrated in figure 1 which depicts the phrase-structure of the passive sentence: "The man is greeted by the woman." This sentence consists of the lexical categories: determiner (DET), noun (NOUN), auxiliary (AUX), verb (VERB), preposition (PREP), determiner (DET) and noun (NOUN). The first DET-NOUN sequence can be grouped into a noun phrase (NP). The same is true for the second DET-NOUN sequence. The PREP and second NP can be grouped into a prepositional phrase (PP). At the next higher level, AUX VERB and PP can be grouped into a verb phrase (VP). The first NP and the VP, finally, can be grouped into a sentence (S). Note that the phrasal categories represent the hierarchical ordering of phrases. It is assumed that the build-up of a phrase-structure representation is subject to temporal constraints. These are discussed next.

2.2.2 RETRIEVAL AND MEMORY TIME

The availability of phrase-structure elements in time is determined by two parameters: retrieval and memory time. The first one, retrieval time, determines how long it takes to retrieve an element and make it available for processing. The second one, memory time, determines how long an element remains available for processing once it has been retrieved. Retrieval time and memory time determine the length of two discrete process phases that follow each other in The SYNCHRON model is not the only possible specification of Kolk and van Grunsven's temporal restriction hypothesis. One specification that we did not pursue is to model the temporal availability of phrase-structure elements as a continuous activation process in which activation and decay rate determine the height of an element's activity value simultaneously (see for instance Cottrell & Small, 1985; Waltz & Pollack, 1985). One then could assume that an element is only available to processing if its activity value exceeds a certain critical value. In such a model, the length of the time period that an element needs to become available and the length of the time period that an element remains above critical value are interdependent. When the activation rate is decreased, an element rises above critical value later and drops back below it sooner. The same is true when the decay rate is increased. Our specification, instead, allows to independently manipulate the time period that an element needs to become available and the time period that an element remains available.

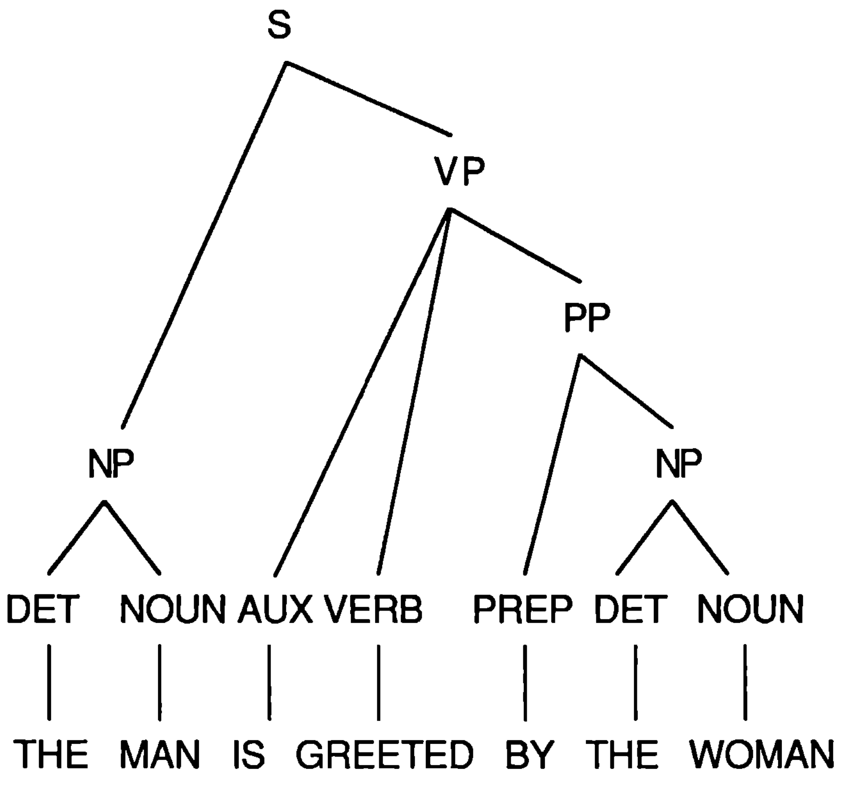

Figure 1. Phrase structure of a passive sentence.

2.2.3 COMPUTATIONAL SIMULTANEITY

Construction of the phrase-structure representation proceeds from bottom to top. Input words trigger the retrieval of word-forms. Word-forms trigger the retrieval of their associated lexical categories. Lexical categories trigger the retrieval of phrasal categories. The retrieval of phrasal categories is subject to an important temporal constraint: A phrasal category is only retrieved if all its daughter categories are computationally simultaneous. To be computationally simultaneous all daughter categories have to be in their memory time phase. Daughter categories are the syntactic categories that together make up a phrase. Both NP's in figure 1, for example consist of two daughter categories, a DET followed by a NOUN. The PP in figure 1 consists of two daughter categories, PREP and NP.

2.2.4 PROCESSING EXAMPLE

The temporal build-up of a verb phrase (VP) is illustrated in figure 2a. Figures 2b and 2c show how the requirement of computational simultaneity that is necessary for VP retrieval can be violated by increasing retrieval time (2b) or by decreasing memory time (2c). An artificial time scale of positive integer values has been defined with 1 as a unit. Within each subfigure, all three types of phrase-structure elements, i.e. wordforms, lexical and phrasal categories, are subject to the same retrieval time. With the exception of the word form "GREET" in figure 1a, retrieval of word forms has not been indicated. The same is true for memory time. The values for retrieval and memory time have been arbitrarily chosen to match the example.

Figure 2a depicts the 'normal' build-up of a VP like "greets the woman." At every new time interval (1 time unit), a new word is introduced. For the first word "greets", it is shown how retrieval of the wordform GREET at time interval 1 triggers retrieval of its lexical category VERB (V) at time interval 2. At time interval 3, the memory time phase of the VERB category starts for 4 time intervals. Also, at time interval 3, the retrieval of the lexical category DET (D) is triggered. At time interval 4, the memory time phase of the DET category starts for 4 time intervals. Furthermore, at time interval 4, the retrieval of the lexical category NOUN (N) is triggered. At time interval 5, the memory time phase of the NOUN category starts for 4 time intervals. Simultaneously, at time interval 5, retrieval of the phrasal category NP is triggered. Note that the requirement of computational simultaneity, necessary for NP retrieval, is fulfilled. The NP has two daughter categories, DET and NOUN, which are both in their memory time phase at time interval 5. At time interval 6, the memory time phase of the NP starts for 4 time intervals. Also, at time interval 6, retrieval of the phrasal category VP is triggered. Again, note that the requirement of computational simultaneity is fulfilled. The VP has two daughter categories, VERB and NP, which are both in their memory time phase at time interval 6. At time interval 7, finally, the memory time phase of the VP starts for 4 time intervals.

Figure 2b demonstrates the effect of increasing retrieval time on computational simultaneity. Memory time is kept the same as in figure 2a: 4 time intervals. Retrieval time, which was 1 time interval in figure 2a, has been set at 2 time intervals. Although the lexical categories VERB, DET and NOUN arrive at their memory time phase one time interval later than in figure 2a, the temporal relations that exist between these categories have not been changed. The memory time phase of DET and NOUN starts one time interval later. Consequently, retrieval of the NP is triggered one time interval later, at time interval 6. Note that the requirement of computational simultaneity necessary for NP retrieval is fulfilled. The

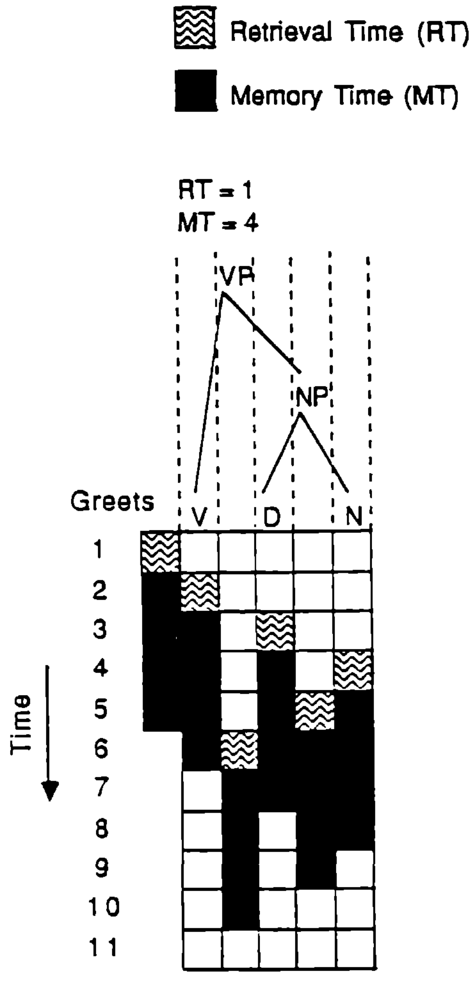

Figure 2a. Simultaneity fulfilled.

NP has two daughter categories, DET and NOUN, which are both in their memory time phase at time interval 6. Retrieval of the NP takes 2 intervals instead of just 1 as in figure 2a. At time interval 8, the memory time phase of the NP starts. The memory time phase of the preceding VERB has ended, however, 1 time interval earlier, at time interval 7. Therefore, the requirement of computational simultaneity necessary for VP retrieval is not met and retrieval of the VP is not triggered. The example in figure 2b demonstrates that increasing retrieval time

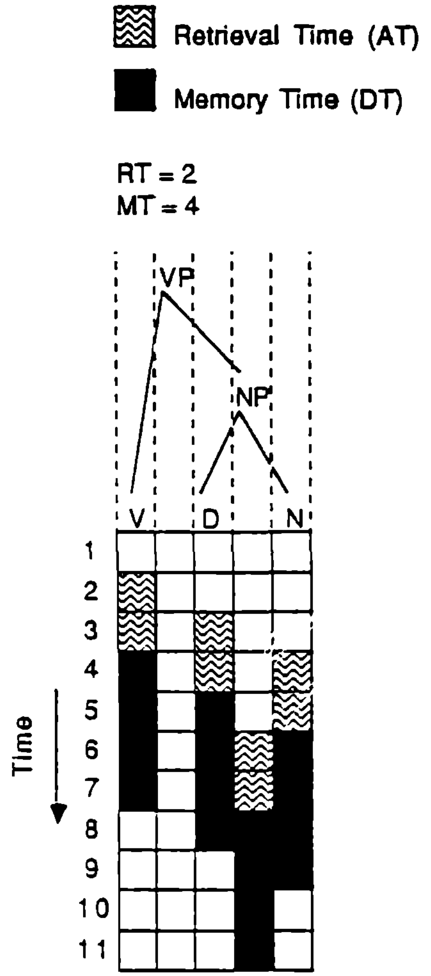

Figure 2b. Simultaneity disrupted by retrieval time increase.

not merely slows down overall processing, but can disrupt computational simultaneity between elements in a hierarchical phrase-structure representation.

Figure 2c showes the effect of decreasing memory time on computational simultaneity. Memory time, which was 4 time intervals in figure 2a, has been decreased with 1 time interval to 3 time intervals. Retrieval time is kept the same as in figure 2a, 1 time interval. The lexical categories VERB, DET and NOUN arrive at their memory time phase during the same time intervals, 3, 4 and 5, respectively, as in figure 2a. The difference with figure 2a is that these

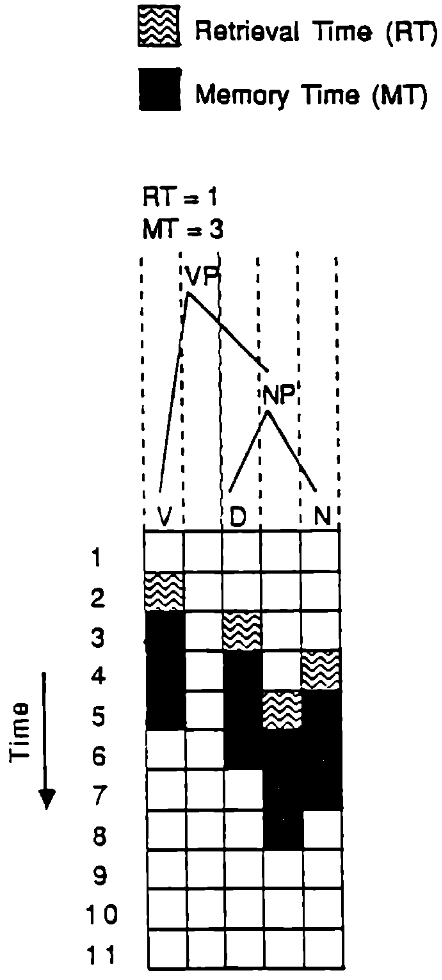

Figure 2c. Simultaneity disrupted by memory time decrease.

categories remain in their memory time phase only 3 instead of 4 time intervals. At time interval 5, both DET and NOUN are in their memory time phrase, and by definition, are computationally simultaneous. Consequently, retrieval of the NP can be triggered. The VP, however, cannot be retrieved. The categories VERB and NP are not computationally simultaneous: at time interval 6, when the memory time phase of the NP starts, the VERB is no longer in its memory time phase.

2.2.5 DEGREES OF SEVERITY

The first step towards our conceptualization of degrees of severity is the observation that on a particular sentence type patients do not always perform at chance level (Caramazza and Zurif, 1976; Heilman and Scholes, 1977; Blumstein, Goodglass, Stadlender and Biber, 1983), but also above chance level (Goodglass, Blumstein, Gleason, Hyde, Green and Stadlender, 1979; Caplan, Matthei and Gigley, 1981; Ansell and Flowers, 1982; Kolk and Friederici, 1985; Kolk and van Grunsven; Martin, Wetzel, Blossom-Stach, & Feher, 1989). One could try to explain above-chance performance by assuming that patients use heuristic strategies to compensate for a lost ability to derive thematic roles from phrase-structure. However, Kolk and Friederici (1985) and Kolk and van Grunsven argued that such an account could not explain their set of data (see the respective papers for details).

An alternative account for above-chance performance is to assume that agrammatic aphasics sometimes succeed in building up a phrase-structure representation and sometimes not. In SYNCHRON, this characteristic is realized by assuming that, within a patient, one of the two temporal parameters, retrieval time or memory time, varies from moment to moment according to a probability distribution with a patient-specific mean. The effect of within-subject variation in retrieval time or memory time can be illustrated by means of figures 2a, 2b and 2c. With retrieval time fluctuating between 1 and 2, the same subject would sometimes be in the situation depicted in figure 2a (simultaneity fulfilled) and sometimes in the situation depicted in figure 2b (simultaneity violated). Alternatively, with memory time fluctuating between 4 and 3, the same subject would sometimes be in the situation depicted in figure 2a (simultaneity fulfilled) and sometimes in the situation depicted in figure 2c (simultaneity violated). In both cases, the phrase-structure representation would be available for derivation of thematic roles for only a certain percentage of times. The percentage of times that computational simultaneity is fulfilled is dependent on the mean and variance of probability distribution that determines retrieval time or memory time. In SYNCHRON, differences in degree of severity among patients are conceptualized by different increases in the mean of the probability distribution that determines retrieval time or by different decreases in the mean of the probability distribution that determines memory time.

It should be pointed out that it is not possible to conceptualize degrees of severity without making the assumption that retrieval time or memory time have a certain probability distribution. Consider the processing example in figure 2a and b. When the retrieval time is 1 time interval, build-up of the VP succeeds. When the retrieval time is 2 time intervals, the VP cannot be retrieved. With a retrieval time of 3 time intervals or longer (not shown in figure 2), retrieval of the VP also fails. In other words, there is a certain retrieval time at and beyond which retrieval of the VP fails. Thus, for patients with a constant retrieval time of 1 time interval one would predict errorless performance and for patients with a constant retrieval time of 2 or more one would predict chance-level performance. With retrieval time kept constant, it is not possible to obtain any other error percentages in between.

2.2.6 SENTENCE COMPLEXITY

In SYNCHRON, the complexity of processing a sentence is determined by the temporal demands of building a hierarchical phrase-structure representation. Throughout the paper it will be assumed that, broadly speaking, the number of syntactic categories determines syntactic complexity (other definitions are possible as well, see for instance Frazier, 1985). Specifically, syntactic complexity is dependent on the width and the depth of the phrase-structure representation. Width refers to the number of immediate daughter categories of a phrasal category. With more daughter categories in between the first and the last retrieved daughter category, simultaneity is more difficult to achieve because the first retrieved daughter category has to remain in its memory time phase for a longer period of time. Depth refers to the number of levels of subcategories. The more subcategories a syntactic daughter category has, the longer it takes to retrieve that daughter category and the higher the probability that already retrieved daughter categories are no longer available. This effect is enhanced both with increased retrieval time and decreased memory time.

A remark of caution should be made, however. As the simulation results presented in the next section show, the generalization that width and depth of the phrase-structure representation determine processing complexity does not always hold. With certain sentence orders and with certain phrase-structure elements affected by temporal changes, counter-intuitive results may be obtained.

2.3 SIMULATIONS

An attempt was made to simulate degrees of severity and the sentence complexity effect as obtained in two studies of agrammatic sentence understanding (Schwartz et al. and Kolk and van Grunsven). In this section, these studies as well as our simulation procedure are described in more detail. Three important aspects of that procedure are stressed: definition of normal processing, definition of degrees of severity and subsequent selection of those degrees of severity for which the group error percentages can be simulated best. Other aspects of our simulation procedure, such as which phrase-structures were assumed for the various sentence types and the number of runs per sentence type are also mentioned. Finally, the simulation results that were obtained under the different hypotheses of degrees of severity (see introduction) are discussed. From the previous section, it should be clear that these hypotheses should be rephrased in terms of changes in mean retrieval and memory time.

2.3.1 EMPIRICAL STUDIES

Schwartz et al. and also Kolk and van Grunsven auditorily presented agrammatic Broca's aphasics with 3 sentence types: active, locative and passive sentences. Sentences (1) to (4) below form a representative sample of active, locative and two passive sentence types, respectively. The number of instances per sentence type that patients were presented with is noted in parenthesis after each example.

(1) De man groet het meisje. (N=20)
(The man greets the girl.) (N=24)

(2) De man is/loopt achter het meisje (N= 14)
(The man is/walks behind the girl.) (N= 24)

(3) Het meisje wordt gegroet door de man.
(The girl is greeted by the man.)(N=24)

(4) Het meisje wordt door de man gegroet. (N=20)
*(The girl is by the man greeted.)

The two studies used different types of passive sentences Schwartz et al. used the first type of passive (3) and Kolk and van Grunsven the second one (4). Contrary to English, Dutch not only allows the first type of passive but also the second one. Kolk and van Grunsven report that it made no difference whether the verb in the locative sentences was the verb "to be" or a more contentive verb "to lie". Schwartz et al. only included the first type of verb. All sentences were semantically reversible, that is, the agent and direct object roles could be reversed. Subjects had to choose between two picture alternatives, one depicting the meaning of the input sentence and the other one representing the inverse relation. This forced patients to take syntactic structure into account while trying to fulfill their task. Separate tests were used to check for the lexical understanding of locative prepositions (both studies) and nouns (only Kolk and van Grunsven). The percentage of lexical errors appeared to be negligible, as was to be expected for Broca agrammatics.

The group error percentages for active, locative and passive sentences were 13, 22 and 22, respectively, in the study of Kolk and van Grunsven and 28, 44 and 48, respectively, in the study of Schwartz et al.. The error percentages for active sentences in experiments I and III in the latter study were pooled in order to obtain a more reliable estimate. Patients in both studies had more problems with locative and passive sentences than with active sentences, whereas locative and passive sentences appeared to be equally difficult. The results also seem to indicate an interaction between sentence complexity and degree of severity. As the average degree of severity increases, the difference between active and locative sentences increases from 9 to 16 and the difference between active and passive sentences increases from 9 to 20. Unfortunately, the small number of patients, inequality of group size and difference in type of passive sentences in both studies preclude the use of analysis of variance to statistically verify the presence of such an interaction.

How reliable is the sentence-complexity effect reported in both studies? The finding that aphasics have more processing difficulties with reversible passive sentences than with their active counterparts has not only been reported by Schwartz et al. and Kolk and van Grunsven, but also by others (Laskey, Weidner & Johnson, 1976; Brookshire & Nicholas, 1980; Ansell & Flowers, 1982; Caplan & Futter, 1986; Moore, 1986; Friederici & Graetz, 1987; Caplan & Hildebrandt, 1988). We are aware of only one deviant result. Jarema, Kadzielawa and Waite (1987) report a Polish agrammatic patient for whom reversible active sentences were more difficult to understand than reversible passive sentences. This deviant result can be easily explained, however. The past participle in Polish corresponds in number and gender with the noun-phrase that occupies the agent role. In the sentences used by Jarema, Kadzielawa and Waite, this noun-phrase always had a different number than the noun-phrase that corresponded to the direct-object role. Thus, their aphasic patient had an extra clue for deriving the agent and direct-object roles.

Much less data are available about the relative difficulty of locative sentences. The finding of locative and passive sentences being equally difficult was not only reported by Kolk and van Grunsven but also by Kolk and Friederici (1985). In the latter study, the result was obtained for Dutch as well as German Broca's and Wernicke's aphasics.

2 3.2 DEFINING NORMAL PROCESSING

The first step in our simulation studies was to define normal processing, that is, to tune the model so that it could account for normal processing. Tuning refers to the choice of word introduction times and parameter values for both retrieval and memory time. Values for these parameters were obtained so that the set of sentences used in the studies of Schwartz et al. (1980) and Kolk and van Grunsven (1985) would be processed without failure in 100 runs. This set included active, locative and passive sentences of the types that are listed above (1-4). Their assumed phrase-structure representations expressed in rewrite form can be found in appendix B. A processing failure occurred if a phrase-structure representation could not be constructed completely because of one or more violations of the simultaneity requirement. We assume that without a complete phrase-structure representation, thematic roles cannot be determined. The possibility that a patient applies strategies based on a linear sequence of lexical categories, e.g. the agent comes first in a NOUN VERB NOUN sequence (Caplan & Hildebrandt, 1988), or the possibility that a patient parses only the beginning of a sentence, e.g. the first three words of "the man greets the woman," (Kolk & Friederici, 1985) is not taken into account in the simulations reported here (see also Kolk and van Grunsven, 1985, p. 365). However, the possibility that a patient can select the correct picture by guessing was taken into account. The guess-correction of processing failures (p. 0.5) was computed on-line, i.e. each time a processing failure occured.

In the absence of empirical data about the timing properties of our model, assumptions about such properties were kept as simple as possible. On an artificial time scale of positive integer values with 1 as the time unit, new input words were introduced at every time interval. All three types of phrase-structure elements, word forms, lexical and phrasal categories, were assumed to be subject to the same retrieval time. The same was true for memory time. Normal tuning was achieved in two different ways depending on whether the obtained parameter values served as the starting point for the simulations in which degrees of severity were conceptualized by increases in mean retrieval time (1) or by decreases in mean memory time (2). In the first case (1) , memory time was set at 13 and retrieval time was given a probability distribution. Retrieval times were 1, 2 and 3 and their respective probabilities were .25, .50 and .25. In the second case (2), retrieval time was set at 1 and memory time was given a probability distribution. Memory times were 9, 10, and 11 and their respective probabilities were .25, .50 and .25. Note that in both cases a symmetrical probability distribution was chosen with the smallest possible standard deviation (.71).

A check was performed to see whether the normally tuned model could distinguish between performance on complex sentences that normals can still process and performance on complex sentences that normals find difficult to process. Several researchers (Millar & Isard, 1964; Blumenthal, 1966; Stolz, 1967; Frazier & Fodor, 1978) have reported on the extreme processing difficulties that normals have with sentences that contain 2 center-embedded relative clauses (5).

(5) The girl that the boy that the woman knew greeted smiled.

(6) The girl that the boy greeted smiled.

(7) The girl that the boy greeted gave his book to the woman.

Sentences that contain only one center-embedded relative clause can still be understood (6) (7). With both types of normal tuning (see above), SYNCHRON processes single center-embedded sentences, like (6) and (7) below, 100 percent correctly in 100 runs, respectively.

Double center-embedded sentences like (5), on the other hand, are processed with 0 percent correctly in 100 runs. This is a somewhat extreme result as real human subjects may occasionally succeed in understanding even double center-embedded sentences. However, relaxing the temporal constraints (i.e., by decreasing the retrieval time and increasing the memory time) to achieve such occasional understanding is unlikely to have any influence on the relative order of difficulty among sentence types. The assumed phrase-structure representation of sentences 5,6 and 7 can be deducted from the rewrite grammar in appendix B.

2.3.3 DEGREES OF SEVERITY: DEFINITION AND SELECTION

Except for those phrase-structure elements that were hypothesized to be effected by a temporal disorder, retrieval and memory time were the same as for the normally tuned case. A continuum of degrees of severity was defined so that a continuum of percent correct could be simulated for each of the three sentence types (active, locative and passive) ranging from 0 to 100 percent correct. For the simulations in which degrees of severity were conceptualized as corresponding to increases in mean activation rate, 16 degrees of severity had to be defined with means ranging from 2 to 17 time units. Either function word categories or phrasal categories were affected by these temporal changes. For the simulations in which degrees of severity were conceptualized as corresponding to decreases in mean memory time, 9 degrees of severity had to be defined with means ranging from 10 to 2 time units. Again, either function word categories or phrasal categories were affected by these temporal changes. The form of the distributions was the same as for the normally tuned case with a standard deviation of .71. The error percentages obtained per simulated degree of severity per sentence type are based on the average error percentage in 10 blocks of 20 runs. This procedure was followed in order to get a reliable estimate of the error percentage in a block of 20 runs, i.e. the approximate number of instances of a sentence structure used in the empirical studies. The non-deterministic nature of the model causes this error percentage to fluctuate. The following procedure was used to select those degrees of severity for which the group error percentages in the empirical studies could be simulated best. For each individual patient in the empirical studies and also for each degree of severity in the simulations, the average error percentage across active, locative and passive sentences was computed. Next, those particular degrees of severity were chosen for which the average performance across the three sentence types matched most closely that of the individual patients. Thus, each actual patient corresponds with a simulated patient, that is, a particular degree of severity. Then, for each empirical study separately, the average error percentages across simulated patients were computed.

2.3.4 SIMULATION RESULTS

Table 1 lists the mean number of errors and standard deviations for active, locative and passive sentences for the studies of Schwartz et al. and Kolk and van Grunsven as well as for their simulated counterparts for four different simulated hypotheses. The actual number of sentences for each sentence type in each of the two empirical studies is reported above. The mean error percentages for obtained and simulated data are depicted in figure 3. Figures 3a,b,c and d show the simulated data that were obtained under four different hypotheses. Indicated by numbers, these hypotheses are: Degrees of severity correspond to different increases in the mean retrieval time of function word categories (1) or of phrasal categories (3) or to different decreases in the mean memory time of function word categories (2) or of phrasal categories (4).

Under all four hypotheses it was possible to simulate two groups of patients that differed in overall degree of severity. However, only under hypothesis 3 (Fig. 3c), when phrasal categories were affected by an increase in mean retrieval time, and under hypothesis 4 (Fig. 3d), when phrasal categories were affected by a decrease in mean memory time, the pattern of between-sentence variability was simulated that was obtained in both empirical studies. First, both locative and passive sentences were more difficult to process than active sentences. Second, there was an interaction between degree of severity and sentence complexity. As the average degree of severity increased, the difference in error percentage between active and locative sentences and between active and passive sentences increased from 17% to 19% and from 14% to 25%, respectively under hypothesis 3 (Fig. 3c) and from 16% to 19% and from 18% to 29%, respectively under hypothesis 4 (Fig. 3d). In particular, the relative difficulty of passive sentences, when compared to active and locative sentences, increased, as was the case for the empirical results.

The pattern of between-sentence variability, as found by both empirical studies, could not be simulated under hypotheses 1 (Fig. 3a) and 2 (Fig 3b). Under hypotheses 1 and 2, the simulated pattern of between-sentence variability was dependent on the type of passive used. When the passive with English word-order was used, the simulated pattern of between-sentence variability was the same as the one found by Schwartz et al. (Fig. 3a and 3b). As was stated above, Kolk and van Grunsven used a passive sentence whose word-order deviates from English in that the by-phrase precedes the past-participle. When this type of passive was used, the simulated pattern of between-sentence variability deviated from the one found by Kolk and van Grunsven in which passive sentences were more difficult than actives and equally difficult as locative sentences. Under hypothesis 1 (Fig. 3a), that is, when

TABLE 1

Mean number of errors (M), standard deviations (SD) and ranges (R)

		Schwartz et al., '80			Kolk & van Grunsven, '85		
		ACT	LOC	PAS	ACT	LOC	PAS
Obtained:	M	5.67	8.67	9.88	2.64	4.42	4.46
	SD	2.29	5.15	2.86	3.58	3.25	4.05
	R	2-8	3-18	6-14	0-13	0-10	0-10
Simulated:							
Retrieval time increase							
function word categories	M	5.10	8.72	8.44	2.92	6.29	2.09
	SD	3.70	1.46	1.44	3.44	3.49	3.20
	R	1-11	6-10	7-10	0-11	0-11	0-10
phrasal categories	M	4.44	8.30	9.48	1.42	4.87	4.09
	SD	4.02	1.33	0.95	3.14	2.97	3.70
	R	0-11	7-10	8-10	0-11	0-10	0-10
all categories	M	3.66	8.84	9.46	1.09	6.04	5.15
	SD	3.41	2.16	1.63	2.66	3.94	3.39
	R	0-9	5-11	6-10	0-9	0-11	0-11
Memory time decrease							
function word categories	M	2.52	7.82	9.44	0.76	3.47	6.40
	SD	2.06	2.93	0.08	1.62	4.26	3.46
	R	0-4	2-10	9-10	0-4	0-10	0-10
phrasal categories	M	4.82	8.68	10.48	1.11	4.41	4.71
	SD	4.13	1.09	0.59	2.96	3.57	3.43
	R	0-10	7-10	10-11	0-10	0-10	0-11
all categories	M	5.02	8.52	9.04	1.02	4.48	4.89
	SD	4.13	0.96	0.61	2.68	3.67	3.64
	R	0-9	7-10	8-10	0-9	0-10	0-111

Note. ACT(ive), LOC(ative), PAS(sive); N = 20 per sentence type. Schwartz et al. data transformed from N = 24 to N = 20. Simulated data averaged across 10 blocks.

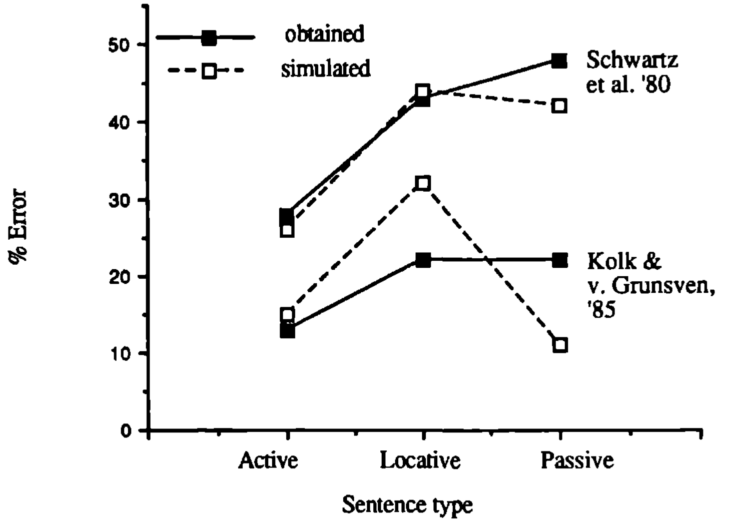

Figure 3a. Simulated hypothesis: Degrees of severity correspond to different increases in the mean retrieval time of function-word categories.

function word categories were affected by a mean increase in retrieval time, the simulated error-percentage for the 'deviant' type of Dutch passives was lower than the simulated error-percentage of active sentences. Under hypothesis 2 (Fig. 3b), that is, when function word categories were affected by a mean increase in memory time, passive sentences produced more errors than locative sentences which produced more errors than active sentences. The absolute difference in percentage of errors was about the same between passive and locative sentences (15%) as between locative and active sentences (13%).

2.3.4.1 INDIVIDUAL VARIATION

There were two types of individual variation in our simulation studies. First, variation across individual simulated patients due to differences in mean degree of severity, i.e. mean retrieval or memory time. Second, variation within each individual simulated patient due to the stochastic nature of retrieval or memory time and due to the on-line nature of the guess correction. We compared obtained and simulated data with respect to indicators of each type of individual variation.

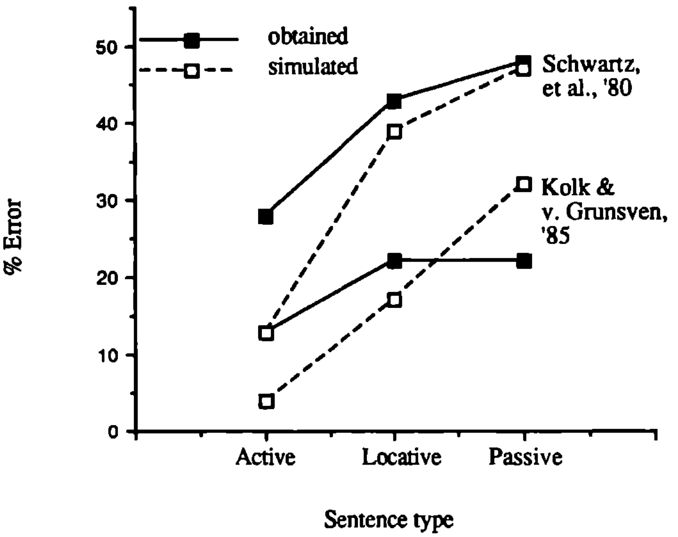

Figure 3b. Simulated hypothesis: Degrees of severity correspond to different decreases in the mean memory time of function-word categories.

Both the standard deviation and the range of variation around the mean number incorrect per sentence type at the group level can be taken as an indicant of between-patient variation. Most differences between obtained and simulated standard deviations and between obtained and simulated ranges were only slight ones (see Table 1). However, the simulated standard devations and ranges for the locative and passive sentences in the study of Schwartz et al. were systematically smaller than the obtained ones. This is due, mainly, to the below-chance performance of one of the patients in this study. We will further address this deviant result in the discussion.

Variation within individual simulated patients causes a patient's performance on a particular sentence type to fluctuate from block to block.[2] This fluctuation is such that, for a particular patient and for a particular block, deviations from the group pattern of sentence-complexity might be obtained. Therefore, we compared the number of deviations from the group pattern in the group of real and simulated patients. Four patients scored at chance level

[2] Unfortunately, we cannot compare the standard deviations across blocks per sentence type for real and simulated patients because real patients were presented with only one block of instances per sentence type.

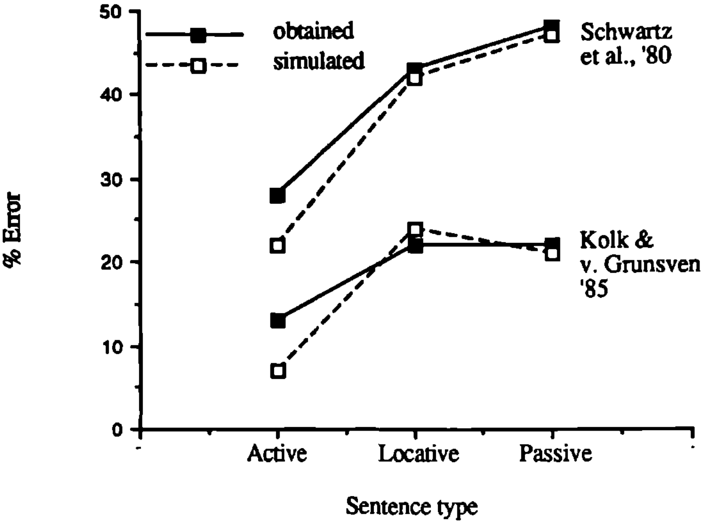

Figure 3c. Simulated hypothesis: Degrees of severity correspond to different increases in the mean retrieval time of phrasal categories.

for all three sentence types, while one patient made no errors at all. These ceiling-level and bottom-level performances were not defined as deviant. All deviant patterns either involved situations where locatives were not more difficult than actives (i.e., equally or less difficult) or situations where passives were not more difficult than actives (i.e., equally or less difficult). In the group of real patients, combining subjects from the studies of Schwartz et al. and Kolk and van Grunsven, 4 out of 16 individual patients showed such deviant patterns. For the simulation studies, we computed the number of deviant patterns per block across patients and then averaged across blocks. When phrasal categories were affected by an increase in mean retrieval time, an average of 3 deviant patterns across blocks was simulated, with a range from 0 to 5 deviant patterns. When phrasal categories were affected by a decrease in mean memory time, an average of 1.4 deviant patterns across blocks was simulated, with a range from 0 to 4 deviant patterns. We did not perform this analysis for the simulations involving a change in the temporal availability of function words categories, since these simulations did not yield reliable patterns of sentence-complexity at the group level (see above).

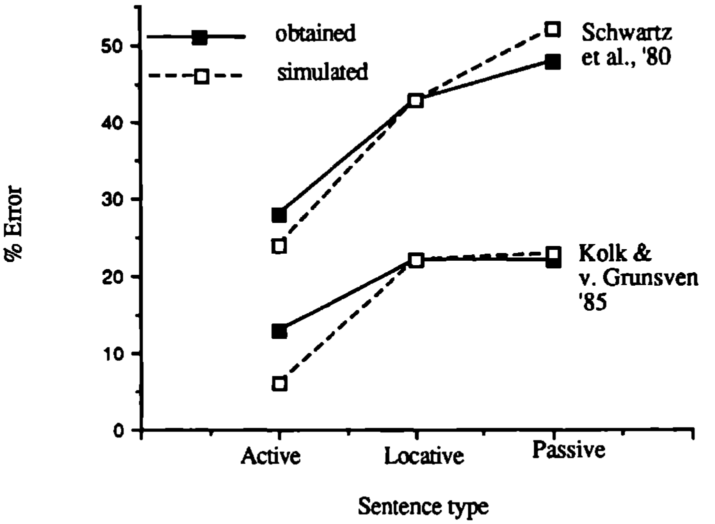

Figure 3d. Simulated hypothesis: Degrees of severity correspond to different decreases in the mean memory time of phrasal categories.

2.4 DISCUSSION

2.4.1 EVALUATION SEVERITY HYPOTHESES

Four hypotheses regarding degrees of severity in agrammatic sentence understanding were put to a test. Which ones were supported?

The group-error percentages found by Schwartz et al. and Kolk and van Grunsven, i.e. the same qualitative sentence-complexity effect at two different average levels of severity, were simulated under both hypotheses in which the temporal availability of phrasal categories was altered. It did not matter much to the fit whether degrees of severity were simulated by different increases in mean retrieval time or by different increases in mean memory time. This is what one would expect since both types of temporal changes produce variation in likelihood that one constituent will still be available when another becomes available. The results will not be exactly equivalent, for two reasons. First, recall that the requirement of computational simultaneity states that a phrasal category is only retrieved when all of its immediate daughter categories are available at the same time. Especially critical is whether the first retrieved daughter category is still available when the last retrieved daughter category becomes available. In other words, computational simultaneity is only fulfilled if the offset of the first retrieved daughter category occurs after the onset of the last retrieved daughter category. Now both these points are affected by a variation in retrieval time, whereas only the first point is affected by variation in memory time. Therefore, the amount of simultaneity might be different for a given level of retrieval time variation than for the same level of memory time variation. In order to gain some insights about the relative effects of retrieval and memory time variation on simultaneity, we ran some simulations in which a phrasal category with two daughter categories had to be retrieved. In these simulations, we assumed normally distributed retrieval and memory times with the same standard deviation. Which type of variation, retrieval vs memory time variation, produced more simultaneity appeared to be dependent on whether the mean onset of the last retrieved daughter category preceded the mean offset of the first retrieved daughter category or not. With mean onset preceding mean offset, memory time variation produced more simultaneity than retrieval time variation. With mean onset following mean offset memory time variation produced less simultaneity than retrieval time variation. A second reason that the effects of increases in retrieval time and decreases in memory time do not necessarily produce results which are exactly equivalent is that in a hierarchical representation these effects accumulate differently. The effects of increased retrieval time at a lower level in the phrase-structure representation are always noticeable at a higher level, whereas this is not necessarily true for the effects of decreased memory time. Take for example a DET and NOUN forming a NP which is attached to a PP. The increase in retrieval time or alternatively the decrease in memory time might be such that DET and NOUN are not simultaneous so that the NP and also the attached PP cannot be retrieved. Consider what happens, however, if the increase in retrieval time or the decrease in memory time is such that the DET and NOUN are still computationally simultaneous so that the NP can be retrieved. In case of an increase in retrieval time at the level of the DET and NOUN, the NP will be retrieved later than normal. Delayed retrieval of the NP also delays retrieval of the PP to which it is attached. In case of a decrease in memory time of the DET (memory time of the NOUN does not play a role), the NP is retrieved at a normal rate and does not delay retrieval of the PP to which it is attached.

The simulated standard deviations, which were obtained under both phrasal-category hypotheses, were systematically lower than the ones that Schwartz et al. obtained for locative and passive sentences. This might be due to a ceiling effect that is present in the simulated data but absent in the obtained data. The group-error percentages in Schwartz et al. for locative and passive sentences were near chance level performance, 43% and 48%, respectively. SYNCHRON's performance over several blocks does not drop below chance level, since it is guess-corrected. One of the five subjects in the study of Schwartz et al., however, performed significantly below chance level on both locative and passive sentences. This might have resulted from some systematic response bias that is not incorporated in SYNCHRON.

Under the hypotheses that the temporal availability of function word categories was changed a deviant pattern of results was obtained.[3] In particular, two unexpected results occurred. To begin with, a counter-intuitive result was obtained for the Dutch passive used in the study of Kolk and van Grunsven with the past participle in sentence-final position. This type of passive was easier to process than its active counterpart when the retrieval time of function word categories was increased, even though the passive sentence contained two more function words (an auxiliary and a preposition) than the active. A second, unexpected finding was that the two temporal changes, increase in retrieval time and decrease in memory time, resulted in a qualitatively different sentence-complexity effect (cfr. Gigley, 1983). When, on the one hand, memory time was decreased, the Dutch passive was more difficult to process than both active and locative. When, on the other hand, retrieval time was increased, the Dutch passive appeared to be easier to process than both active and locative.

Why was the Dutch passive easier to process than its active counterpart when function word categories were affected by an increased retrieval time? Remember that it is critical for simultaneity that the first retrieved daughter category is still available when the last retrieved daughter category becomes available. Simultaneity is, therefore, negatively affected by a delay in the retrieval of the last retrieved daughter category, while it is positively affected by a delay in the retrieval of the first retrieved daughter category. Now, take a closer look at the processing of the VP of the active and passive. In both active and passive, the last retrieved daughter categories of the VP, NP and PP, respectively, are delayed in their retrieval (caused by a delay in DET retrieval), which affects simultaneity negatively. In case of the passive VP, this negative influence on simultaneity is counteracted by a delay in the retrieval of the first retrieved daughter category, AUX, which is a function word category. In case of the active VP, however, there is no such counteracting influence, since the first retrieved daughter

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[3] We ran two simulations in which all syntactic categories, including those of function words, were affected by an increase in retrieval time and by a decrease in memory time, respectively (see table 1). SSM and KVG's finding of a similar sentence-complexity effect at two different average levels of severity could be simulated, though the absolute fit was less optimal as when only phrasal categories were affected. Based on these simulation results, we do not want to deny that agrammatic aphasics do have a timing problem with function word categories. However, we do claim that a selective timing problem with function word categories only is not sufficient to explain the findings of SSM and KVG.

category, VERB, is a content word category which is not affected by an increase in retrieval time. This predicts an unexpected processing advantage of the passive over the active when function word categories are affected by an increase in retrieval time. But why did such a processing advantage occur only for the Dutch passive and not for the English passive? Recall that the English and Dutch passive used different VP word orders: AUX VERB PP in English and AUX PP VERB in Dutch. Now, in English the effects of a delay in PP retrieval will be more detrimental on the processing of the passive VP than in Dutch, since in English but not in Dutch the PP occurs in sentence final position and, therefore, occurs at a larger distance from the AUX in Dutch than in English. This position effect must have overridden the positive influence on simultaneity of the delay of the AUX so that the English passive became more difficult to process than its active counterpart. When higher order phrasal categories, NP, PP and VP are delayed in their retrieval, not only the English but also the Dutch passive becomes more difficult to process than the active. There are two factors that contribute to this effect. To begin with, the first daughter category of the passive VP, AUX, is no longer delayed in its retrieval and, therefore, no longer has a positive influence on simultaneity. Furthermore, in case of a phrasal delay, the last retrieved daughter category of the passive, PP, is delayed more than the last retrieved daughter category of the active, NP, because delay accumulates across an extra phrasal level during PP processing, i.e. the NP that the PP contains.

Both unexpected results bring to mind Lenneberg's (1967, p. 218) comment on the difficulty of thinking through the implications of the temporal hypothesis: "the dimensions of language patterns are entirely of a temporal nature. This seems logical enough, a priori, since utterances progress through time; however, it is difficult for our imagination to carry this thought to its logical conclusion." Particularly for this reason, Gigley (1982) recommended to use computer simulation to develop theories about aphasia that hypothesize a timing disorder. Especially when process times are stochastically distributed, as in SYNCHRON, counter-intuitive results might be obtained (cfr. Vorberg, 1985).

2.4.2 LIMITATIONS OF THE CURRENT MODEL VERSION

It should be stressed that this study represents only a first attempt to simulate degrees of severity and sentence-complexity effects; therefore, it obviously has some limitations to which we will now turn our attention.

2.4.2.1 INDIVIDUAL DIFFERENCES

The object of our simulations was to simulate group data. One might object to such an approach because the averaging process used to obtain group data might have obscured individual differences in pattern (Badecker & Caramazza, 1985; Caramazza, 1986). Indeed, as mentioned in the previous section, 4 of the 16 patients in the studies of Schwartz et al. and Kolk and van Grunsven showed deviant patterns of sentence-complexity. Such deviant patterns could very well point to different specific impairments (see Caplan & Hildebrandt, 1988 and also Martin et al., 1989, p. 185, for such accounts) so that we were not justified in regarding individual patients as a homogeneous group. A patient from Kolk and van Grunsven, Oo, could serve as an example. This patient deviated from the group pattern of sentence-complexity. Though Oo had more problems in processing locatives than actives, the error percentages for passives and actives were the same for him. A similar pattern of sentence-complexity was simulated when function word categories were affected by an increase in retrieval time. Maybe then, was this patient affected by an increase in the retrieval time of function word categories (Martin, personal communication), while patients whose pattern of sentence-complexity corresponded to that of the group as a whole, suffered from a timing problem affecting phrasal categories. Deviant patterns of sentence-complexity, thus, do not necessarily argue against the hypothesis of a timing disorder. Different patterns can be obtained as a function of what particular linguistic elements are affected by a timing disorder.

Deviant individual patterns need not only be explained by assuming patient-specific impairments, however. Our simulation results suggest an alternative account for the occurrence of such patterns: within patient variability in the same underlying impairment. Due to stochastic variation in temporal processing and imperfect guessing, an individual patient's performance on a certain sentence-type will fluctuate. Such fluctuation can yield a 'deviant pattern'. When phrasal categories were affected by an increased retrieval time, the number of deviant patterns for the group of real and simulated patients, 4 and 3 respectively, were similar. Future simulation studies might obtain an even closer match in the number of pattern deviations in two different ways: First, by adding another potential source of variability, i.e. variability in retrieval time of content words and second, by increasing the variance of the retrieval or memory time distributions. Such an increase will probably increase the variability in the performance on a particular sentence type, thereby increasing the chance that a deviant pattern occurs. Much like the mean, the variance of the distribution of temporal parameters is also a source of individual variation. The mean, then, corresponds to degree of severity. The variance, in turn, would determine the number of deviations from the group pattern of sentence-complexity. It should be stressed that the assumption of within-subject variability in retrieval or memory time, which is responsible for the occurrence of deviant patterns, is independently motivated by the need to explain an individual's above-chance performance on a particular sentence structure (cfr. section 2.5).

2.4.2.2 DEFINITION OF SIMULTANEITY REQUIREMENT

In the current version of the model, it is required that all immediate *daughter* categories are available simultaneously. This of course is a simplification in several respects. The simplication appeared reasonable given the simple sentence set with which we have worked. However, with more complex sentences, some modifications may be necessary. First of all, the simultaneity principle requires that all immediate daughter categories are available for a mother category to be retrieved. This is the property of SYNCHRON's purely bottom-up parsing scheme. There are many reasons why one may consider a time-based model which allows for top-down influences to occur. In fact, top-down parsing was a major characteristic of Gigley's (1983) model. In that model for instance, an article predicts a noun category: as a consequence a NOUN node is activated. Somewhat later the incoming lexical item (a noun) receives activity from this NOUN node. Now synchrony is also required, but it is of a different nature as in a bottom-up parsing scheme: it is synchrony between the top-down and the bottom-up activation. Incorporation of top-down effects will probably lead to different predictions for aphasic performance. In particular, the function word hypothesis, which yielded a deviant pattern of results in our simulation study, might fare better when not only the bottom-up activation of function word categories is delayed but also the top down hypothesizing of the syntactic structure that is predicted by a certain function word, e.g. a NP predicted by a PREP.

A second property of the simultaneity requirement is that it involves only *immediate* daughter categories. This particular aspect of the definition of the simultaneity principle may lead to a wrong sentence-complexity prediction for certain sentence types. More specifically, when in a sentence a phrasal category is preceded by a complex phrasal category, simultaneity may be easier to fulfill than when it is preceded by a more simple phrasal category. This can be explained by means of the following two sentences: (a) "the man in the park greets the woman" and (b) "the man greets the woman." The complexity of the subject NP in (a) will cause it to be retrieved later than the more simple subject NP in (b), which does not have a PP complement. Therefore, simultaneity between subject NP and VP will be easier to achieve in (a) than in (b). Such an effect can be prevented by changing the definition of computational simultaneity to not only include the *immediate* daughter categories of a phrasal category, but all of its *daughter* categories.[4] Future versions of the model might therefore better incorporate

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[4] The syntactic categories, PREP, NP, DET, and NOUN in figure 1 are all daughter categories of the PP. Only PREP and NP are immediate daughter categories of the PP.

this extended definition of the simultaneity requirement. The simulated error percentages for the sentences, as used by Schwartz et al. and Kolk and van Grunsven, will probably not change significantly by requiring all instead of just immediate daughter categories to be simultaneous, since these sentences did not contain complex NPs.

A third critical aspect of the simultaneity principle is that it requires that *all* immediate daughter categories are available. The problem with this assumption is that it implies that sentences with long embedded clauses which would exceed the temporal limits would remain completely uninterpreted. Take a sentence like "The man greeted the woman who was walking in the park with the two children of her sister's friend." In the current model, the S node of the embedded relative clause is only activated after the word "friend" has come in. As a consequence, the object NP and the S node of the main clause become available only after this point and the same holds for the semantic interpretation of the sentence as a whole. Even in a bottom-up scheme, there must be some way to "close" the sequence to be parsed even if it is still incomplete. Early closure may lead to false analyses. Later closure on the other hand has the risk of losing the sentence representation before it has been interpreted. Frazier and Fodor (1978) discuss several proposals on where closure points could lie but we do not want to commit us to any specific hypothesis. We just assume that at some optimal point, the parsing mechanism stops to include new words in the current parse. Now of course, sentence material coming in after this break has to be integrated with the representation of the first part. We assume that in such a case, simultaneity is still essential, in particular between the newly derived nodes and the nodes to which they have to be attached. This process of parsing part-by-part will have different synchrony conditions than parsing the sentence in a single run. Again, for the simple sentences we have studied this will have had little consequence but for more complex sentences, as the one above, the predictions may come out differently.

The assumption of part-by-part parsing may allow us to deal with one critical question, raised by one of the reviewers. Caplan and Hildebrandt (1988) have observed that sentences with object-relative clauses (e.g. "The boy pushed the woman that kissed the old lady") are easier for aphasics than sentences with subject-relative clauses (e.g. "The boy that the woman pushed kissed the old lady"). If we assume that closure occurs at the clause end, that the listener first encounters, then two relevant differences exist between the two sentence types. To begin with, the first part is more complex in case of the subject-relative sentences than in case of the object-relative sentences (e.g. "The boy that the woman pushed" versus "The boy pushed the woman"). Secondly, the NP to which the second part (e.g. "kissed the old lady" versus "that kissed the old lady") must be connected is at a closer distance in time in case of the object-relative ("the woman") as compared to the subject-relative sentences ("the boy"). This may account for the greater difficulty of the latter type of sentence.

Even if we allow for part-by-part parsing, one specific difficulty remains that was brought to our attention by one of the reviewers. In the current version of the model, we have chosen normal memory time such that multiple center-embedded sentences could not be analyzed; however, we could have set memory time such that short multiple-embedded sentences (e.g. "The girl the boy the man saw met smiled") would be successfully processed, while sentences that merely have a very long embedded relative clause would not (e.g. "the girl that the boy met on his recent overnight stay in Barcelona smiled"). Nevertheless, this second sentence appears to be easier to understand than the first. How could we deal with this difficulty? We have to assume that the short, multiple-embedded sentence is so hard because temporal demands cannot be met, neither when the sentence is processed as a whole, nor when it is processed part-by-part. But then, why do we have the impression that the second sentence is less difficult to understand, since this sentence is also too long to fit into the time-window. A suggestion we can offer is that semantic integration of sentence parts is easier in the 'Barcelona' *sentence than in the short, multiple center-embedded sentence. If the parser works* part-by-part and if these parts cannot be integrated syntactically, because of the temporal constraints, then it is critically dependent what semantic interpretation has been carried out on the various parts. Now, a clear difference between the two sentences is the degree to which sentence parts can receive their final interpretation. If for instance the listener takes samples of six words, he can already derive two thematic roles in case of the Barcelona sentence ("boy" as the actor of "met" and "girl" as the patient of "met"), but none in the case of the short, multiple-embedded sentence. With the latter type of sentence, semantic interpretation has to wait until the complete sentence is parsed. In case of the Barcelona sentence, useful partial semantic interpretations can already be derived, which later can be semantically integrated.

All of this, of course, is quite speculative. The argument depends upon the assumption that there is something like palt-by-part parsing. Arguments in favor of this assumption are discussed by Frazier and Fodor (1978; however, see also Wanner, 1980). Nevertheless, if one does not want to assume that memory times are endlessly long then, given our model, such an assumption seems inevitable.

A final limitation of the simultaneity principle is that it deals only with hierarchical relations among syntactic categories (i.e., mother-daughter relations). There is another type of relation between syntactic categories that could be incorporated into SYNCHRON's description of phrase-structure complexity as well. According to Chomsky's (1981) Government and Binding theory, certain phrase-structure elements are coindexed. That is, certain elements have been moved from their deep structure position to a new position in S-structure and have left behind a trace in their old position that has become empty (e.g. the object of a verb that has been moved to subject position in forming a passive). Simultaneity might be more difficult to achieve in sentences containing traces (see Caplan and Hildebrandt, 1988). First, an extra empty node has to be constructed. Second, a relation between the moved element and the empty node it has left behind can only be established if both are computationally simultaneous. Whether under such an account it is still possible to simulate an equal percentage of errors between locatives and passives as was found for Kolk and van Grunsven's aphasics is dependent on a number of factors. First, does one assume passives to contain a trace or not? Second, does the syntactic disorder indeed involve problems with the processing of traces? Third, when patients are only mildly impaired as those of Kolk and van Grunsven, problems with the processing of traces might only appear for sentences of greater structural complexity than passives. With more syntactic categories intervening between a moved element and an empty node it might become increasingly harder to establish a relation between them under conditions of increased retrieval or decreased memory time.

2.4.3 CONCLUDING REMARKS

Despite the limitations mentioned above, we think our simulation results are instructive in at least three ways. First, an example is provided of how a timing disorder may cause agrammatic sentence understanding. This is important, since time has been a neglected dimension in theories of aphasia (cfr. Kolk, Van Grunsven and Keyser, 1985). Second, it is shown that the hypothesis of a timing disorder may be expanded to not only account for the deficit as such, but to also incorporate degrees of severity and the sentence-complexity effect. However, except for this study, no attempts have been made to define an explicit information processing model to account for these latter two phenomena. Is such an attempt really necessary? Is it not sufficient to assume that a particular characteristic of language processing is disturbed to different degrees and that the processing of those sentence types, that rely the most on this characteristic, is disturbed most? Our simulation results suggest that this assumption may not always be warranted. Under only one of two specific timing-disorder hypotheses, i.e. the phrasal-category hypothesis but not the function-word-category hypothesis, could the same qualitative sentence-complexity effect be simulated at two different average levels of severity. A third important demonstration of this simulation study, therefore, is that an explicit information processing account about degrees of severity and the sentence-complexity could be valuable in that it may help to constrain hypotheses about what particular linguistic elements are affected by the timing disorder.

It should be pointed out that the great advantage of a model like SYNCHRON lies in the fact that it is able to make a literally infinite number of predictions. In appendix C, a list of sentence types is included, along with the ones used by Schwartz et al. and Kolk and van

Grunsven, together with two sets of predictions regarding percentage correct. The two versions of the model that were successful in the fitting of the Kolk and van Grunsven data, ie. phrasal categories affected by increased retrieval time or by decreased memory time, were used to generate these predictions. The Schwartz et al. data were not used because for both locative and passive, performance was already at ceiling level. The assumed sentence-structures can be found in appendix B. Note that a few implausible predictions were obtained for sentences with a complex subject NP. In the previous section, we have attributed these predictions to the fact that only the immediate daughter categories of a phrasal category had to be simultaneous instead of also its deeper represented daughter categories.

In conclusion, our simulation results suggest that the temporal restriction hypothesis is a fruitful source of thinking about syntactic disorders, particularly because it permits an account of degrees of severity and sentence-complexity effects. When put to a further test, the specific version of the temporal restriction hypothesis that was implemented in SYNCHRON might well fail. As we have indicated, however, there are numerous possibilities to adapt this particular implementation. If this paper will stimulate others to develop their own versions of the temporal restriction hypothesis, it will have more than achieved its purpose, especially since the area of aphasic language processing is so deficient in explicit computational models.

2.5 ADDENDUM

Kempen and Vosse (1989), inspired by a previous version of this chapter, have made a successful attempt to simulate the two data sets on severity and complexity in agrammatic comprehension collected by Schwartz et al. (1980) and Kolk and van Grunsven (1985). Their parser is called "Unification Space." In addition, Kempen and Vosse successfully simulated psycholinguistic effects obtained in normals, in particular, effects of clause embedding, minimal attachment, right association, and lexical ambiguity. In order to understand their simulation of agrammatic comprehension, the normal operation of the Unification Space parser has to be explained first.

Triggered by the left to right introduction of words, this parser uses a process of unification and simulated annealing in order to arrive at a parse tree representing the phrase-structure of the input sentence. The process of unification is used to join subtrees called segments together in vertical or horizontal direction. Two segments can only be unified if certain linguistic conditions are met (for a formal set theoretical definition see De Smedt, 1990). However, whether two segments that satisfy these conditions are actually unified is determined by their unification probability. Besides the grammatical goodness-of-fit summarized in a strength parameter, the unification probability is positively affected by the activation level of the two syntactic nodes defining the junction at which segments may merge. Once two segments have actually unified, there is a probability that the resulting subtree may disintegrate again into its composing segments. This breakup probability is negatively affected by the activation levels of the two syntactic nodes forming the outer ends of the unified segment. Because of a process of spontaneous activation decay, the breakup probability increases as time proceeds. In fact, as Kempen and Vosse point out, without any special provision, all unification operations would be ultimately undone because of this characteristic. In order to intercept and "freeze" satisfactory parse trees, a kind of simulated annealing process is applied. Both the unification and the breakup probability are made dependent on a global excitation parameter (E) in a negative and positive manner, respectively. E is analogous to the temperature variable in simulated annealing. By gradually lowering the value of E over time there is a high probability that the parser intercepts and "freezes" an optimal parse tree. Unlike in standard simulated annealing, the schedule by which E is reduced over time is not explicitly specified by the modeler, but arises as an emergent property of the model. E is determined by the summed activation level of all syntactic nodes making up the segments. There are two factors which cause E to reduce over time. First, as node activation is subject to a process of spontaneous decay, E is gradually reduced over time. This effect is enhanced by the property that higher values of E increase the decay rate. Second, the unification of two segments reduces the number of syntactic nodes by one and, hence, also reduces the summed node activation determining E.

In Kempen and Vosse's Unification Space parser, the global excitation measure E is not only a positive function of the summed activation level, but also of a chaos parameter C which serves to aggregate external influences upon E, such as the neuropathological conditions found in agrammatic aphasics. By assuming an increasing amount of chaos in these patients, Kempen and Vosse (1989) were able to simulate the same severity and complexity effects on agrammatic comprehension as Haarmann and Kolk (1991a) did. Unfortunately, Kempen and Vosse do not provide an analysis of how the model arrived at this result. Therefore such an analysis will be attempted here. Due to the positive link between the chaos parameter and the global excitation measure and also between the global excitation measure and the decay rate, the simulated patients suffer both from a pathologically increased global excitation level and from a pathologically increased decay rate. As explained in the preceding paragraph, both of these effects increase the breakup probability resulting in more prematurely disintegrating tree segments. Severity effects are due to increased amounts of chaos. Complexity effects are due to the higher number of syntactic nodes involved in complex parse trees. The causal chain of events proceeds as follows. More complex trees imply more syntactic nodes, causing a higher amount of summed activation, causing a larger level of global excitation, causing a faster decay rate, and, consequently, causing a higher breakup probability and a higher percentage of failures to find the correct parse tree.

Compared to Haarmann and Kolk's (1991a) SYNCHRON model, Kempen and Vosse's Unification Space model suggests an alternative way to implement the temporal deficit theory of Kolk and van Grunsven (1985). The latter model suggests that a pathological increase in the decay rate, may have a deeper underlying cause, that is, an increase in chaos. Nevertheless, it would be interesting to determine in future simulations whether the agrammatic comprehension data can also be simulated by a direct increase in the decay rate of the Unification Space parser. What about the pathological decreases in activation rate which are postulated by the temporal deficit theory and which are modeled in the SYNCHRON model by means of the retrieval time parameter? Again the Unification Space model suggests an alternative way of conceptualizing decreases in activation rate. An increase in chaos causes an increase in the global excitation level and thereby an increase in the breakup probability of unified segments. Such a higher breakup probability not only reduces the likelihood that a satisfactory syntactic tree will be found by the model, but it also increases the time that it takes to find one. In short, a pathological increase in chaos leads not only to an increase in decay rate, but also to a a reduction in processing speed. Though not yet implemented, the Unification Space model allows for an alternative way of conceptualizing the disturbing effects of a decrease in activation rate which is closer to the approach taken by Haarmann and Kolk in their SYNCHRON model. In the current version of this model, every node of a segment is upon its introduction immediately initialized at its maximum activation value. There is no gradual buildup of activation. One could of course activate the nodes of a segment with a certain activation rate and, furthermore, assume a pathological decrease in the activation rate of agrammatic aphasics. In case of a decrease in the activation rate, earlier activated syntactic nodes would have to wait longer and, therefore, would decay to a lower level before they can be unified with later activated syntactic nodes. This in turn would decrease the unification probability of these syntactic nodes.

Thus, both the SYNCHRON and Unification Space model provide alternative ways of implementing the temporal deficit theory, but which model is to be preferred? On the one hand, the Unification Space model seems to be preferable over the SYNCHRON model in two respects. First, as discussed in chapter 2, SYNCHRON's requirement of computational simultaneity which demands that all immediate daughter categories are available before a higher order parent node can be retrieved, is unrealistic and difficult to achieve in case there are phrasal categories with many immediate daughter categories. In contrast, in the Unification Space model, not all immediate daughter categories have to be available. Instead, immediate daughter categories may be attached to a parent node upon their introduction (through a unification operation called furcation). Second, in the SYNCHRON model, co-activation is modeled in a discrete, all-or-none manner, so that an earlier activated syntactic node either is or is not available to further processing. In the Unification Space model, co-activation is modeled in a continuous manner. The unification probability of two segments is dependent on their activation level, which in turn is dependent on the amount of decay that has taken place within a certain time period. This aspect is not taken into account in the SYNCHRON model. On the other hand, there are also two reasons which make the SYNCHRON model preferable over the Unification Space model. First, qua processing dynamics, the SYNCHRON model is clearly a more simple and, therefore, more tractable model than the Unification Space model. As Kempen and Vosse (1989, p. 285) themselves remark "... we immediately admit that the model leaves much to be desired. For example, we do not know which assumptions underlying the specific equations and parameters are indeed necessary. Better motivations are desirable here, and variants of the model need to be explored." Second, as will be argued in section 6.2, the experimental results of the syntactic priming and monitoring studies (see chapters 3 and 4, respectively) suggest a trade-off relation between speed of processing (i.e., determined by the activation rate) and activation maintenance (i.e., determined by the decay rate) so that stressing one aspect goes at the expense of the other. Though the SYNCHRON model itself does not provide a mechanism for this trade-off relation, the independent manipulation of the retrieval and memory time parameters nevertheless allows for the modeling of its assumed effects. As was explained in the preceding paragraph, this is not possible in the Unification Space model because in this model an increase in decay rate also implies a decrease in processing speed.

APPENDIX A

OUTLINE ALGORITHM

The algorithm implements the model assumptions described in section 2 for one run of a sentence.

1 Read phrase-structure representation input sentence
2 Read word introduction times
3 FOR EACH type of phrase-structure element DO
3.1 Read RT (retrieval time) distribution (or constant RT)
3.2 Read MT (memory time) distribution (or constant MT)
4 FOR EACH phrase-structure element DO
4.1 Initialize a 3-place retrieval time vector (RB RT RE) at 0

```
                with RB moment of retrieval begin of that element
                with RT retrieval time (i.e., duration) of that element
                with RE moment of retrieval end of that element
5       FOR EACH phrase-structure element
                going from the lowest (lexeme) to the highest (S) phrase-structure level DO
5.1     IF element is a lexeme THEN
5.1.1           RB = introduction time of associated word
5.2     IF element is a lexical category THEN
5.2.1           RB = RE of associated lexeme
5.3     IF element is a phrasal category THEN
5.3.1           Get daughter category with highest RE
                (i.e., last retrieved daughter category)
5.3.2           RB = RE of daughter category with highest RE
5.4     IF type of element has an associated probability distribution THEN
5.4.1           RT = Generate RT from this distribution
5.5     IF type of element has a constant RT THEN
5.5.1           RT = RT for that type of element
5.6     RE = RB + RT
6       FOR EACH phrasal category going bottom-up DO
6.1     IF # daughter categories > 1 THEN
6.1.1           REL = Get RE of daughter category with Lowest RE
                        (i.e., first retrieved daughter category)
6.1.2           REH = Get RE of daughter category with Highest RE
                        (i.e., last retrieved daughter category)
6.1.3         IF type of daughter category with Lowest RE has an
                associated probability distribution THEN
6.1.3.1         MTL = Generate MT from this distribution
6.1.4         IF daughter category with Lowest RE has a constant MT
                (i.e., first retrieved daughter category)
6.1.4.1         MTL = MT for that type of daughter category
6.1.5         IF REH - REL > MTL OR
                one of phrasal daughter categories not computationally simultaneous THEN
6.1.5.1         Register violation of computational simultaneity for current category
7       IF # violations of computational simultaneity >= 1 THEN
7.1     Register 1 error with (wrong-guess) probability p.
```

Note. Step 5: The moment that retrieval of a phrasal category ends is computed as if there were no memory time limitation present.
Step 6: It is checked whether retrieval of a phrasal category could have occurred given a memory time limitation.
The number of steps that the algorithm has to go through is independent of the particular RT and MT values used for the computation of computational simultaneity. Simulating more time does not cost more execution time.

APPENDIX B

SENTENCE STRUCTURE IN REWRITE FORMAT

S --> NP VP
S' --> COMP S
NP --> DET NOUN
NP --> DET ADJ NOUN
NP --> DET NOUN PP
NP --> DET NOUN S'
NP --> NP and NP
PP --> Prep NP
VP --> VERB
VP --> VERB NP
VP --> VERB PP
VP --> VERB NP PP
VP --> AUX VERB PP
COMP --> that

APPENDIX C

PREDICTED ERROR PERCENTAGES

Predicted error percentages for the retrieval time (RT) and memory time (MT) versions of the phrasal category hypothesis used to fit the Kolk and van Grunsven data.

			RT	MT
1.	the man greets the woman	(5)	6	6
2.	the man walks behind the woman	(6)	26	23
3.	the woman is greeted by the man	(7)	32	35
4	the small man greets the tall woman	(7)	8	12

5	the man sends the woman to the boy	(8)	40	43
6	the small man walks behind the tall woman	(8)	32	35
7	the boy and the man greet the woman	(8)	7	5
8	the tall woman is greeted by the small man	(9)	39	44
9	the man with the hat greets the tall woman	(9)	29	5
10	the boy and the man walk behind the woman	(9)	22	12
11	the man with the hat walks behind the tall woman	(10)	33	12
12	the woman and the boy are greeted by the man	(10)	7	5
13	the woman with the hat is greeted by the small man	(11)	37	22

Note. Sentence length (number of words) between parentheses.

Chapter 3

Syntactic Priming in Broca's Aphasics: Evidence for Slow Activation[1]

ABSTRACT

Recently, several investigators have suggested that the parsing system of Broca's aphasics is affected by a resource limitation which could involve (1) a reduction in the size of a syntactic buffer (2) slow activation of syntactic information or (3) fast decay of syntactic information. The results of a syntactic priming experiment, which varied the SOA (stimulus onset asynchrony: 300, 700 and 1100 ms) between a prime fragment and target presented for lexical decision, provided support for the slow activation hypothesis. A group of thirteen age-matched controls showed syntactic priming, ie. significantly faster response times in the grammatical than ungrammatical condition, at all three SOAs. A group of thirteen Broca's aphasics, on the other hand, showed significant syntactic priming only at the 1100 ms SOA.

3.1 INTRODUCTION

It is a well-known observation that Broca's aphasics often have problems with the understanding of sentences, especially when understanding hinges on grammatical structure (Blumstein et al., 1983; Kolk and Friederici, 1985). In the recent past, many studies (see below) have concluded that Broca's agrammatic comprehension does not involve a loss of structural, grammatical knowledge but rather a problem in processing this type of knowledge. Several of these studies have shown that Broca's aphasics are still sensitive to violations of grammaticality in a number of different experimental paradigms including off-line syntactic judgment (Baum, 1988; Crain et al., 1984; Linebarger et al., 1983; Tyler, 1985), on-line syntactic judgment (Shankweiler et al., 1989), syntactic priming using lexical decision (Friederici and Kilborn, 1989; but see Baum, 1988) and word monitoring (Hagoort, 1989). Another line of evidence against the loss-of-structural knowledge hypothesis and in favour of the processing deficit hypothesis comes from sentence-picture matching studies. Different subgroups of Broca's have been reported that show a qualitatively similar effect of sentence

[1] Haarmann, H.J., & Kolk, H.H.J. (1991). *Aphasiology, 5(3)*, 247-263.

complexity but perform at different overall levels of severity (compare the results of Schwartz et al., 1980 and Kolk and Van Grunsven, 1985; also see Caplan and Hildebrandt, 1988). Kolk and Van Grunsven (1985) and Caplan and Hildebrandt (1988) have argued that such findings are difficult to reconcile with the loss-of-structural-knowledge hypothesis (see Martin et al., 1989 for discussion) instead they point to a processing deficit. More specifically, these researchers have postulated a limitation in processing resources that especially affects syntactically demanding sentences (see also Frazier and Friederici, 1991) and that can vary in degree.

The concept of processing resources is rather vague, however, and in need of specification. In the context of research on the effects of aging, Salthouse (1988) maintains that "the bulk of references to the concept of processing resources could be encompassed within three categories organized around the metaphors of energy, space and time" (p. 258). What is the situation with respect to resource limitation accounts of Broca's receptive syntactic deficit? To our knowledge, the energy metaphor has not been applied in this area (see, however, LaPointe, 1985, for its application to Broca's expressive syntactic deficit). But the metaphors of space and time have. Let us first consider the spatial metaphor. It has been suggested (Caplan et al., 1986; Caplan and Hildebrandt, 1988; Kolk and Van Grunsven, 1985) that Broca's aphasics suffer from a reduction in the storage capacity of a specialized working memory which holds the intermediate results of parsing. Using the classical metaphor of Working Memory (Atkinson and Shiffrin, 1968), this reduction in storage capacity can be viewed as a spatial limitation in buffer size[2].

Next, consider the time metaphor which is the focus of this study. Two different types of hypotheses have been proposed using this metaphor. The first one assumes that Broca's suffer from a slow down in parsing speed. It states that there is a slow down in the activation rate of structural information (Friederici, 1988; Friederici and Kilborn, 1989; Gigley, 1982; Huber et al., 1990; Kolk and van Grunsven, 1985). Also the hypothesis that Broca's suffer from a loss of automaticity in their access to syntactic representations (Baum, 1988; Milberg et

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2 A more recent view of working memory capacity by Anderson (1983) does not make use of the spatial metaphor of processing resources but of a combination of the energy and time metaphor. Anderson proposed that working memory capacity reflects a limitation in the number of elements that can be maintained active simultaneously. He suggests that a finite amount of activation is distributed among nodes (energy metaphor) with a particular rate (time metaphor). In Broca's, there could be a reduction in the amount of activation distributed per time unit in the parsing module. In that case, the reduced-memory-capacity hypothesis and the slow activation hypothesis (Kolk and van Grunsven, 1985) would be identical.

al., 1985; Tyler, 1985) could be taken to imply a slow down in parsing speed or syntactic activation rate. The reason is that the concept of automaticity has speed as one of its defining characteristics. On the other hand, loss of automaticity could also be taken as a loss of the procedures that are used for automatic syntactic access (see for example Bradley et al., 1980) In that case, we are not dealing with a resource restriction hypothesis.

The second hypothesis that refers to a temporal resource restriction is the fast decay hypothesis (Gigley, 1982, 1983; Hagoort, 1989; Kolk and Van Grunsven, 1985). It states that the activity level of information that plays a role during parsing drops back to threshold with a faster than normal rate.

As Kolk and Van Grunsven (1985) have argued, all of the above three types of syntactic resource limitations, reduction in storage capacity, slow activation and fast decay, may disrupt sentence processing by preventing various types of linguistic information to become co-active during parsing. Haarmann and Kolk (1991a) have given a computer demonstration of the two temporal hypotheses. They were able to simulate sentence-complexity and severity effects on Broca's agrammatic understanding by either selectively slowing the activation rate of syntactic categories or by selectively increasing their decay rate. Thus, these simulation results lend support for both the slow activation and fast decay hypotheses. Unfortunately, experimental evidence that would allow to decide in favour of one of the three resource limitation accounts in particular is lacking at the moment. With the expection of a study by Friederici and Kilborn (1989) to be discussed below, we are not aware of any previous studies that have been designed to contrast the reduced-buffer-size, slow activation and fast decay hypotheses experimentally. The present syntactic priming study was designed to fill this gap.

The critical manipulation in our syntactic priming experiment involved the SOA (stimulus onset asynchrony: 300, 700 and 1100 ms) between a two word sentence fragment and a target letter string presented for lexical decision. Of special interest were the response times to word targets. Target words either formed a grammatical or ungrammatical continuation with a preceding prime fragment. With normal, neurologically healthy subjects one typically observes syntactic priming, that is lexical decision times are significantly faster in the grammatical than in the ungrammatical condition. This is a robust finding, especially when multi-word primes are used in combination with lexical decision (West and Stanovich, 1986). With naming, syntactic priming is either absent (Seidenberg et al., 1984) or smaller in size and found only in conjunction with larger response times (West and Stanovich, 1986). It therefore has been concluded (Seidenberg et al., 1984; West and Stanovich, 1986) that the locus of the syntactic priming effect is post-lexical and that the result of the syntactic integration of prime and target facilitates or inhibits the lexical decision or naming response.

For present purposes the precise nature of the mechanism is not important (see Seidenberg et al., 1984 , West and Stanovich, 1986, and Wright and Garrett, 1984, for suggestions). It is important to realize, however, that syntactic priming only occurs if the syntactic representation of the prime fragment can be integrated with that of the target fragment before the target is responded to. This in turn will only happen if the syntactic representation of the prime fragment is available at the right moment in time. Both slow activation and fast decay can change the moment of availability of the syntactic representation of the prime fragment so that no syntactic priming occurs. First, consider the effect of slow activation on syntactic priming. In case of slow activation, the target might have already been responded to before the syntactic representation of the prime fragmnent gets available. By increasing the SOA between prime fragment and target, the syntactic representation of the prime fragment gets more time to become available before the target is presented. Consequently, with slow activation, one would expect a late appearance of syntactic priming in Broca's aphasics, that is at larger SOA's than in a group of normal controls. Now consider the effect that fast decay has on syntactic priming. In case of fast decay, the syntactic representation of the prime fragment might be no longer available when the target is responded to. This is more likely to be the case as the SOA between prime fragment and target gets larger. Therefore, with fast decay, one would expect Broca's aphasics to show an early disappearance of syntactic priming, that is at smaller SOA's than in a group of normal controls. It is also conceivable that both slow activation and fast decay are at work in Broca's aphasics. In that case, one would expect a later appearance and an earlier disappearance of syntactic priming in Broca patients than in normal controls. Finally, we have to make predictions for the reduced-buffer-size hypothesis. In cases where the syntactic load posed by the syntactic integration of prime and target is too high, this hypothesis predicts that there will be no syntactic priming regardless of SOA. Otherwise, the same syntactic priming pattern as in normals should be observed.

In the light of these predictions, we should discuss three previous studies of syntactic priming in Broca's aphasics. In two studies (Baum, 1988; Milberg et al., 1985) a significant syntactic priming effect was obtained in normal controls but not in Broca's aphasics. In both studies, off-line judgment of the grammatical acceptability of the same material as was used in the priming task appeared to approach the level of normal controls. These findings were interpreted as consistent with the hypothesis of impaired automatic syntactic access (Baum, 1988; Milberg et al., 1985). Above, we suggested that this hypothesis could be taken to imply a slow down in activation rate. In both syntactic priming studies, however, the inter stimulus interval between the auditorily presented prime and target was kept constant at 500 ms, so that it is not possible to evaluate the different predictions of the slow activation and fast decay hypotheses regarding the direction of the interaction between SOA and syntactic priming.

A third study of syntactic priming in Broca's aphasics has been conducted by Friederici and Kilborn (1989) testing Dutch Broca's aphasics and age-matched controls. Unlike Baum (1988), these investigators did vary the SOA between prime fragment and target. The SOA was either 0 ms or 200 ms. The findings seem to support both the slow activation hypothesis and the fast decay hypothesis of Broca's agrammatic comprehension. Evidence consistent with the slow activation hypothesis came from the finding of a 'context effect'. For Broca's aphasics, response times to target words were significantly slower when presented in context (regardless of grammaticality condition) than when presented in isolation. The context effect of Broca's was larger at the 0 ms SOA than at the 200 ms SOA. For age-matched controls there was no context effect As Friederici and Kilborn (1989) point out, the presence of a context effect in Broca's aphasics suggests that these patients were still processing the prime fragment when the target word was encountered, probably more so at the 0 ms SOA than at the 200 ms SOA. This in turn, suggests that Broca's aphasics were slowed down in their processing of the prime fragment. Friederici and Kilborn (1989) also found support for a fast decay effect. Broca's aphasics showed significant syntactic priming at the 0 ms SOA but not at the 200 ms SOA, while the control group showed significant syntactic priming at both SOA's. In our opinion, there are two reasons why it is too early to accept the suggestion from Friederici and Kilborn's (1989) study that both slow activation and fast decay affect the syntactic representations of Broca's aphasics. First, it is unclear whether the context effect is a syntactic effect. As Friederici and Kilborn point out, it could also be the result of a more general slowing down of processing. Second, order of SOA presentation was not counterbalanced in Friederici and Kilborn's study. All subjects were first administered the syntactic priming experiment with an SOA of 0 ms and then with an SOA of 200 ms. It is conceivable therefore that the two effects of an increased SOA, ie. a decrease in context effect and a disappearance of syntactic priming, were due to practice effects. The decrease in context effect might also be attributed, for example, to a speeding up of response times as a result of practice. The disappearance of syntactic priming might be explained by assuming that Broca aphasics had learned to ignore the auditorily presented context. The results of a follow-up experiment by Kilborn and Friederici (1989) indeed suggested that Broca's aphasics were able to ignore the context. Contrary to normal controls, Broca's aphasics no longer showed syntactic priming with the 0 ms SOA when explicitly instructed to ignore the context. To control for such and other potential effects of practice, the order of SOA presentation was counterbalanced in the present syntactic priming study.

To sum, the predictions of three contrasting resource limitation accounts of Broca's agrammatic comprehension were put to a test in the present syntactic priming study. When comparing the time-course of syntactic priming in Broca's aphasics and normal controls, the slow activation hypothesis predicts a late appearance of priming, the fast decay hypothesis predicts an early disappearance of priming and the reduced-buffer-size hypothesis predicts no priming or the same priming pattern as in the control group.

3.2 METHOD

3.2.1 SUBJECTS

Two groups of subjects, 17 Broca's and 17 controls, participated in the experiment. 4 Broca's had to be excluded, so that the final sample to be studied included 13 Broca's and 13 matching controls. Reasons for exclusion included illness, vacation and problems with visual lexical decision. All subjects were right handed, native speakers of Dutch. The control subjects were healthy individuals with no history of neurological disorder that were matched for age, sex, and years of education with the Broca's aphasics. Mean age for both the Broca's aphasics and the controls was 54, while age range was from 24 to 72. The Broca patients were selected from the patient pool of the Max Planck Institute and had been administered a translated, Dutch version of the German Aachen Aphasia Test (AAT) (Graetz et al., 1991; Huber et al., 1983). Syndrom classification was unanimously reached by a team of three neurolinguists based on a recording and transcription of the spontaneous speech interview of the AAT. The criteria for classification as Broca's aphasic were: relatively intact auditory comprehension (as assessed by the patients' answers to questions during the interview of the AAT), non-fluent agrammatic language production with impoverished melodic line, disturbed articulatory agility, many phonemic paraphasias and only few semantic paraphasias (Goodglass and Kaplan, 1983; Poeck et al., 1975). Agrammatic language production was defined as a shortening of sentences accompanied with a reduction in the variety of grammatical form and as a tendency to omit (not substitute) both bound and free grammatical morphemes. All patients had suffered from a right-sided hemiplegia and had sustained left hemispheric damage. With two exceptions, involving a case of inflammatory meningitis and a case of trauma (patients 1 and 6, respectively), all Broca patients had sustained a cerebral vascular accident (CVA) involving the region of the left middle cerebral artery. Patients had no previous history of neurological disease , with the exception of patient 12 who had suffered two more CVAs after the first one. These CVAs, however, were of a minor and transient nature as suggested by both CT-scan and re-test results with the AAT which showed steady improvement since the first CVA accident. Mean post onset time of brain damage was 8 yr and 1 mo (range: 4 yr and 8 mo - 13 yr +8 mo).

Table 1 gives a summary of further relevant background information per individual Broca patient: age, sex, occupation, post onset time, etiology, Token Test and comprehension scores from the AAT and, finally, some quantitative data on patients production agrammatism. Scores on the the Token Test confirm the presence of aphasia and indicate different degrees of severity of aphasia (Huber et al., 1983). The mild impairment revealed by the auditory comprehension scores of the AAT is consistent with the classification as Broca patient. The reading comprehension scores in table 1 suggest an almost preserved ability to read and understand words. This ability is necessary to perform the visual lexical decision task in the present study. Table 1 also gives quantitative information of Broca's productive agrammatism, ie. omission percentages for finite verbs, determiners and prepositions from spontaneous speech which were kindly made available by Hofstede (Hofstede and Kolk, submitted). These omission percentages suggest that productive agrammatism occurred to various degrees.

3.2.2 MATERIALS

A list with a total of 360 test items, with each item consisting of a two word prime fragment followed by a target letter string for lexical decision, was constructed in two steps. First, two sublists of 180 test items were created according to the same principles but containing different Dutch target words. Second, target words from one list were changed into pronounceable non-words by substituting, interchanging, adding or deleting one or two letters. Each sublist of 180 test items consisted of 120 critical items and 60 filler items. The 120 critical items in the word condition are listed in the appendix. Of the 120 critical items, 60 prime-target combinations formed grammatical sentences, while 60 prime-target combinations formed ungrammatical sentences. Grammaticality was manipulated by keeping the prime fragment constant and by changing the target word. There were a total of four different material types each involving a different type of grammaticality violation (see Table 2 for an example of each). Two material types, "passive" and "perfect" involved violations of agreement between an auxiliary and past participle verb. These violations were of the same kind as had been used in Friederici and Kilborn's (1989) syntactic priming study with Broca's aphasics. The two remaining material types, "modal verb" and "preposition" involved violations of syntactic category of the kind that have been used by Wright and Garrett (1984) and West and Stanovich (1986) in syntactic priming studies with students. These last two material types were added to the ones used in

TABLE 1

Background data on Broca's aphasics.

No.	Sex[a]	Age	Onset[b]	Occupation	Etiology	TT[c]	Comprehension[d] auditory W[g]	Comprehension[d] auditory S[h]	Comprehension[d] visual W	Comprehension[d] visual S	Omissions[e] V[f]	Omissions[e] Det & Prep[i]
1	m	25	116	none	Bacterial Meningitis L. fronto temporal	34	28	26	26	20	74	56
2	m	61	77	fitter	Occlusion L. artery carotis interna	30	18	30	26	21	12	9
3	m	70	109	teaching head	Occlusion L. artery carotis interna	7	28	26	29	22	15	10
4	f	58	164	Farmer's wif	Occlusion L. mid cerebral artery	18	25	24	28	27	41	57
5	m	56	78	Mechanic	Occlusion L. artery carotis interna	19	29	23	30	23	31	20
6	m	25	56	None	Trauma	21	28	28	27	21	--[j]	--
7	m	72	87	Fireman	Infarct L. mid cerebral artery	3	30	30	30	30	42	17
8	f	35	146	Bank employee	Aneurysm L. mid cerebral artery	31	26	23	21	15	65	63
9	m	60	89	Municipal official	Infarct L. mid cerebral artery	5	25	23	28	28	86	68
10	m	62	89	Quality controler	Same	21	28	23	30	21	--	--
11	m	60	88	Bank employee	Same	28	23	15	22	18	75	51
12	f	57	62	Nurse	Same	33	22	29	23	19	--	--
13	m	65	103	Construction worker	Same	50	23	23	23	21	40	25

Note. [a]Sex: m = male, f = female. [b]No. of months since onset. [c]Token Test (Maximum number of errors: 50). [d]Maximum score per subtest: 30. [e]Percentage omissions (ie., number of omissions/number of contexts) in spontaneous speech interview (from Kolk & Hofstede, submitted). [f]V = finite verb. [g]W=isolated words. [h]S=sentences. [i]Det & Perp = determiners and prepositions. [j]-- = no data available for this subject.

Friederici and Kilborn's study to achieve greater generality in the results. For the passive material type, the prime fragment consisted of personal pronoun in plural nominative form followed by the Dutch auxiliary verb for passive WORDEN (BE) also in plural form and present tense. This passive prime fragment was followed by a transitive past participle verb in the grammatical condition and by an intransitive past participle verb in the ungrammatical condition. Compare, for example, the grammatical sentence WIJ WORDEN GETEST (WE ARE BEING TESTED) with the ungrammatical sentence WIJ WORDEN GELOPEN [WE ARE BEING WALKED]) in Table 2. For the perfect material type, the prime fragment consisted of a personal pronoun in plural, nominative form form followed by the Dutch auxiliary for perfect tense HEBBEN (HAVE) in plural, present tense form. In the grammatical condition, this perfect prime fragment was followed by a past participle verb which takes HEBBEN (HAVE) as perfect auxiliary and in the ungrammatical condition by a past participle verb which takes ZIJN (HAVE) as perfect auxiliary. It should be pointed out that Dutch uses two auxiliaries for perfect tense, HEBBEN and ZIJN. Some past participles demand HEBBEN as perfect auxiliary, while others demand ZIJN as perfect auxiliary. Compare, for example, the grammatical sentence WIJ HEBBEN GESLAPEN (WE HAVE SLEPT) with the ungrammatical sentence WIJ HEBBEN GEVALLEN (WE HAVE FALLEN) in Table 2. For the modal verb material type, the prime fragment consisted of a personal pronoun in plural, nominative form followed by the Dutch modal verb KUNNEN (CAN) in plural form and present tense. In the grammatical condition, this modal verb prime fragment was followed by a main verb in infinitive form and in the ungrammatical condition by a noun in singular form. Compare, for example, the grammatical sentence WIJ KUNNEN PRATEN (WE CAN TALK) with the ungrammatical sentence WIJ KUNNEN NEUS (WE CAN NOSE) in Table 2. For the preposition material, the prime fragment consisted of a locative preposition followed by the determiner DE (THE). In the grammatical condition, the preposition context was followed by a singular noun and in the ungrammatical condition by a verb in infinitive form. Compare, for example, the grammatical sentence OP DE KAST (ON THE CUPBOARD) with the ungrammatical sentence OP DE ROKEN (ON THE SMOKE) in Table 2. For all material types, three different words, which occured equally often served as the first word of the prime fragment. For passive, perfect and modal verb prime fragments, this word was either the plural pronoun WIJ (WE), JUllIE (YOU) or ZIJ (THEY). For preposition contexts it was either the locative preposition IN (IN), OP (ON), NAAST (NEXT TO). For the passive material type and also for the perfect material type, the past participle verbs in the grammatical and ungrammatical condition were matched on the basis of isolated lexical decision time, word length and number of syllables. These isolated lexical decision times were obtained from an pre-experiment with 20 students that did not participate in the syntactic priming study. Likewise, infinitive verbs preceded by modal contexts were matched with infinitive verbs preceded by preposition prime fragments and nouns preceded by preposition contexts were matched with nouns preceded by modal verb prime fragments. In addition, to the 120 critical items, 30 past participles verbs, 15 infinitive verbs and 15 nouns served as targets for filler items. These filler items were preceded by two separate rows of four hashmarks which replaced the prime fragment.

TABLE 2

Examples of material types.

	Prime	Target[a]
1.	Passive Auxiliary	
	Wij worden	getest/*gelopen
	(We are being	tested/*walked)
2.	Perfect Auxiliary	
	Wij hebben	geslapen/*gevallen
	(We have	slept/*fallen[b]
3.	Modal verb	
	Wij kunnen	praten/*neus
	(We can	talk/*nose)
4.	Preposition	
	Op de	kast/*roken
	(On the	cupboard/*smoke

Note. [a]* = Ungrammatical phrase. [b]Only ungrammatical in Dutch(see text)

3.2.3 PROCEDURE

For each subject, a total of four individual sessions were run which were separated by a period of at least three weeks. Age-matched controls were tested in a quiet room at the University, while Broca's aphasics were tested at home. The same material was presented at three different stimulus onset asynchronies (SOA) between the two context words and the target. SOA was counterbalanced across the first three sessions, with one SOA per session per subject. A fourth session was run, in which all targets were presented in isolation. The difference score between a target presented in context (sessions 1,2 and 3) and in isolation (session 4) was used to provide a basis for comparing targets belonging to the grammatical and ungrammatical condition. In other words, each target served as its own control. The 360 stimuli were randomized separately for each subject for each session. Stimuli were presented in blocks of 60 each. Subjects were given an opportunity to pause in between two blocks. A minimum pause of at least 30 s. between blocks was required for each subject. Prior to each session. 40 isolated targets and 48 primed targets were presented for practice. The 48 primed targets were similar in composition to the 360 test stimuli. During pilot testing some subjects spontaneously engaged in syntactic judgment. In order to avoid this, experimental subjects were made aware of the grammaticality manipulation, so that it could be explained to them that lexical decision and not syntactic judgment was the task to be performed. Previous research by Goodman et al. (1981) has shown that making subjects aware of the occurance of syntactic violations does not interfere with syntactic priming. These researchers, like us, used the visual presentation mode.

A trial consisted of the following events. After a 500 ms. warning signal and 500 ms pause, subjects were presented with three stimuli which appeared from left to right on the computer screen. The first two stimuli served as prime fragment and their onset times were 0 and 300 ms., respectively, after the pause. The within-subject factor SOA (300, 700 and 1100 ms.) determined the stimulus onset asynchrony between the second and the third stimulus which served as the target for lexical decision. Subjects were instructed to attend to all three stimuli and to decide as quickly and as accurately as possible whether the target letter string was a word or a nonword by pressing a "YES" or "NO" button with their left hand. All three stimuli remained in view until the subject responded or until 10 s. had elapsed. As in the syntactic priming study by Friederici and Kilborn (1989) the analysis (see below) was restricted to responses of 3 s. or less. After each response, subjects were automatically given good/wrong feedback which remained on the computer screen for 1 s. The next trial was automatically initiated after 1 s.

An ATARI mega ST2 computer equiped with a CRT screen, pushbutton interface and software timer (Van Kruysbergen, 1989) controled stimulus presentation and recorded both response correctness and response time (ie. the latency between target onset and depression of the key). Together the two-word prime fragment and the target stimulus subtended at a visual angle of 12.5 deg. horizontally and 1 deg. vertically at a viewing distance of 40 cm. (15.7 inches).

3.3 RESULTS

Statistical analysis was restricted to critical trials, ie. grammatical and ungrammatical prime - target word combinations. Responses to nonwords and filler words were thus left unanalyzed. Response times of critical trials on which outliers or errors occurred were replaced by the subject's mean response time over the remaining trials of a condition. An outlier was defined as a response time that exceeded 3000 ms or occured more than two standard deviations below or above both the subject's condition mean and the item mean. The overall percentage of outliers for critical trials was 4 for Broca's aphasics and 3 for the controls.

Table 3 lists the mean response times, standard deviations and mean error percentages across subjects in the Group (Broca's aphasics, controls) X Material type (passive, perfect, modal verb, preposition) X Prime (grammatical, ungrammatical) X SOA (300, 700, 1100 ms, no SOA) cells ("no SOA" refers to targets presented in isolation which served as baseline condition). It should be pointed out that, while in the experiment the same baseline condition was used for all three SOA's, table 3 shows slight differences between the baseline scores of different SOA's for several Prime X cells. This is due to the treatment of outliers and errors: A subject's correct, baseline response to an item was replaced when that subject's response to the same item presented in context constituted an outlier or error (and vice versa).

For each subject in the two groups, difference scores were calculated between the mean response time of a target presented in context and the mean response time of the same target presented in isolation for each of the Material type (passive, perfect, modal verb, preposition) X Prime (grammatical, ungrammatical) X SOA (300, 700, 1100 msec.) cells. These difference scores served as data entries in an overall by-subjects anova with material type, prime and SOA as within factors. In addition, the predictions of the three resource limitation accounts were tested by means of a series of planned comparisons which evaluated the syntactic priming effect (collapsed over material type) at each of the three SOAs for each of the two groups. Figure 1 depicts the mean size of the priming effect (ungrammatical - grammatical difference scores) for controls and Broca's aphasics. as a function of SOA collapsed over material type. In order, the mean size of the priming effect at the 300, 700 and 1100 ms SOA was 27, 45 and 60 ms for Broca's aphasics and 55, 39 and 45 ms for controls. Thus, for both groups, priming was in the expected direction, ie. slower response times in the ungrammatical than grammatical condition, for all SOAs.

Controls. For controls, the overall ANOVA revealed a main effect of prime [$F(1,12) = 42.02$, $MSe = 3{,}942$, $p < .000$], a main effect of material type [$F(3,36) = 6.66$, $MSe = 3{,}427$, $p = .001$] and an interaction between prime and material type [$F(3,36) = 3.24$, $MSe = 3{,}830$, $p = .033$]. This interaction was further broken down into the simple main effects of prime per material type collapsing over SOA. Using Dunn's procedure (Kirk, 1982, p.

TABLE 3

Mean response time, standard deviation and error percentage as a function of group, soa, material type and prime condition.[a]

		Material type			
SOA[b]	Cond[c]	Passive	Perfect	Modal verb	Preposition
		Broca's			
300	G	964(175)[12]	881(127)[4]	931(172)[5]	795(149)[2]
300	Gb	959(178)[11]	890(130)[7]	830(126)[4]	764(111)[2]
300	U	1037(207)[9]	932(181)[4]	826(122)[2]	933(167)[11]
300	Ub	978(169)[14]	846(135)[2]	751(107)[3]	918(197)[8]
700	G	934(182)[7]	874(195)[3]	869(155)[5]	785(172)[2]
700	Gb	981(184)[11]	892(138)[7]	829(129)[4]	772(113)[2]
700	U	996(228)[14]	896(246)[3]	816(146)[4]	958(222)[10]
700	Ub	986(186)[14]	846(131)[2]	752(103)[3]	914(196)[8]
1100	G	1005(341)[1]	935(299)[3]	899(267)[6]	816(271)[2]
1100	Gb	971(182)[11]	897(138)[7]	827(129)[4]	767(111)[2]
1100	U	1048(353)[1]	935(398)[4]	835(251)[2]	1063(404)[7]
1100	Ub	963(165)[14]	838(125)[2]	754(108)[3]	897(204)[8]
		Controls			
300	G	753(111)[3]	715(119)[2]	673(102)[2]	628(81)[0]
300	Gb	676(92)[4]	641(87)[2]	643(85)[2]	593(86)[1]
300	U	848(216)[9]	715(109)[4]	691(98)[1]	766(141)[7]
300	Ub	705(136)[2]	634(81)[3]	607(79)[0]	637(84)[2]
700	G	714(117)[4]	687(110)[1]	676(120)[3]	664(126)[1]
700	Gb	677(92)[4]	639(87)[2]	640(85)[2]	594(86)[1]
700	U	797(164)[7]	712(126)[2]	670(94)[3]	748(114)[3]
700	Ub	700(121)[2]	632(79)[3]	611(81)[0]	637(82)[2]
1100	G	723(99)[2]	699(131)[0]	671(89)[1]	647(100)[1]
1100	Gb	678(94)[4]	641(86)[2]	642(87)[2]	595(89)[1]
1100	U	793(136)[8]	700(106)[1]	673(108)[1]	769(124)[6]
1100	Ub	695(116)[2]	635(79)[3]	609(80)[0]	635(82)[2]

Note. [a]Standard deviations and error percentages between parentheses and brackets, respectively. [b]SOA is stimulus onset asynchrony in ms. [c]Cond = condition, G = grammatical prime condition, Gb = corresponding baseline, U=ungrammatical prime condition, Ub = corresponding baseline. Baseline values differ slightly across SOA's (for explanation see text).

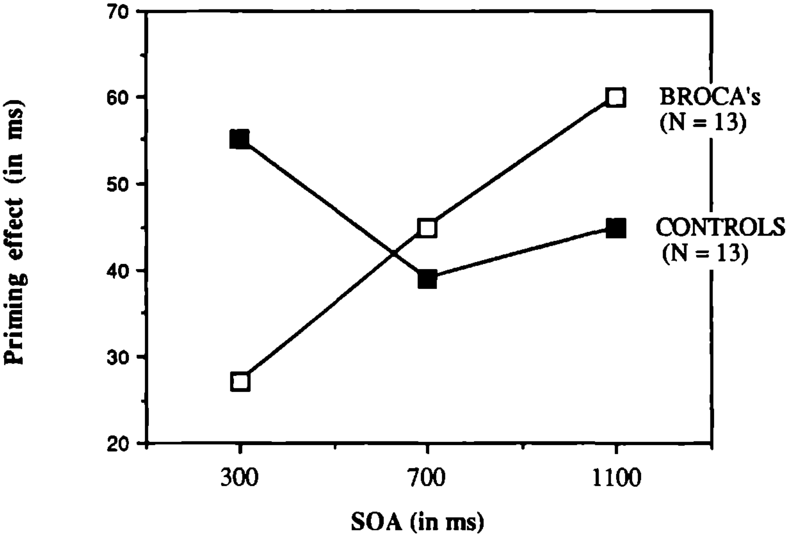

Figure 1. Mean priming effect (ungrammatical minus grammatical condition) as a function of group and SOA.

370) alpha was set at .025. This breakdown indicated that the prime effect for the perfect material type was not as reliable as the prime effect for the other material types. There was a simple main effect of prime for the passive material type [F(1,12) = 11.73, MSe = 5901, p = .005] , the modal verb material type [F(1,12) = 9.20, MSe = 3036, p = .01] and the preposition material type [F(1,12) = 17.96, MSe = 5648, p = .001]. The simple main effect of prime for the perfect material type just fell short of significance at the level required by Dunn's procedure [F(1,12) = 5.03, MSe = 845, p = .045]. In order, the amount of priming for passive, perfect, modal verb and preposition material types was 60, 15, 38 and 72 ms. The planned comparisons revealed a significant prime effect for the 300 ms SOA [F(1,12) = 22.31, MSe = 3544, p < .001], the 700 ms SOA [F(1,12) = 12.64, MSe = 3078, p = .004] and the 1100 ms SOA [F(1,12) = 26.54, MSe = 1931, p < .000].

Broca's aphasics. For Broca's aphasics, the overall ANOVA revealed a main effect of prime [F(1,12) = 4.97, MSe =29836, p = .046]. None of the other effects was significant. The planned comparisons revealed a significant prime effect for the 1100 ms SOA [F(1,12) =

5.75, MSe = 15871, p = .034] but not for the 300 ms [F(1,12) = 1.84, MSe = 10232, p = .20] and 700 ms SOA [F(1,12) = 1.75, MSe = 29576, p = .21]

Error analysis

From table 3 difference scores were derived between the mean percentage of errors in the grammatical condition (G) and its corresponding baseline condition (Gb) and between the mean percentage of errors in the ungrammatical condition (U) and its corresponding baseline condition (Ub) for each of the three SOAs, collapsed over material types and for Broca's aphasics and controls separately. These difference scores provide a measure of the relative accuracy by which subjects responded to the grammatical and ungrammatical condition. Controls made 4, 2 and 3.5 percent more errors in the grammatical than ungrammatical condition for the 300, 700 and 1100 ms SOA, respectively. For Broca's these differences in error percentages are 0, 2.75 and 0, respectively. Thus, longer response times in the ungrammatical than grammatical condition are accompanied in the controls by more errors and in the Broca's aphasics by more or an equal number of errors. The priming effect observed in both groups can therefore not be due to a speed-accuracy trade-off.

Individual assessment priming effect

Recall that SOA was not counterbalanced within subjects but only across subjects with subjects receiving one SOA per session. It is therefore possible that at the individual level the SOA manipulation is confounded with the order in which subjects received the three SOA's, so that a SOA X Prime interaction might in fact be due to Order X Prime interaction. For example, with practice response times might become so fast as to obscure the priming effect. On the other hand, since sessions were separated by at least three weeks there might be no practice effect and therefore no Order X Prime interaction. To check for the presence of such an interaction, a 3 (Order: first, second, third session) X 4 (modal verb, preposition) X 2 (Prime: grammatical, ungrammatical) ANOVA was run for controls and Broca's separately[3]. No significant main effects or interactions involving the Order factor were obtained. The absence of an Order X Material type X Prime or Order X Prime interaction in both controls and Broca's seems to justify statistical analysis of the SOA X Prime interaction in individual subjects despite the fact that SOA was not counterbalanced within subjects.

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[3] A sample of 9 subjects was chosen for each group such that counterbalancing of SOA across sessions was ideal, ie. with all three SOA's represented equally often (3 times) at all three sessions. Counterbalancing was not ideal for the 13 subjects that completed the study because it was based on the 17 subjects that were originally selected to participate.

Per individual subject planned comparisons of the prime effect per SOA collapsed over material type were carried out. The results of these statistical analyses as well as the amount of priming per subject per SOA are given in Table 4. As in the group analyses, the amount of priming was obtained by subtracting the difference scores for response times in the ungrammatical condition from those in the grammatical condition. To summarize, the results, the following seven priming patterns emerged from the SOA X Prime analysis of variance. (1) Priming at all three SOAs (1 Control). (2) Priming at none of three SOA's (3 Controls, 5 Broca's). (3) Late appearance of priming (1 Controls, 3 Broca's): priming at 700 ms SOA or priming at 700 and 1100 ms SOAs. (4) Early disappearance of priming (5 Controls, 1 Broca): priming at 300 ms SOA or priming at 300 and 700 ms SOAs. (5) Late appearance+early disappearance (2 Control, 2 Broca's): priming at 700 ms SOA. (6) Priming in negative direction at 700 ms SOA and no priming at 300 and 1100 ms SOAs (2 Broca's). (7) Early and late priming (1 Control): priming at 300 and 1100 ms SOA.

3.4 DISCUSSION

The goal of our syntactic priming study was to shed more light on the nature of the resource limitation that seems to disturb Broca's aphasics' syntactic understanding. For this purpose, three competing hypotheses were put to a test: the slow activation hypothesis, the fast decay hypothesis and the reduced-buffer-size hypothesis. All three hypotheses have in common that they locate the resource limitation in a system specialized for parsing sentences. As explained in the Introduction, however, they make different predictions regarding the priming pattern, that is, the time-course of syntactic priming over SOA, in Broca's aphasics compared to that of normal controls. The slow activation hypothesis predicts a late appearance of syntactic priming, the fast decay hypothesis an early disappearance and the reduced-buffer-size hypothesis no priming at all or the same priming pattern as in normal controls. Our findings seem to provide support for the slow activation hypothesis, since there was evidence for a late appearance of syntactic priming in Broca's. For controls, there was significant syntactic priming at all three SOAs, ie. the 300, 700 and 1100 ms SOA. For Broca's aphasics, on the other hand, syntactic priming failed to reach significance at the 300 and 700 ms SOA and only became significant at the largest SOA of 1100 ms SOA.

How well do our findings fit in with the findings of the previous studies of syntactic priming in Broca's aphasics (Baum, 1988; Friederici and Kilborn, 1989; Milberg et al., 1985, see introduction). As we discussed, Milberg et al. (1985) and Baum (1988), using unimodal auditory presentation and an interstimulus interval of approximately 500 ms, did find a significant syntactic priming effect in a group of normal controls but not in a group of

TABLE 4
Individual priming patterns.[a]

	GROUP					
	BROCA's			CONTROLS		
SOA[b]:	300	700	1100	300	700	1100
Subject						
1	90	110	44	92**	33	58
2	51	138*	116*	64**	2	25
3	28	39	4	51**	55**	24
4	37	-8	36	59	65*	40
5	49	267*	21	2	-32	-12
6	-68	-154*	-4	55	36	30
7	135**	62**	20	69**	49**	41
8	3	-3	-2	108**	29	108*
9	78	193*	46	144**	18	45
10	27	36	81*	14	105*	100**
11	-151	-173*	11	39*	81*	45*
12	49	55	67	15	-14	40
13	20	18	332*	5	78**	34

Note. [a]Cells in table indicate amount of syntactic priming in ms. [b]Stimulus Onset Asynchrony between prime fragment and target. $^{*}p < .05$, $^{**}p < .01$

Broca's aphasics. This result is consistent with our finding of no syntactic priming in Broca's aphasics at the 300 and 700 ms SOA, since the 500 ms inter stimulus interval used in Baum's study falls between these two SOAs. Baum (1988) speculates that the absence of a syntactic priming effect in her Broca's aphasics could mean two things: NO or IMPERFECT access of the parser via automatic process routines. The first interpretation seems to imply a loss of the routines that are responsible for automatic access to the parser. The second interpretation, that of imperfect access to the parser via automatic process routines, seems to be more consistent with our findings. In fact, the re-appearance of the syntactic priming effect in Broca's aphasics at the 1100 ms SOA suggests that imperfect automatic access can be further specified in terms of speed as slower access.

We could not replicate the results of Friederici and Kilborn (1989) who found evidence of an early disappearance of syntactic priming in Broca's aphasics as predicted by the fast decay hypothesis. Several factors could be responsible for this replication failure such as the (partial) difference in materials used, lack of counterbalancing of order of SOA in the Friederici and Kilborn (1989) study and the appearance in the latter study of a delay in response time due to the presence of a context sentence: this has the effect of increasing the effective SOA.

Next, we would like to draw attention to the finding that our Broca patients showed a considerable amount of between-subject variation in priming pattern. It is tempting to interpret such variation as reflecting different deficits in different Broca's aphasics. However, there are two reasons to argue against such an interpretation. First, four of the five priming patterns observed in different Broca patients were also observed in different healthy control subjects[4] . Second, even if all control subjects had shown the same syntactic priming pattern, it would not necessarily follow that differences in syntactic priming pattern in Broca's aphasics reflect different deficits. It could be that such differences are an outcome of within-subject fluctuation in the syntactic activation rate. Of particular relevance here is a computer simulation of sentence-picture matching data (Haarmann and Kolk, 1991a), in which within-subject fluctuation in the syntactic activation rate was assumed in order to account for the above-chance performance of individual Broca patients on a particular sentence type. An interesting side-effect of this assumption was that simulated individual patients, much like real individual patients, occasionally showed a reversal (or absence) of the sentence-complexity effect that was observed at the group level. With the same low number of sentence repetitions as in the empirical sentence-picture matching studies, the sentence-complexity effect obtained at the group level could not always be reliably similated at the individual level. In a similar manner,

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[4] Our analysis of the time-course of syntactic activation in individual subjects illustrates that our syntactic priming technique can only be used to compare the priming patterns of groups of subjects. Given the overlap in priming patterns between Broca's aphasics and normal controls it would be wrong to conclude something about the deficit of a single patient by comparing the performance of this patient to the mean performance of the entire control group The reason is that in most cases one can find a healthy control subject that shows a similar priming pattern as the patient. We therefore do not recommend the use of the syntactic priming technique in single case studies, unless it can be shown that the priming effect is invariably present in the individual control subjects. Unfortunately, this issue was not explicitly addressed in a word monitoring study by Tyler (1985) in which the performance pattern of a single Broca patient was compared to the mean performance pattern of a control group.

due to within-subject fluctuation in the syntactic activation rate, it is possible that the priming pattern of our subjects could not be reliably established with only one testing session per SOA.

To conclude, the results of our syntactic priming study fit well within a framework which assumes that Broca's restriction in parsing resources involves a temporal dimension. In particular, the finding of a late appearance of significant syntactic priming in Broca's (i.e., only at the largest SOA) suggests that syntactic information is activated at a slower than normal rate in these patients. As was already pointed out in the introduction, such a slow down might disrupt Broca's parsing by preventing the co-activation of syntactic information (Haarmann & Kolk, 1991a; Kolk & van Grunsven, 1985).

APPENDIX

MATERIALS: CRITICAL WORD ITEMS

Condition	Prime fragment[a]		Continuation: Grammatical	Continuation: Ungrammatical[b]
Passive	wij	worden	gezocht (sought after)	geknoeid (messed)
	jullie	worden	genoemd (named)	gezwegen (not spoken)
	zij	worden	getroost (comforted)	getwijfeld (doubted)
	wij	worden	gekwetst (hurt)	gegokt (gambled)
	jullie	worden	geschoren (shaved)	gebladerd (skimmed)
	zij	worden	gewond (wounded)	geklommen (climbed)
	wij	worden	geprezen (praised)	gedwaald (roamed)
	jullie	worden	getest (tested)	gesnurkt (snored)
	zij	worden	gegroet (greeted)	gewandeld (walked)
	wij	worden	gekeurd (inspected)	gezucht (sighed)
	jullie	worden	geschorst (suspended)	getreurd (grieved)
	zij	worden	gedood (killed)	gezworven (wandered)
	wij	worden	gestreeld (stroked)	gezeild (sailed)
	jullie	worden	gemeden (avoided)	gebeefd (trembled)
	zij	worden	gewantrouwd (mis-trusted)	gewuifd (waved)
Perfect	wij	hebben	geslapen (slept)	gevallen (fallen)
	jullie	hebben	gedronken (drunk)	gebotst (collided)
	zij	hebben	gekeken (watched)	gevlucht (fled)
	wij	hebben	gehoopt (hoped)	gezonken (sunken)
	jullie	hebben	gevochten (fought)	geslipt (skidded)
	zij	hebben	gerookt (smoked)	gestart (started)
	wij	hebben	gegild (screamed)	geschrokken (frightened)
	jullie	hebben	gewacht (waited)	gestorven (died)
	zij	hebben	geoefend (practiced)	geworden (become)

	wij	hebben	gebokst (boxed)	geweest (been)
	jullie	hebben	gekletst (talked)	getrouwd (married)
	zij	hebben	gefeest (partied)	gebleven (stayed)
	wij	hebben	gegeten (eaten)	gekomen (come)
	jullie	hebben	gewerkt (worked)	gegaan (gone)
	zij	hebben	gestudeerd (studied)	gestikt (choked)
Modal verb	wij	kunnen	vissen (fish)	trap (staircase)
	jullie	kunnen	scheiden (divorce)	tafel (table)
	zij	kunnen	proberen (try)	neus (nose)
	wij	kunnen	fietsen (bike)	buik (stomach)
	jullie	kunnen	stemmen (vote)	boterham (sandwich)
	zij	kunnen	glijden (slide)	spiegel (mirror)
	wij	kunnen	handelen (act)	taxi (cap)
	jullie	kunnen	spreken (talk)	boot (boat)
	zij	kunnen	staren (stare)	telefoon (telephone)
	wij	kunnen	stijgen (ascend)	tempel (temple)
	jullie	kunnen	graven (dig)	ladder (ladder)
	zij	kunnen	kletsen (talk)	tekening (drawing)
	wij	kunnen	luieren (rest)	drempel (threshold)
	jullie	kunnen	kneden (knead)	koelkast (fridge)
	zij	kunnen	morsen (spill)	leuning (railing)
Preposition	voor	de	klok (clock)	schuilen (shelter)
	op	de	piano (piano)	raden (guess)
	naast	de	school (school)	roken (smoke)
	voor	de	auto (car)	toveren (conjure)
	op	de	handdoek (towel)	aarzelen (hesitate)
	naast	de	brug (bridge)	mopperen (complain)
	voor	de	markt (market)	wennen (adapt)
	op	de	berg (mountain)	zeuren (complain)
	naast	de	schouder (schoulder)	spotten (mock)
	voor	de	pagina (page)	loeren (peer)
	op	de	kast (cabinet)	knagen (gnaw)
	naast	de	kamer (room)	genieten (enjoy)
	voor	de	steen (stone)	poetsen (clean)
	op	de	vleugel (wing)	mompelen (mumble)
	naast	de	plank (shelf)	zweten (sweat)

Note. [a] English translation of words in prime fragments: wij (we), jullie (you), zij (they), op (on), naast (next to), voor (in front of), worden (are being), hebben (have), kunnen (can), de (the). [b] The continuation in the perfect condition is only ungrammatical in Dutch (see text for explanation).

Chapter 4

On-line Sensitivity to Subject-Verb Agreement Violations in Broca's Aphasics: The Role of Syntactic Complexity and Time[1]

ABSTRACT

The study reported in this chapter explored on-line sensitivity to subject-verb agreement violations in age-matched controls and in Broca's aphasics using a word monitoring paradigm. The agreement violations were couched in either simple or complex syntactic frames. In a first experiment, these syntactic frames were immediately followed by the noun phrase containing the target. In a second experiment, there was a 750 ms separation. The results suggest that Broca's suffer from a pathological limitation in parsing resources which results from a too-fast decay of syntactic information. Contrary to age-matched controls, Broca's only showed an agreement effect (i.e., significantly faster monitoring latencies for agreeing than non-agreeing sentences) for simple sentences, but not for complex ones. Furthermore, the delay in target presentation resulted in a disappearance of the agreement effect in Broca's but not in age-matched controls.

4.1 INTRODUCTION

Part of the behavioral definition of the syndrome of Broca's aphasia is its lack of syntactic variety in spontaneous speech which often has a telegraphic-like quality. Broca's problems in language production are parallelled in language comprehension, though not always (Miceli, Mazzucci, Menn and Goodglass, 1983; Kolk, van Grunsven and Keyser, 1985). The performance of Broca's in off-line sentence-picture matching tasks (e.g., Caramazza and Zurif, 1976; Goodglass et al., 1979; Heilman and Scholes, 1976; Schwartz, Saffran and Marin, 1980) and sentence-acting-out tasks (e.g., Caplan and Hildebrandt, 1988) is typically impaired when understanding (i.e., determining thematic roles such as actor, theme and recipiens) is made dependent on syntactic cues, such as word order and structural embedding, and when lexical-semantic cues to understanding are missing. In an attempt to elucidate the nature of Broca's receptive syntactic deficit several researchers have recently focussed their studies on the on-line properties of Broca's syntactic processing (e.g., Baum, 1989;

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[1] Haarmann, H.J., & Kolk, H.H.J. (submitted). *Brain and Language*.

Shankweiler, Crain, Gorrell and Tuller, 1989; Tyler, 1985, 1989). On-line tasks are particularly suitable for detecting differences in real-time sentence processing which may go unnoticed when using off-line tasks (see Tyler, 1985 for an example).

Shankweiler et al. (1989) recently compared Broca's and normal controls in an on-line syntactic judgement task which required subjects to detect as quickly and accurately as possible grammatical anomalies involving the closed-class vocabulary, in particular, determiners, prepositions, verb particles, and auxiliary verbs. The major finding was that Broca's and normal controls showed nearly identical performance profiles both with respect to response latency and accuracy. This was most evident in the response latencies which indicated similar effects of position and proximity. That is, for both groups, latencies were faster when the two lexical elements defining the grammatical anomaly occurred at later positions in the sentence and when the distance between them was close as opposed to far (i.e., no and more than two words intervening, respectively). In addition, though overall slower and less accurate, Broca's seemed to able to give their responses without much conscious reflection as most responses were given either before or slighly after (i.e., 182 ms on average) the offset of the auditory sentence signal. The finding of similar on-line performance characteristics in Broca's and normal controls was interpreted by Shankweiler et al. as evidence against the hypothesis that Broca's receptive syntactic deficit reflects a partial loss of syntactic knowledge (for a similar conclusion see Baum, 1988; Friederici and Kilborn, 1989; Haarmann and Kolk, 1991b; Kolk and van Grunsven, 1985; Linebarger, Schwartz and Saffran, 1983; Tyler, 1985, 1989; Wulfeck, 1988). Instead, Shankweiler et al. argued that Broca's receptive syntactic deficit reflects a problem in the processing of syntactic knowledge.

The task facing the aphasia researcher is to find out under which adverse processing conditions Broca's syntactic processing may become derailed. One relevant factor in this context is the syntactic complexity of a sentence's phrase-structure representation which was not manipulated in Shankweiler et al.'s study. Syntactic complexity roughly corresponds with the number of constituent nodes in a hierarchical phrase-structure representation of a sentence (cf., Haarmann and Kolk, 1991a). Recently, there have been several speculations about the nature of Broca's receptive syntactic deficit, such as for instance that it involves a rapid decay (Friederici and Kilborn, 1989; Hagoort, 1989; Kolk and van Grunsven, 1985), or slow activation of syntactic information (Friederici and Kilborn, 1989; Gigley, 1983; Haarmann and Kolk, 1991b; Huber, Cholewa, Wilbertz and Friederici, 1990; Kolk and van Grunsven, 1985), or a capacity reduction of syntactic working memory (Kolk and van Grunsven, 1985; Caplan and Hildebrandt, 1988). All these accounts predict an adverse effect of syntactic complexity (Haarmann and Kolk, 1991a). Syntactic complexity indeed has been found to negatively affect sentence processing in many off-line studies. In sentence-picture matching studies, Broca's aphasics have been shown, for example, to have better syntactic understanding for simple declarative SVO actives than for structurally more complex passives (Kolk and van Grunsven, 1985; Schwartz et al., 1980), locatives (Kolk and van Grunsven, 1985; Schwartz et al., 1980), and datives (Caplan, Baker and Dehaut, 1985; Heilman and Scholes, 1976) (for more examples see for instance Blumstein, Katz, Goodglass, Shrier and Dworetsky, 1985, and Caplan and Hildebrandt, 1988).

Unfortunately, in off-line studies, syntactic complexity was often confounded with at least one of the following three variables: the length of the sentence, its meaning content, and the ease by which thematic roles can be assigned after a phrase-structure representation has been derived (for an explanation of the effect of this latter variable see Schwartz, Linebarger, Saffran and Pate, 1987). In the present study, we made an attempt to control for these variables by only including (critical) sentences of equal length and equal meaning content and by using a task that minimizes the importance of thematic role assignment, namely, an identical word monitoring task. Results of two earlier word monitoring studies by Tyler (1985, 1989) and Baum (1989) were consistent with the syntactic complexity hypothesis. Both studies will be discussed in turn.

Tyler (1985, 1989) conducted a series of word monitoring experiments with one Broca patient, DE, in order to test his ability to process syntactic structure. As was the case for normal controls, DE's overall monitoring latencies were faster for anomalous (i.e., syntactically but not semantically coherent) prose than for scrambled (i.e., both syntactically and semantically incoherent) prose (Tyler, 1985). DE's advantage of anomalous over scrambled prose, while indicating sensitivity to syntactic structure, seemed to be due to local rather than global syntactic processing. Whereas DE's monitoring latencies appeared to be normally interfered with by violations of local syntax (i.e., word order as in "hot very kitchen" Tyler, 1989, and verb subcategorization as in "... slept the guitar" Tyler, 1985), DE did not show the normally obtained word position effect (i.e., faster word monitoring latencies for later occurring targets in anomalous but not scrambled prose) (Tyler, 1985, 1989). Tyler and colleagues have attributed the word position effect in normals to the development of a global syntactic representation which has an increasingly predictive value for targets occuring late in the sentence input. DE's lack of a word position effect seemed to indicate his failure to develop a global syntactic representation spanning the entire sentence. Unfortunately, Tyler's results, though consistent with the hypothesis that DE was not able to construct syntactic representations beyond a certain level of complexity, have to be interpreted with caution. Syntactic complexity was not explicitly manipulated as an independent variable and her study involved only a single Broca patient.

A group study by Baum (1989) also seemed to indicate that Broca's have more difficulties in the on-line processing of global than local syntactic representations. Baum investigated to what extent the word monitoring latencies of normal controls and Broca's were interfered with by grammaticality violations which reflected either local or global dependencies. Local dependencies all occurred within a clause boundary and could involve one of the following three types: verb subcategorization, auxiliary agreement and the use of reflexives. Global dependencies all occurred across a clause boundary and could also involve one of three types: the coordinate structure constraint, the filling of question gaps and the filling of relative clause gaps. Global dependencies all involved the movement of a constituent out of a clause (e.g., * "Whom did the boy see Tom PLAYING in the schoolyard", arterisk indicates ungrammaticality, monitoring target in capitals). Normal controls showed a grammaticality effect (i.e., significantly slower word monitoring latencies in the ungrammatical than grammatical condition) for both local and global dependencies. Broca's, on the contrary, only showed a grammaticality effect for local but not for global dependencies.

Baum's word monitoring results are consistent with the hypothesis that syntactic processing in Broca's is negatively affected by the syntactic complexity of the sentence material. Under this hypothesis, the detection of local, within-clause grammaticality violations is easier than the detection of global, across-clause grammaticality violations because a sentence's syntactic structure can be thought of as more complex as more clauses are involved. Thus, it is possible that a quantitative increase in syntactic complexity disrupted Broca's detection of grammaticality violations in Baum's study. However, as is apparent from the above description of Baum's materials, the local-global manipulation was confounded with the type of anomaly. Local dependencies involved different anomalies than global dependencies. As Baum herself suggests, it is therefore possible that the absence of a grammaticality effect for global dependencies reflected an impairment in a qualitatively different type of process than is involved in the analysis of local dependencies. In Baum's study all local dependencies could be processed based on syntactic knowledge that is stored in the lexicon (e.g., subcategorization information about the verb), whereas global syntactic dependencies required the build-up of an abstract supra-lexical phrase-structure representation. An inability to represent and process any phrase-structure -- as opposed to only those phrase-structures that exceed a certain level of complexity -- could therefore also explain Baum's results.

We wanted an explicit test of the hypothesis that an increase in syntactic complexity creates adverse processing conditions for sentence processing. Unlike Tyler (1985, 1989) we directly manipulated syntactic complexity and unlike Baum (1989) we kept the type of grammatical anomaly constant across our two levels of complexity. In our choice of the type of grammatical anomaly, that is, subject-verb number agreement violations, we were inspired by the results of an off-line acceptability judgement study by Grossman and Haberman (1982). These results suggested that Broca's detection of several types of pronoun-verb agreement violations (i.e., subject-verb number agreement violations among others) was dependent on the syntactic complexity of the sentence frames in which they were couched. Broca's detection of such pronoun-verb agreement violations was significantly better for active declaratives (e.g., "They is kissing Jane.") and interrogatives (e.g., "Is they kissing Jane?") than for passives (e.g., "They is kissed by Jane."). Note, however, that in Grossman and Haberman's study there is a confound between syntactic complexity and sentence length. Passives were not only structurally more complex but also one word (i.e., the preposition "by") longer than the active declaratives and interrogatives. The approach in our study was similar to Grossman and Haberman's in that we assessed Broca's sensitivity to subject-verb agreement violations as a function of the syntactic complexity of the sentence frame in which they were couched. Unlike Grossman and Haberman, we did not asses this sensitivity directly by asking for an acceptability judgement but indirectly by noticing whether subject-verb agreement violations in a certain syntactic context slowed down the monitoring latencies to noun targets relative to a control condition with subject-verb agreement. Thus, the detection of the subject-verb agreement violations in the word monitoring task is not the primary task of the subject. This has the advantage of keeping the influence of strategies to detect such violations to a minimum, so that one is more likely to asses a subject's automatic as opposed to controlled processing capabilities (cf., Tyler, 1989).

Below we will report two nearly identical experiments. The first experiment was designed to compare Broca's and controls' sensitivity to subject-verb agreement violations in sentences of equal length (i.e., both number of words and signal duration) and propositional content but of different syntactic complexity, that is, being either syntactically simple or complex. In simple sentences, two verb phrases were expressed by a conjunction as in "The girls carry the child and eats ICECREAM in the park." (word monitoring target in capitals). In their complex counterparts, one of these two verb phrases was embedded in the subject noun phrase as in "The girls that carry the child eats ICECREAM in the park." From a structural point of view 'embedded' sentences are more complex than their 'conjoined' counterparts because an extra level of depth is created in the phrase-structure representation containing an embedding as opposed to a conjunction. This difference in syntactic processing load is more likely to show up in persons whose sentence processing is subject to a limitation in speed of processing (Haarmann and Kolk, 1991a). Using a sentence-picture matching paradigm, Goodglass et al. (1979), for example, found that especially those Broca's that had poor comprehension scores benefited the most from changing sentences containing an embedding (e.g., "The man greeted by his wife was smoking a pipe.") to sentences expressing the same information in an expanded manner as a conjunction (e.g., "The man was greeted by his wife, and he was smoking a pipe."). As for our own study we expected the agreement effect (i.e., signficantly slower monitoring latencies in sentences without subject-verb agreement than in sentences with subject-verb agreement) to be present in both normal controls and Broca's in the syntactically simple, conjoined sentences but only in normal controls also in the syntactically complex, embedded sentences. The first experiment was designed to test this prediction. We also conducted a second experiment in which we gave subjects somewhat more time (i.e., 750 ms) to analyze the syntactic frame containing the agreement violation before the target noun was encountered. As we will discuss further below, this experiment was conducted in order to contrast the predictions of two different hypotheses about the exact nature of Broca's processing impairment, namely, that it involves either a too slow activation (Friederici and Kilborn, 1989; Gigley, 1983; Haarmann and Kolk, 1991b; Huber, Cholewa, Wilbertz and Friederici, 1990; Kolk and van Grunsven, 1985) or too fast decay (Friederici and Kilborn, 1989; Hagoort, 1989; Kolk and van Grunsven, 1985) of syntactic information.

4.2 EXPERIMENT 1

4.2.1 METHOD

Subjects. Two different subject groups took part in the experiment: (1) age-matched controls and (2) Broca's aphasics, all native speakers of Dutch.

(1) The age-matched controls (n = 20) were in the same age range (27 yr - 74 yr) as the Broca's aphasics. They had no history of neurological damage, reported no known hearing impairments and were largely drawn from the subject pool of the Max Planck Instituut in Nijmegen. They were paid for their participation.

(2) The Broca's aphasics (n = 15) (mean age 54 yr) were selected from the patient pool of the Max Planck Institute and had been administered a translated, Dutch version of the German, Aachen Aphasia Test (AAT) (Graetz, de Bleser, Willmess and Heeschen, 1991; Huber, Poeck, Weniger and Willmes, 1983). Syndrom classification was unanimously reached by a team of three neurolinguists based on a recording and transcription of the spontaneous speech interview of the AAT. The criteria for classification as Broca's aphasic were relatively intact auditory comprehension (as assessed by the patient's answers to questions during the interview of the AAT), non-fluent agrammatic language production with impoverished melodic line, disturbed articulatory agility, many phonemic paraphasias and only a few semantic paraphasias (Goodglass and Kaplan, 1972; Poeck, Kerschensteiner, Stachowiak and Huber, 1975). Agrammatic language producton was defined as a shortening of sentences

accompanied by a reduction in the variety of grammatical forms and as tendency to omit (not substitute) both bound and free grammatical morphemes. All patients had suffered a right-sided hemiplegia and had sustained left hemispheric damage. With two exceptions, one involving a case of inflammatory meningites and the other a case of trauma (patients no. 15 and 14, respectively), all patients had sustained a cerebral vascular accident (CVA) involving the region of the left middle cerebral artery. Patients had no previous history of neurological disease, with the exception of patient 13 who had suffered two more CVAs after the first one. These CVAs, however, were of a minor and transient nature, as suggested by both CT-scan and retest results with the AAT, which showed a steady improvement since the first CVA accident. Mean post-onset time of brain damage was 10 yr and 4 m. (range: 5 yr and 3 m. - 19 yr). Table 1 gives a summary of further relevant background information per individual patient: sex, age, former occupation, post-onset time, aetiology, Token Test and auditory word and sentence comprehension scores from the AAT. Scores on the Token Test confirm the presence of aphasia and indicate different degrees of severity of aphasia (Huber et al., 1983). The mild impairment revealed by the Auditory comprehension scores of the AAT is consistent with the classification as Broca's patient.

Materials. Three lists of Dutch sentences were created: a practice list, a critical list and a filler list.

The practice list consisted of 4 grammatical and 4 ungrammatical sentences with target nouns (one per sentence) occupying word positions 2 to 9 and of 2 grammatical and 2 ungrammatical catch trial sentences. The types of ungrammaticality formed a subset of the types of ungrammaticality that occurred in filler sentences (see below).

The critical list consisted of 20 different sentences each of which occurred in four different versions (see table 2 for an example). The four different versions of a sentence corresponded to the cells of a two-by-two design in which the (within) factors syntactic complexity (conjoined verb phrase versus embbedded verb phrase) and subject-verb agreement (present versus absent) were completely crossed. All four different versions of a particular sentence used the same content words, expressed the same two propositions and were of equal length (i.e., number of words). Sentence length ranged from 13 to 16 words.

Conjoined sentences always consisted of a subject noun phrase followed by two verb phrases connected by the word "en" ("and"). The first verb phrase always consisted of a transitive verb followed by a direct-object noun phrase, while the second verb phrase always consisted of verb followed by an indirect- or direct-object noun phrase followed by a remaining part which differed across sentences. Noun phrases always consisted of a

TABLE 1

Background data Broca's aphasics.

No.	Sex[a]	Age	Onset[b]	Former occupation	Aetiology	TT[c]	Comprehension W[d]	Comprehension S[e]
1	M	61	42	Factory director	Infarct L. mid cerebral artery	32	23	25
2	M	51	194	Motor Mechanic	Infarct L. temporoparieto-occipital	33	26	26
3	M	64	157	Fitter	Infarct L. mid cerebral artery	17	23	21
4	M	53	228	Designer	Aneurysm L. mid cerebral artery	42	20	19
5	M	57	105	Mechanic	Occlusion L. artery carotis interna	19	29	23
6	F	37	173	Bank employee	Aneurysm L. mid cerebral artery	31	26	23
7	M	45	103	Welder	Infarct L. frontotemporaal	10	27	27
8	M	74	114	Fireman	Infarct L. mid cerebral artery	3	30	30
9	M	62	116	Municipal official	Infarct L. mid cerebral artery	5	25	23
10	F	64	63	Secretary	Infarct L. mid cerebral artery	11	26	24
11	M	67	130	Construction Worker	Infarct L. mid cerebral artery	50	23	23
12	M	64	116	Quality Controler	Infarct L. mid cerebral artery	21	27	23
13	F	59	89	Nurse	Infarct L. mid cerebral artery	33	22	29
14	M	27	83	None (highschool)	Trauma	21	28	28
15	M	27	143	None (highschool)	Bacterial meningitis L. fronto temporal	34	28	26

Note. [a]Sex: M = male, F = female. [b]No. of months since onset. [c]Token Test (Maximum number of errors: 50). [d]W = auditory comprehension isolated words (Maximum score: 30). [e]S= auditory comprehension sentences (Maximum score: 30).

TABLE 2

example of set of critical sentences

experimental

simple constituent structure							
agreement:	De vrouwen[a]	dragen het	kind en	eten	I[b]	een	IJS[c] etc.
	(The women	carry the	child and	eat	I (a)	ICECREAM etc.)	
no agreement:	De vrouwen	dragen het	kind en	eet	I een	IJS etc.	
	(The women	carry the	child and	eats	I (a)	ICECREAM etc.)	
complex constituent structure							
agreement:	De vrouwen	die het	kind dragen	eten	I een	IJS etc	
	(The women	that carry[d]	the child	eat	I (a)	ICECREAM etc.)	
no agreement:	De vrouwen	die het	kind dragen	eet	I een	IJS etc.	
	(The women	that carry	the child	eats	I (a)	ICECREAM etc.)	

etc = midden in het park (in the middle of the park)

Note. [a]The two lexical elements that define the grammatical anomaly are underlined [b]I = position of the ISI (Inter Stimulus Interval) [c]The target word to be monitored for is written in capitals [d]The subject- and object-relative clause have the same word order in Dutch, but a different one in English.

determiner followed by a noun. The noun in the noun phrase immediately following the second verb was designated as the target for the monitoring task. An example of a conjoined sentence is: "De agenten horen de dief en proberen de DEUR zo zachtjes mogelijk te sluiten." (Literal English translation "The cops hear the thief and try the DOOR as softly as possible to close")(Proper English translation: "The cops hear the thief and try to close the door as softly as possible.")(word monitoring target in capitals). For another example see table 2.

Embedded sentences were almost identical to conjoined sentences. They also consisted of a subject noun phrase followed by two verb phrases. These two verb phrases, however, were not conjoined by the word "en" ("and"). Instead, the first verb phrase was expressed as a subordinate clause to the subject noun phrase and was immediately followed by the second verb phrase. The embedded counterpart of the above example of a conjoined sentence (see also table 2) is "De agenten die de dief horen proberen de deur zo zachtjes mogelijk te sluiten." (Literal English translation: "The cops that the thief hear try the door as softly as possible to close.")(Proper English translation: "The cops that hear the thief try to close the door as sofly as possible."). Notice that in Dutch subordinate clauses starting with "die" ("that") the verb occupies clause final position.

Each particular sentence occurred in a grammatical version for which there was number agreement between the subject noun phrase and the verb of the second verb phrase and in an ungrammatical version for which there was no such agreement (see table 2). Between the subject and the first verb there was always number agreement. All subject and verbs occurred in third person. For sentences with number agreement, the subject and the second verb were in half of the sentences both plural and in half of the cases both singular. For sentences without number agreement, the subject and the second verb were in half of the sentences plural and singular, respectively, and in half of the sentences singular and plural, respectively.

Sentences were constructed so that non-syntactic strategies to detect the subject-verb agreement violations would fail. First, a semantically based strategy would be to apply the agreement check only to those nouns that meet the verb's selection restrictions for the agent or actor role. Such a strategy would fail if more than one noun would meet the verb's selection restrictions for the agent role. Therefore, sentences were constructed in such a way that not only the subject noun but also the direct-object noun (of the first verb phrase) could serve as a potential (i.e., semantically but not syntactically) and plausible agent of the main verb of the second verb phrase. For example, in the sentence "the baker greets the customers and asks the boy to not make so much noise", both the noun "baker" and the noun "customers" can serve as potential agents of the verb "to ask" which requires a human actor. Moreover, in the baker-greets-customers situation it is entirely plausible for both a baker or customers to ask a boy to be less noisy. The subject and direct object of the first verb phrase were always animate. A second strategy to infer subject-verb agreement whithout phrase-structure analysis is to take only the linear order of syntactic categories into account and apply the agreement check to the verb in the second verb phrase and the noun immediately preceding it, that is the direct object noun of the first verb phrase. Applied to our sentences, however, such a strategy would fail because the subject noun and the direct-object noun of the first verb phrase always disagreed in number. For example, in "de bakker groet de klanten en vraagt ..." ("the baker greets the customers and asks"), the noun phrase "the bakker" ("the baker") and the noun phrase "klanten" ("customers") disagree in number. A third potential strategy that bypasses syntactic analysis to infer subject-verb agreement is morphologically based. In our sentences, a subject-verb agreement violation can be inferred whenever there is disagreement in number between the verb of the first and second noun phrase. Therefore, all filler sentences contained two verbs which disagreed in number but nevertheless showed correct subject-verb agreement. For example, "De kok brengt de mannen die lachen een heel lekkere maaltijd" ("The cook brings the men that laugh a very tasty meal.").

Like the critical list, also the filler list consisted of 20 different sentences each of which occurred in four different versions. Again the four different versions of a sentence corresponded to the cells of a two-by-two design, now however, with the (within) factors grammaticality (grammatical versus ungrammatical) and catch-trial (target present versus target absent) completely crossed. An equal number of versions (i.e., four) for both critical and filler sentences was chosen so that the subject's attention would not be selectively drawn to the critical sentences. Filler sentences ranged in length from 12 to 18 words and the position of the target noun (or its catch trial replacement) was systematically varied from the 2nd to the 11th word. The following kinds of ungrammaticality occurred in half of the filler sentences: a determiner with the wrong gender or number, an adjective with the wrong ending, a wrong relative pronoun, a wrong verb particle, a wrong syntactic preposition, a determiner-noun inversion, a preposition substituted by an adjective, a finite verb substituted by a past participle verb and an adverb substituted by a count word. These different types of ungrammaticity occurred at random positions before the target noun. This was done in order to make the position of the target noun in the critical sentences (i.e., always immediately following the subject-verb agreement violations) less predictable. Half of the filler sentences were catch trials.

Sentences were produced by a male speaker at a rate of approximately 130 words per minute and digitized onto a MAC/SE computer using a sampling frequency of 22 kHz. Special care was taken to produce the ungrammatical sentences with a natural sentence melody. For each of the 20 critical sentences, two sound segments were recorded separately.

The first sound segment contained the signal from the beginning of the sentence up to and including the main verb of the second verb phrase (e.g., "the baker greets the customers and ask"). Thus, the first sound segment contained the syntactic frame over which the subject-verb agreement violations were defined. The second sound segment contained the rest of the sentence (e.g., "the BOY to not make so much noise") and started with the noun phrase (e.g., " "the BOY") containing the target (e.g., "BOY"). In this experiment, there was a silent inter-stimulus interval (ISI) of 0 ms between the offset of the first sound segment and the onset of the second sound segment (for an illustration of the ISI location see also table 2). In our second experiment (see below), this ISI was increased from 0 to 750 ms. In both experiments, the target noun occurred on average 229 ms (range 104 ms - 320 ms) into the second sound fragment. The experimental control program (see below) measured monitoring times from the beginning of the second sound segment (with the duration of the determiner preceding the target noun substracted). The second sound segment was the same for all four different versions of a particular sentence. This recording procedure ensured that for all four different versions of a particular sentence the same target onset time was used. The first sound segment differed across the four different versions of a particular sentence (e.g., "the baker greets the customers and asks" versus "the baker greets the customers and ask"). The four different, first-part sound segments of a particular sentence were equated for length by adding a pause where there is a natural pause in the sentence (i.e., after "and" in conjoined sentences and after the second verb in embedded sentences). In order to avoid the break between the first and second sound segment from predicting the upcoming of the target noun, the filler sentences contained two breaks which did not occur immediately before the target noun or its catch trial replacement.

Procedure. Subjects were tested individually, in a quiet room during one session that lasted approximately 35 minutes. Testing of the control subjects took place at the University of Nijmegen, while aphasic patients because of distance considerations had to be tested in their homes. An APPLE SE/30 computer with a 40 MB harddisk, a buttonbox and an experimental control program, ECS (kindly made available by Brian MacWhinney), were used to administer the auditory monitoring task. This program randomized the order of stimulus presentation separately for each subject. Each trial consisted of the following events. (1) The internal speaker of the APPLE was used to present a 500 HZ warning signal for 250 ms. (2) Immediately after the offset of the warning signal, the target word appeared in a rectangular box in the center of the computer screen and remained visible until the subject responded or until the entire sentence had been heard. The target word subtended at a visual angle of 3.15 degree horizontally and 1.15 degree vertically. (3) 2500 ms after the onset of the target word on the screen, the sentence was presented through the internal speaker of the

APPLE. (4) Subjects were instructed to listen carefully to each sentence and to press a button as soon as the target word appeared in the spoken sentence or to do nothing in case the target word did not appear in the spoken sentence. All subject's responded with the index finger of their non-dominant hand. Monitoring times (i.e., the time in ms from target onset to reaction onset) and errors (i.e., on go-trials: no reaction or a reaction that was too early and on nogo-trials: a reaction) were automatically recorded by the computer for later analysis. (5) After a subject's response or after the auditory offset of the sentence, the computer automatically went on to the next trial in about 3 seconds (i.e., the approximate time it took to retrieve a new auditory sentence from the harddisk). Before the actual experiment began, subject's were acquainted with this procedure. The experimenter read a visual instruction on the computer screen and initiated presentation of the 12-item practice set.

4.2.2 RESULTS

Data analysis. For each condition for each subject we calculated the mean error percentage as well as the mean monitoring latency across items. In calculating the mean monitoring latency, responses on which outliers or errors occurred were replaced by the subject's mean response time over the remaining trials of a condition. An outlier was defined as a response that occurred more than two and a half standard deviations below or above both the subject's condition mean and the item mean. Outlier replacement never changed the overall pattern in the data or significances of test results. In view of the large differences in within-group homogeneity, statistical tests were carried out for each of the two subject groups separately. The subject-condition mean monitoring latencies were entered as data entries in an overall repeated measurements Agreement (present, absent) X Complexity (conjoined, embedded) ANOVA. Especially for Broca's, we carried out planned comparisons that assessed whether there was an agreement effect (i.e., slower monitoring latencies in the non-agreeing than agreeing condition) for simple and complex sentences, respectively. This was done in view of the fact that we had reasons to expect the agreement effect in Broca's to be dependent on syntactic complexity. Finally, in order to get an extra check on the sensitivity of our procedure, we carried out planned comparisons for both groups to asses whether there was a grammaticality effect (i.e., slower monitoring latencies in the ungrammatical than grammatical condition) for filler sentences requiring a response (i.e., non-catch trials). Below we will report the test results for each group. In order to get an impression of the overall difficulty of the monitoring task we also report the average percentage of outliers for non-catch trials as well as the average percentage of errors on non-catch and catch trials, respectively. Error percentages were only entered into a statistical test in case they suggested that an agreement or grammaticality effect might have been due to a speed-accuracy trade-off (i.e., faster grammatical responses accompanied by a higher error rate). The mean monitoring latencies, standard deviations and error percentages per condition across subjects for both groups are summarized in table 3. Figure 1 displays for both groups the average size of the agreement effect (i.e., mean monitoring latencies in the non-agreeing condition minus those in the agreeing condition) for simple and complex sentences. The results for each group were as follows.

(1) Age-matched controls. Across subjects (n = 20), the average percentage of outliers and errors for non-catch trials was 1.88 and 1.00, respectively. The average error percentage for catch trials was 1.88. In the overall ANOVA, there was a main effect of agreement (F(1,19) = 8.51, MSe = 514, p < .01). Monitoring latencies for agreeing sentences (M = 329 ms) were on average 15 ms faster than those for non-agreeing sentences (M = 344 ms). Both the complexity effect and the Complexity X Agreement interaction were far from significant (F < 1). Furthermore, grammatical (non-catch) filler sentences (M = 420 ms) were responded to significantly faster (i.e., 36 ms) than ungrammatical (non-catch) filler sentences (M = 456 ms)(F(1,19) = 6.94, MSe = 1900, p = .017). An inspection of the error percentages in table 3 shows that the reported grammaticality effects cannot be to a speed-accuracy trade-off.

2) Broca's aphasics. Across subjects (n = 15), the average percentage of outliers and errors for non-catch trials was 1.72 and 3.06, respectively. The average error percentage for catch trials was 11.00. In the overall ANOVA, there was a marginally significant (i.e., .05 < p < .10) effect of agreement (F(1,14) = 3.62, MSe = 3809, p = .078) but no significant effect of complexity (F < 1) nor an interaction between Complexity and Agreement (F < 1). The planned comparisons revealed an almost significant agreement effect for conjoined sentences (F(1,14) = 4.24, MSe = 3922, p =.059) with monitoring times for agreeing conjoined sentences (i.e., M = 491 ms) being on average 47 ms faster than monitoring times for non-agreeing conjoined sentences (i.e., M = 538 ms). Furthermore, grammatical (non-catch) filler sentences (M = 684 ms) were responded to significantly faster (i.e., 61 ms) than ungrammatical (non-catch) filler sentences (M = 745 ms)(F(1,14) = 9.89, MSe = 2860, p < .01). Agreeing embedded sentences (M = 517 ms) were responded to 14 ms faster than non-agreeing embedded sentences (M = 531 ms). This difference in monitoring latencies, though in the expected direction, was far from significant (i.e., F < 1). Both the agreement effect for conjoined sentences and the grammaticality effect for filler sentences cannot be attributed to a speed-accuracy trade-off. Agreeing conjoined sentences were not only responsed to faster than non-agreeing conjoined sentences, they were also accompanied by less (i.e., 1.4 percent) errors. Somewhat more errors were made on the faster grammatical filler sentences (i.e., 7.33 percent) than on the slower ungrammatical filler sentences (i.e., 6.33 percent) but this 1 percent difference failed to reach significance (F < 1). As far as consistency of responding

TABLE 3

Mean monitoring latencies (in ms), standard deviations (between parentheses), and error percentages (between brackets) for experiment 1 (ISI = 0 ms).

	SENTENCE TYPE					
	CONJOINED		EMBEDDED		FILLER	
GROUP	AGR[a]	DAGR[b]	AGR	DAGR	GRA[c]	UGRA[d]
AGEMATCHED	331	345	327	343	420	456
(n = 20)	(60)	(69)	(63)	(75)	(85)	(93)
	[1.3]	[1.3]	[1.0]	[0.5]	[1.0]	[1.0]
BROCA'S	491	538	517	531	684	745
(n = 15)	(231)	(225)	(199)	(245)	(247)	(296)
	[0.3]	[1.7]	[1.7]	[1.0]	[7.3]	[6.3]

Note. [a]agr = *sentence with subject-verb agreement,* [b]dagree = *sentence* without subject-verb agreement (disagreement), [c]gra = grammatical sentence, [d]ugra = ungrammatical sentence.

across subjects is concerned, 11 of the 15 Broca's (i.e., 73 percent) showed the agreement effect for conjoined sentences in the expected direction (i.e., faster monitoring times for agreeing than for non-agreeing sentences) as compared to 15 of the 20 elderly controls (i.e., 75 percent)[2].

[2] It should be pointed out that one patient's monitoring times were deviant in that he was the only subject showing reversed agreement effects (i.e., marginally significant faster monitoring times for non-agreeing than for agreeing sentences) for both conjoined and embedded sentences. With this deviant subject (i.e., no. 12) excluded from the data analysis, the agreement effect for conjoined sentences increased from 47 ms (i.e., marginally significant) to 56 ms (i.e., $F(1,13) = 6.10$, $MSe = 3589$, $p = .028$), while the difference in response latency between non-agreeing and agreeing embedded sentences (increasing from 14 to 20 ms) remained nonsignificant ($F < 1$). In addition, the overall effect of agreement became significant ($F(1,13) = 7.53$, $MSe = 2849$, $p < .05$).

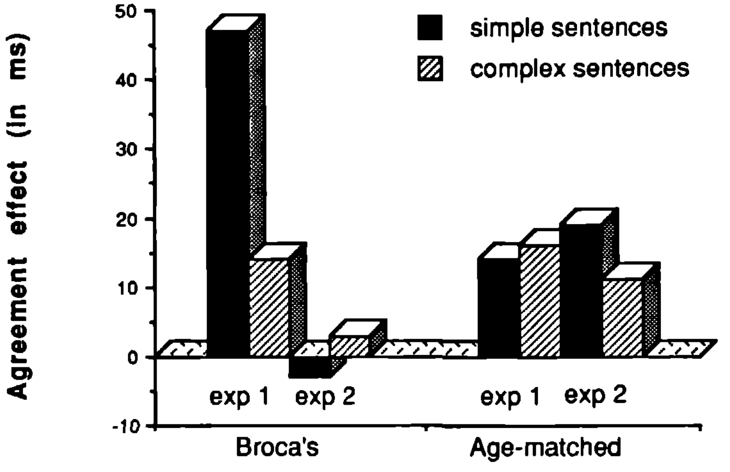

Figure 1. Comparison of mean agreement effects (disagreeing - agreeing condition) in experiments 1 and 2 reported in sections 4.2 and 4.3, respectively.

4.2.3 DISCUSSION

The goal of this experiment was to examine the role of syntactic complexity in normals' and Broca's ability to detect subject-verb agreement violations under on-line processing conditions that did not explicitly ask for such detection. The word monitoring times of age-matched controls showed sensitivity to subject-verb agreement violations (i.e., slower times in the disagreeing than agreeing condition) irrespective of whether these violations were couched in simple (i.e., conjoined) or complex (i.e., embedded) syntactic frames. This was indicated by the fact that the analysis of variance yielded a small (i.e., 15 ms) but significant main effect of agreement in the absence of an interaction between Agreement and Complexity. Moreover, the absolute size of the agreement effect for simple and complex sentences was almost the same, that is, 14 and 16 ms, respectively. The word monitoring times of Broca's, on the contrary, only showed sensitivity to subject-verb agreement violations when these violations occurred in simple syntactic frames but not when they occurred in complex syntactic frames. This was indicated by the fact that Broca's showed a large (i.e., 47 ms) and an almost significant agreement effect for simple sentences, but only a small (i.e., 14 ms) and insignificant agreement effect for complex sentences. It should be pointed out, however, that the expected interaction between Agreement and Complexity failed to reach significance. Especially in view of the large variability in the behavior of the aphasic patients, we think this failure could have been due to a lack of power. Unfortunately, the number of Broca's available for testing was limited, so we could not increase the power of our test. The results of the planned comparisons are in accordance, however, with those of many sentence-picture matching studies (e.g., Blumstein et al., 1985; Caplan et al., 1985; Caplan and Hildebrandt, 1988; Goodglass et al., 1979; Heilman and Scholes, 1976; Kolk and van Grunsven, 1985; Schwartz et al., 1980) and suggest that Broca's sentence processing is negatively affected by a quantitative increase in syntactic complexity, which in our study is caused by embedding instead of conjoining a verb phrase. As we mentioned in our introduction, in previous studies the syntactic complexity manipulation was confounded by one or more of the following factors: sentence length (i.e., number of words and signal duration), meaning content (e.g., the presence or absence of an indirect object) and ease by which thematic roles can be assigned after a phrase-structure representation has been derived. What makes the results of the present experiment especially relevant is the fact that we controlled for these variables by only including (critical) sentences of equal length and equal meaning content and by using a task (i.e., word monitoring) which minimizes the importance of thematic role assignment.

Our findings are difficult to reconcile with several hypotheses about the nature of Broca's receptive syntactic deficit. To begin with, our data cannot easily be accounted for by the mapping hypothesis according to which Broca's have a problem with mapping the products of syntactic analysis onto thematic roles but not with carrying out the syntactic analysis itself (Linebarger et al., 1983, Schwartz et al., 1987). We do not deny the possibility that our Broca's could have had problems with thematic role mapping. It is difficult to see, however, that problems with thematic role mapping can account for our findings. We found Broca's sensitivity to subject-verb agreement violations to be dependent on the syntactic complexity of the sentence frames in which these violations were couched. The detection of a subject-verb agreement violation is a parsing operation which requires the build-up of syntactic structure, not, however, the mapping of syntactic structure onto thematic roles. Therefore, our results can only be accounted for if one postulates a problem with syntactic analysis itself.

Furthermore, our results suggest that Broca's problem with syntactic analysis is not absolute in the sense that they suffer from an inability to construct any phrase-structure representation beyond the level of lexical categories. Rather, Broca's sentence processing seems to break down when a sentence's phrase-structure representation exceeds a certain level of complexity (Frazier and Friederici, 1991; Haarmann and Kolk, 1991a).

In addition, our results suggest a further refinement of the recent claim that Broca's are impaired in their automatic processing routines (e.g., Baum, 1988; Blumstein, Milberg, Dworetzky, Rosen and Gershberg, 1991). More specifically, our results suggest that such an impairment does not reflect a complete loss of automatic processing routines but rather a less efficient use of such routines. Our Broca's showed sensitivity to subject-verb agreement violations when their detection was dependent on the analysis of simple syntactic frames (i.e., conjoined sentences). One interpretation of this agreement effect is to assume a complete loss of automatic processing routines and attribute it to controlled processing. However, we do not believe the agreement effect to be entirely due to controlled processing as it occurred under conditions in which (1) detection of agreement violations was not explicitly asked for and (2) the target occurred on average only 229 ms after the syntactic frame containing the agreement violation. Hence, it is plausible that the agreement effect also reflects some automatic processing, albeit less efficient automatic processing. This lack of efficiency in automatic processing became apparent in our syntactically complex condition, which contrary to the simple condition, did not result in an agreement effect for our Broca's.

Recently, several researchers have proposed that Broca's receptive syntactic deficit can be characterized as a temporal deficit involving either a too-slow activation rate of syntactic information (Friederici, 1988; Friederici and Kilborn, 1989; Gigley, 1983; Haarmann and Kolk, 1991a, 1991b; Huber, Cholewa, Wilbertz and Friederici, 1990; Kolk and van Grunsven, 1985) or a too-fast decay rate of syntactic information (Friederici and Kilborn, 1989; Haarmann and Kolk, 1991a; Hagoort, 1988; Kolk and van Grunsven, 1985). In a computer simulation study of agrammatic comprehension, Haarmann and Kolk (1991a) have demonstrated that both types of temporal deficit can disrupt sentence processing by preventing co-activation of the syntactic nodes in a hierarchical phrase-structure representation, especially when this phrase-structure representation is complex. Thus, our finding that Broca's show sensitivity to subject-verb agreement violations in syntactically simple sentences, but not in syntactically complex ones, is consistent with the hypothesis that Broca's suffer from a too-slow syntactic activation rate or from a too-fast syntactic decay rate. Furthermore, Haarmann and Kolk (1991a) demonstrated that both types of temporal deficit can account for the empirically obtained effects of sentence complexity and comprehension severity in studies by Schwartz et al. (1980) and Kolk and van Grunsven (1985). It should be mentioned that slow activation and fast decay have been postulated as explanatory factors of other types of aphasic symptomatology as well. In the context of Dell's speech production model (1986), a less efficient spread of activation (i.e., reduced activation rate) has been postulated as the primary cause for the abnormally high incidence of perseverations in the speech output of two cases of Jargon aphasia (Bloch and Schwartz, 1989 and Schwartz, Saffran and Dell, 1990).

Furthermore, in the context of the same model, the semantic and phonemic paraphasias that were observed in a case of deep dysphasia have been attributed to a pathologically rapid decay (Martin and Saffran, 1991).

The results of two recent syntactic priming studies were contradictory with respect to the temporal deficit they suggested for Broca's (Friederici and Kilborn, 1989; Haarmann and Kolk, 1991b). In both of these studies, the stimulus onset asynchrony (SOA) between a prime fragment and a target presented for lexical decision was manipulated. These SOAs were 0, and 200 ms in Friederici and Kilborn's study and 300, 700, and 1100 ms in Haarmann and Kolk's study. In both studies, the same syntactic priming pattern was obtained for normal controls. These subjects showed syntactic priming (i.e., faster lexical decision times for grammatical than for ungrammatical prime - target combinations) irrespective of the size of the SOA. The syntactic priming patterns obtained for Broca's, however, differed in both studies. In Friederici and Kilborn's study, Broca's only showed priming at the short SOA, suggesting that the syntactic information associated with the prime fragment was suffering from a too-fast decay rate. Haarmann and Kolk found the opposite pattern, in that their Broca's only showed priming at the longest SOA, suggesting that the syntactic information associated with the prime fragment was activated abnormally slowly. In view of the contradictory results from the two syntactic priming studies, we wanted to explore the use of a different paradigm, that is, word monitoring, as a means of contrasting the slow-activation and fast-decay hypotheses. Our second monitoring experiment was designed to provide this contrast. In the next paragraph we discuss its rationale.

The only difference between experiment I and II was the insertion of a silent inter-stimulus interval (ISI) of 750 ms into the sentence materials. In the critical sentences, this ISI was inserted at the following location: immediately after the offset of the syntactic frame whose analysis was necessary for the computation of subject-verb agreement (e.g., "the baker greets the customer and ask") and immediately before the onset of the noun phase containing the target noun for which subjects had to monitor (e.g., "the BOY to not make so much noise"). With an ISI of 750 ms, we expected to obtain different results in the case of too-slow syntactic activation than in the case of too-fast syntactic decay.

In the case of too-slow syntactic activation, Broca's have an increased chance that an agreement effect will appear for complex sentences. Briefly, the logic is as follows. The computation of subject-verb agreement is based on the syntactic analysis of the sentence segment preceding the monitoring target. Monitoring times will only be negatively affected by subject-verb agreement violations when this syntactic analysis has been completed before the monitoring target is encountered. With the monitoring target presented after some delay (experiment 2), chances are that this indeed will be the case, even for the complex sentence which, especially in the case of a syntactic delay, take a longer time to analyze than simple ones.

In the case of too-fast syntactic decay, Broca's have a higher chance than normal controls of no longer showing an agreement effect for simple sentences. While fast decay has not prevented the construction of a syntactic representation for the simple sentences, it will cause this representation to be less highly activated and, thereby, limit its lifespan. When the monitoring target is presented after a delay (experiment 2), this representation is likely to have disintegrated, so that there is no longer a syntactic basis for the agreement effect.

4.3 EXPERIMENT 2

4.3.1 METHOD

Subjects. The following two subject groups participated in this experiment: (1) 16 of the 20 age-matched controls that had participated in experiment 1 and (2) the same 15 Broca's aphasics as in experiment 1.

Materials. With one exception, the same materials as in experiment 1 were used. This exception concerned the addition of a silent ISI (Inter Stimulus Interval) of 750 ms to the recorded critical and filler sentences. For sentences in the critical list, this ISI was added between the first and the second sound segment, that is, beginning immediately after the offset of the agreeing or non-agreeing second verb and ending immediately before the onset of the determiner-noun sequence containing the target noun. For example, in the "De bakker groet de klanten en vraagt | de JONGEN etc." (The baker greets the customers and asks | de JONGEN etc."), the ISI was inserted at the location of the vertical bar. For sentences in the filler list, the ISI occurred after the first break (see materials section experiment 1) in the recorded sentence. The first break in a filler sentence occurred at a random position before the target noun or its catch-trial replacement. This was done in order to avoid the ISI from becoming a predictor of an upcoming target noun.

Procedure. Except for the ISI manipulation (see preceding paragraph), the same as in experiment 1. Experiment 2 was conducted at least three weeks after experiment 1.

4.3.2 RESULTS

Data analysis. The same data analysis as in experiment 1 was conducted. The mean monitoring latencies, standard deviations and error percentages per condition across subjects for each of the three groups are summarized in table 4. Figure 1 displays for both groups the average size of the agreement effect (i.e., mean monitoring latencies in the non-agreeing condition minus those in the agreeing condition) for simple and complex sentences. The results for each group were as follows.

TABLE 4

Mean monitoring latencies (in ms), standard deviations (between parentheses), and error percentages (between brackets) for experiment 2 (ISI = 750 ms).

	SENTENCE TYPE					
	CONJOINED		EMBEDDED		FILLER	
GROUP	AGR[a]	DAGR[b]	AGR	DAGR	GRA[c]	UGRA[d]
AGEMATCHED	357	376	358	369	417	449
(n = 16)	(74)	(77)	(76)	(91)	(91)	(103)
	[0.3]	[1.3]	[1.3]	[0.0]	[0.3]	[0.3]
BROCA'S	493	490	480	483	665	676
(n = 15)	(197)	(127)	(140)	(161)	(250)	(188)
	[3.0]	[1.3]	[0.7]	[2.7]	[5.7]	[5.3]

Note. [a]agr = sentence with subject-verb agreement, [b]dagr = sentence without subject-verb agreement (disagreement), [c]gra = grammatical sentence, [d]ugra = ungrammatical sentence.

(1) Age-matched controls. Across subjects (n = 16), the average percentage of outliers and errors for non-catch trials was 1.61 and 0.57, respectively. The average error percentage for catch trials was 1.41. In the overall ANOVA, there was a main effect of agreement ($F(1,15) = 13.40$, $MSe = 265$, $p < .01$) in the absence of a complexity effect ($F < 1$) and Complexity X Agreement interaction ($F < 1$). Monitoring times for agreeing sentences (M = 357 ms) were on average 15 ms faster than monitoring times for non-agreeing sentences (M = 372 ms). Furthermore, grammatical (non-catch) filler sentences (M = 417 ms) were responded to significantly faster (i.e., 32 ms) than ungrammatical (non-catch) filler sentences (M = 449 ms)($F(1,15) = 10.80$, $MSe = 794$, $p < .01$). The agreement effect for critical sentences and the grammaticality effect for filler sentences cannot be attributed to a speed-accuracy trade-off. Only slightly more errors were made on the faster agreeing sentences

(i.e., 1.1) than on the slower non-agreeing sentences (i.e., 0.9), but not significantly more ($F < 1$) (cf. table 4). Grammatical and ungrammatical filler sentences produced equal error percentages.

(2) Broca's aphasics. Across subjects (n = 15), the average percentage of outliers and errors for non-catch trials was 2.28 and 3.11, respectively. The average error percentage for catch trials was 10.17. Neither the overall ANOVA, nor the planned comparisons produced any significant results. For the critical sentences, there was no hint of an agreement effect. Agreeing conjoined sentences (M = 493 ms) were responded to slightly but not significantly slower (i.e., 3 ms) than non-agreeing conjoined sentences (M = 490 ms)($F < 1$) and agreeing embedded sentences (M = 480 ms) were responded to slightly but not significantly faster (i.e., 3 ms) than non-agreeing embedded sentences (M = 483 ms)($F < 1$). Grammatical filler sentences (M = 665 ms) were responded to 12 ms faster than ungrammatical filler sentences (M = 676 ms). Though in the expected direction, also this latency difference failed to reach significance ($F < 1$).

4.3.3 DISCUSSION

As in experiment 1, the word monitoring times of age-matched controls showed sensitivity to subject-verb agreement violations irrespective of whether these violations were couched in simple (i.e., conjoined) or complex (i.e., embedded) syntactic frames. This was indicated by the fact that the analysis of variance yielded a small (i.e., 15 ms) but significant main effect of agreement in the absence of an interaction between Agreement and Complexity. Moreover, the absolute size of the agreement effect for simple and complex sentences was comparable, that is, 19 and 11 ms, respectively (see also figure 1). Only for Broca's, delaying target presentation with 750 ms, changed the sensitivity to subject-verb agreement violations that was observed in experiment 1. Whereas Broca's showed an agreement effect for only simple sentences in experiment 1, they failed to show any agreement effects in experiment 2. The difference between non-agreeing and agreeing sentences was -3 ms for simple sentences and 3 ms for complex sentences (see also figure 3). As we will explain, these results support the hypothesis that Broca's suffer from a pathologically fast decay of their syntactic representations (Friederici and Kilborn, 1989; Gigley, 1983; Haarmann and Kolk, 1991a; Hagoort, 1989; Kolk and van Grunsven, 1985). Our results do not, however, provide any evidence in support of the slow activation hypothesis (Friederici and Kilborn, 1989; Gigley, 1983; Haarmann and Kolk, 1991a, 1991b; Huber et al., 1990; Kolk and van Grunsven, 1985), since delaying target presentation with 750 ms in experiment did not lead to the occurance of an agreement effect for complex sentences in Broca's.

Sensitivity to subject-verb agreement violations requires the construction of a phrase-structure representation. As Haarmann and Kolk (1991a) have stressed, during construction certain phrase-structure elements need to become co-actived. For example, in the conjoined sentences in this study, the subject NP (noun phrase, e.g., "the baker") and the VP (verb phrase, e.g., "greets the customers and ask") need to become co-activated. Phrase-structure elements are not activated at once, usually, certain elements become activated earlier than others. For co-activation between elements to occur, it is therefore important that early activated elements remain in an activated state while later activated elements are still in the process of becoming activated. By shortening the lifespan of early activated elements a too-fast decay rate may have two different effects. First, when fast enough, the decay may prevent the build-up of a phrase-structure representation. For example, in the conjoined sentences in this study, subject-verb (dis)agreement may not be represented because the subject NP has already decayed from memory when the VP becomes activated. Second, when somewhat less fast, though not preventing the build-up of a phrase-structure representation, decay may shorten the lifespan of such a representation. For example, in the conjoined sentences in this study, subject-verb (dis)agreement may be represented but only during a short time because the subject NP decays from memory soon after the VP has become activated. Both effects of decay will especially be enhanced when the later arriving phrase-structure elements are syntactically complex and, consequently, take a longer time to become activated. In addition, in our monitoring study, the effect of a limited lifespan will especially become apparent (i.e., as the absence of an agreement effect) in experiment 2, in which presentation of the target is delayed with 750 ms.

Within this framework, the results of experiment 1 and 2 can be readily explained. In experiment 1 and 2, the age-matched controls showed an agreement effect for both syntactically simple and complex sentences. Apparently, the decay in these subjects was such that the syntactic representation of simple and complex sentences could still be constructed. Now to the Broca's. In experiment 1, contrary to age-matched controls, Broca's did not show an agreement effect for complex sentences but only for simple sentences. This finding is consistent with the idea that the syntactic decay in Broca's was so much faster than that in age-matched controls that it prevented the construction of a syntactic representation for the complex sentences. Direct evidence in support of the hypothesis that Broca's suffer from a pathologically increased decay rate is that, going from experiment 1 to II, the agreement effect for simple sentences disappeared in Broca's but not in age-matched controls. Rather than preventing the construction of a syntactic representation of the simple sentences, Broca's increased decay rate seem to have limited the lifespan of such a representation. This became apparent in experiment 2, in which presentation of the target was delayed with 750 ms.

Similar evidence for a pathologically increased decay rate in Broca's stems from the observation that, going from experiment 1 to 2, the grammaticality effect for filler sentences disappeared in Broca's but not in age-matched controls. This disappearance is especially striking because in experiment 1 Broca's showed a grammaticality effect for filler sentences (i.e., 61 ms) that was almost twice as large as the one for the age-matched controls (i.e., 36 ms).

4.4 GENERAL DISCUSSION

The aim of the present word monitoring study was to further explore the nature of the processing deficit that is responsible for Broca's receptive syntactic problems. For that purpose, Broca's and age-matched controls had to monitor for target nouns in auditorily presented sentences which either did or did not contain violations in subject-verb number agreement. In experiment 1, sensitivity to these agreement violations (i.e., indicated by significantly slower monitoring latencies in the non-agreeing than agreeing condition) was assessed as a function of the syntactic complexity of the sentence frames in which these violations were couched. Controlling for length (i.e., number of words and signal duration) and propositional meaning content, these sentences were either syntactically simple (i.e., conjoined) or complex (i.e., embedded). Experiment 2 was a replication of experiment 1 in all respects, except that the noun phrase containing the monitoring target did not occur immediately after the sentence frame containing the subject-verb agreement violation but only after an added silent pause of 750 ms. The major results of experiments 1 and 2 can be summarized as follows. In experiment 1, age-matched controls showed an agreement effect for both syntactically simple and complex sentences, whereas Broca's only showed an agreement effect for simple sentences. In experiment 2, age-matched controls still showed an agreement effect for simple and complex sentences, whereas Broca's showed an agreement effect for neither complex nor simple sentences. Moreover, going from experiment 1 to 2, the grammaticality effect for filler sentences disappeared in Broca's but not in age-matched controls.

The results of experiment 1 are in accord with previously made suggestions that Broca's, in a rather general sense, suffer from a pathological restriction in the amount of processing resources they can bring to the task of phrase-structure construction (Caplan and Hildebrandt, 1988; Frazier and Friederici, 1991; Friederici and Frazier, 1992). Such a syntactic resource limitation will especially hinder the construction of complex phrase-structure representations. As already argued in the discussion of experiment 2, the combined results of experiments 1 and 2 suggest, moreover, that Broca's syntactic resource limitation is due to a pathological increase in the rate by which syntactic information decays (Friederici and Kilborn, 1989;

Gigley, 1983; Haarmann and Kolk, 1991a; Hagoort, 1989; Kolk and van Grunsven, 1985). The addition, in experiment 2, of a silent pause of 750 ms between the sentence frame containing the agreement error and the noun phrase containing the target noun led to the disappearance of the agreement effect for simple sentences in Broca's, but not in age-matched controls. The same was true for the grammaticality effect for filler sentences. These results strongly suggest that the lifespan of the morpho-syntactic representation of subject-verb agreement is shorter in Broca's than in age-matched controls possibly due to a faster decay rate in Broca's than in age-matched controls. Besides shortening the lifespan of the morpho-syntactic representation of subject-verb agreement in simple sentences, a too-fast syntactic decay rate may have prevented Broca's from constructing such a representation for complex sentences. This then would explain why Broca's contrary to age-matched controls did not show an agreement effect for complex sentences in experiment 1. Briefly the rationale is as follows, the computation of subject-verb agreement requires the co-activation of a subject NP (noun phrase) and a VP (verb phrase). In the case of a too-fast syntactic decay, the subject NP may have already disappeared from working memory before the verb phrase is introduced, especially when the verb phrase is complex and takes a long time to activate. Consequently, there will be no basis for an agreement effect.

While providing support for the fast-decay hypothesis, our results did not provide any evidence in support of the slow activation hypothesis (Friederici and Kilborn, 1989; Gigley, 1983; Haarmann and Kolk, 1991a, 1991b; Huber et al., 1990; Kolk and van Grunsven, 1985). Broca's showed no agreement effect for complex sentences even when the presentation of the target was delayed with 750 ms, as was the case in experiment 2. In an attempt to rescue the slow activation hypothesis, one might argue that the slowing in the rate of syntactic activation was so large that an agreement effect for complex sentences was not detected because the delay in target presentation was not large enough. However, if at all there was a slowing in the rate of syntactic activation, it can never have been very large. The reason is that Broca's showed an agreement effect for simple sentences in experiment 1, in spite of the fact that the target occurred on average only 229 ms after the sentence frame containing the subject-verb agreement violation. In fact, the presence of such an effect suggests that Broca's syntactic processing is still relatively fast, at least when the overall syntactic load is not too large.

While the results from this monitoring study seem to indicate that Broca's syntactic processing is still relatively automatic and fast, results from several syntactic priming studies suggest that this is not the case (Baum, 1988; Blumstein et al., 1991, experiment 1; Haarmann and Kolk, 1991b; Lukatela, 1991). In these studies, normal controls typically showed syntactic priming, that is, lexical decisionss were significantly faster to target words when they were syntactically appropriate continuations of a prime fragment (e.g., "on the table") than when they were syntactically inappropriate continuations (e.g., "we can table"). Broca's aphasics, on the other hand, failed to show syntactic priming, at least when the stimulus onset asynchrony (SOA) or time interval between the prime fragment and the target was of a medium size (i.e., 500 ms in Baum's and Blumstein et al.'s studies, 600 ms in Lukatela et al.'s study and 300 and 700 ms in Haarmann and Kolk's study). In the studies by Haarmann and Kolk and Lukatela et al., syntactic priming was also investigated using a rather large SOA of 1100 ms. Under these circumstances, the Broca's in Haarmann and Kolk's study showed significant syntactic priming, while the Broca's in Lukatela's et al.'s study showed almost significant (i.e., $p = .058$) syntactic priming. Haarmann and Kolk interpreted the late appearance of syntactic priming in Broca's as evidence for the hypothesis that syntactic activation in Broca's, instead of being fast and automatic, occurs at a slower than normal rate. However, as we already discussed above, no such evidence was obtained in this monitoring study. The presence, in Broca's, of an agreement for simple sentences at a target delay of 0 ms in this monitoring study and the lack of syntactic priming at medium sized SOAs in the aforementioned priming studies is rather striking: the sentence frames containing the subject-verb agreement violations in this monitoring study consisted of seven words, while the prime fragments in the syntactic priming studies consisted of only two (Blumstein et al.; Lukatela et al.) or three (Haarmann and Kolk, 1991b) words. A priori, one would expect syntactic analysis to be easier and faster for two-to-three word sentence frames than for seven-word sentence frames.

Thus, Broca's rate of syntactic activation seemed to have been relatively fast in the present monitoring study, but relatively slow in the previously mentioned syntactic priming studies. Our computer model of agrammatic comprehension (Haarmann and Kolk, 1991a) provides no computational mechanism that provides a clue for these seemingly contradictory results. A recent computer model of the time-course of parsing in normals (Just and Carpenter, 1982), called CC READER, may provide a solution to this problem. In CC READER parsing is implemented in the form of a production rule system that is activation driven. Activation is used to fulfill two functions: activation propagation and activation maintenance. The amount of activation allocated to propagation determines the speed of processing, while the amount of activation allocated to maintenance determines the decay rate and, as a result, also the accuracy of processing. In particular, more activation for propagation results in faster processing, while more activation for maintenance results in a less rapid decay. Because in CC READER a single, common pool of activation is used for both activation propagation and activation maintenance, there is the possibility of a trade-off between both functions (Just and Carpenter). On the one hand, allocating more activation to propagation and less to maintenance implies faster processing, but also more rapid decay and, as a result, less accurate processing. On the other hand, allocating more activation to maintenance and less to propagation implies less rapid decay and more accurate processing, but also a slower speed of processing. This trade-off mechanism may help to explain the contradictory results of our experiment 1, which suggested a fast rise and subsequent fast decay of syntactic activation, and the syntactic priming studies, which suggested a slow rise of syntactic activation. Suppose that Broca's suffer from a pathological reduction in the amount of syntactic activation that is available for both activation propagation and activation maintenance. In word monitoring, Broca's emphasis could be on activation propagation at the expense of activation maintenance, whereas in syntactic priming their emphasis could be on activation maintenance at the expense of activation propagation.

The question then becomes why in word monitoring there is an emphasis on activation propagation and, as a result, on speed of processing, while in lexical decision there is an emphasis on activation maintenance and on counteracting decay. We like to offer the following suggestion. First, consider word monitoring. In a typical word monitoring study, a target word can occur at any sentence position. Every next word is a potential target that the subject must try to detect as quickly as possible. To free up resources for target detection, subjects (i.e., normals and Broca's alike) may try to finish the analysis of the already presented words as quickly as possible. This will cause an emphasis on activation propagation and a concomitant limitation in the amount of activation available for maintenance (especially, when the total amount of activation available for propagation and maintenance is low to begin with as we assume to be the case for Broca's). From the perspective of the subject the latter will not have any dramatic consequences, because an accurate interpretation of the sentence material is not required. Next, consider a syntactic priming experiment in which the target requires a lexical decision response. Seidenberg et al. (1984) have proposed two different (post-lexical) mechanisms for syntactic priming in normals: one controlled and the other automatic. The controlled mechanism rests on a subject's strategic use of contextual information to facilitate the lexical decision response. Congruent prime-target pairs are always words, because only syntactically appropriate prime-word pairs are congruent. Incongruent prime-target pairs are likely to be nonwords as prime-nonword pairs tend to occur more often than syntactically inappropriate prime-word pairs. The second syntactic priming mechanism proposed by Seidenberg et al. does not reflect strategic processing, but instead automatic processing. It rests on the Stroop-like interference that is caused when a subject conflates a word/nonword response, with a judgment about the syntactic congruency of the prime-target pair. It is possible that both mechanisms contribute to the syntactic priming effect in normals (Seidenberg et al.). However, syntactic priming in aphasics is likely to be of a strategic nature. Because of their greater difficulties with word/nonword discrimination, aphasics may attempt to strategically use contextual information to facilitate their lexical decision response (see Stanovich, 1980, for evidence for such a compensatory strategy in poor readers). The strategic nature of syntactic priming in Broca's is suggested by the fact that explicit instructions to ignore the context led to the disappearance of syntactic priming in Broca's (Kilborn and Friederici, 1990), but not in normals (Goodman, McClelland and Gibbs, 1981; Kilborn and Friederici, 1990). The presentation in Kilborn and Friederici's experiment of prime fragment and lexical decision target in two different modalities (i.e., auditory and visual, respectivaly) may have made it easy for the Broca's to ignore the prime fragment. The strategic use of contextual information by Broca's would imply an emphasis on activation maintenance. Due to a propagation/maintenance trade-off mechanism (Just and Carpenter, 1992) there could be a concommittant decrease in processing speed. A strategic emphasis on the maintenance of contextual information therefore correctly predicts the late appearance of syntactic priming in Broca's obtained by Haarmann and Kolk (1991b) and Lukatela et al (1991). It may be that the ability to maintain a prime fragment's activation does not play a role yet when the prime fragment and the target are separated by extremely short as opposed to medium sized time intervals. This would explain why Broca's in a crossmodal priming study by Friederici and Kilborn (1989) showed syntactic priming at an ISI (Inter Stimulus Interval between prime fragment and target) of 0 ms, but not at an ISI of 200 ms.

To conclude, fast decay and slow activation do not necessarily have to be treated as mutually exclusive alternatives. In the context of Just and Carpenter's (1992) parsing model, a pathological reduction in the amount of syntactic activation that is shared for activation propagation and activation maintenance can lead to either a too-slow activation rate, a too-fast decay rate or both. Our computer model of agrammatic comprehension (Haarmann and Kolk, 1991a) can be viewed as a specific instantiation of Just and Carpenter's parsing model that allows one to study the selective effects of a too-slow activation rate and a too-fast decay rate. As we argued above, which of these two temporal changes will result may be dependent on whether the task requirements necessitate an emphasis on activation propagation or on activation maintenance. Future studies may be directed towards finding new ways of manipulating these task requirements and investigating their effect on Broca's syntactic processing.

APPENDIX

MATERIALS

Please note the following:
- The English translation is given in parentheses.
- A star (*) refers to a subject-verb agreement violation in critical sentences and to other types of ungrammaticality in filler sentences.
- Some of the ungrammaticalities in the filler sentences do not have a counterpart in English (e.g., gender agreement between article and noun is required in Dutch but not in English) indicated by the absence of a star in the English translation.
- The monitoring target appears in capitals.
- The catch trial replacement of the monitoring target in filler sentences is in capitals and underlined.
- Only the conjoined version of each critical sentence is listed. The embedded version was derived from the conjoined one by changing the first verb phrase of each sentence into a subject relative clause To see how this was done refer to the text and the example in table 2.
- In critical sentences the inter stimulus interval (ISI) always occurred immediately after the second verb. In filler sentences the ISI occurred at random positions before the monitoring target or its catch trial replacement at the position indicated by --- .

Critical list

De bakker groet de klanten en vraagt/*vragen het KIND om niet zoveel lawaai te maken.
(The baker greets the customers and asks/*ask the CHILD to not make so much noise.)

De agenten horen de dief en proberen/*probeert de DEUR zo zachtjes mogelijk te sluiten.
(The cops hear the thief and try/*tries to close the DOOR as silently as possible.)

De leraar helpt de studenten en schrijft/*schrijven een SOM op het grote bord.
(The teacher helps the students and writes/*write a MATH PROBLEM on the big blackboard.)

De vrouwen verzorgen het meisje en pakken/*pakt een BORSTEL om het haar mee te kammen.
(The women take care of the girl and take/*takes a BRUSH to comb the hair with.)

De soldaat schopt de jongens en grijpt/*grijpen een STOK om mee te slaan.
(The soldier kicks the boys and grabs/*grab a STICK to hit with.)

De kinderen betalen de winkelier en stoppen/*stopt het VLEES in een grote tas.
(The children pay the shopkeeper and put/*puts the MEAT in a big bag.)

De schilder tekent de kinderen en zien/*ziet een VOGEL die door de lucht vliegt.
(The painter draws the children and sees/*see the BIRD that flies through the air.)

De matrozen roepen de kapitein en vragen/*vraagt een VAT vol met lekker bier.
(The sailors call the captain and ask/*asks for a VAT full of good tasting beer.)

De slager bedankt de jongen en geeft/*geven de JONGEN een stukje worst om op te eten.
(The butcher thanks the boy and gives/*give the BOY a piece of sausage to eat up.)

De vrouwen dragen het kind en eten/*eet een IJS midden in het grote park.
(The women carry the child and eat/*eats ICE CREAM in the middle of the big park.)

Het varken bijt de honden en zoekt/*zoeken een MANIER om snel weg te vluchten.
(The pig bites the dogs and seeks/*seek a WAY to quickly flee.)

De vrouwen bezoeken de man en pakken/*pakt een STOEL om op te gaan zitten.
(The women visit the man and take/*takes a CHAIR to sit on.)

De kelner bedient de meisjes en hoort/*horen de MOTOR van een auto starten.
(The waiter serves the girls and hears/*hear the MOTOR of the car start.)

De jongens kussen het meisje en zetten/*zet de BLOEMEN in een vaas op de kast.
(The boys kiss the girl and put/*puts the FLOWERS in a vase on the cabinet.)

De zeiler ziet de zwemmers en vreest/*vrezen een BOTSING midden op het grote meer.
(The sailor sees the swimmers and fears/*fear for a COLLISION in the middle of the big lake.)

De toeristen volgen de gids en dragen/*draagt een LAMP om beter te kunnen zien.
(The tourists follow the guide and carry/*carries a LIGHT in order to see better.)

De vrouw slaat de kinderen en vertelt/*vertellen de MAN precies wat er gebeurt is.
(The woman hits the children and tells/*tell the MAN exactly what has happened.)

De zusters wassen de patient en tillen/*tilt een BEEN even een klein beetje omhoog.
(The nurses wash the patient and lift/*lifts a LEG momentarily a little bit in the air.)

De agenten zoeken het kind en duwen/*duwt een STRUIK met de blote handen opzij.
(The cops look for the child and push/*pushes a BUSH aside with the bare hands.)

De vrouw waarschuwt de agenten en ziet/*zien een AUTO over de stoep rijden.
(The woman warns the cops and sees/*see a CAR ride over the pavement.)

Filler list.

De/*het --- JONGENS/GIRLS aan wie de man het geld geeft hebben heel erg hard gewerkt.
(The/the --- BOYS/GIRLS to whom the man gives the money have worked very hard.)

De bekende/*bekend --- DOCTER/ARTS voor wie de vrouwen een lekkere maaltijd koken kan elk moment arriveren.
(The famous/famous --- DOCTOR/PHYSICIAN for the whom the women cook a delicious meal can arrive at any moment.)

De/*het man --- wiens KINDEREN/DOCHTERS zo goed studeren krijgt vaak complimenten van vrienden en kennissen.
(The/the man --- whose CHILDREN/DAUGHTERS study so well often get compliments from friends and acquaintances.)

De meisjes waarmee/*dat --- de JONGEN/MAN wil dansen hebben allemaal blauwe ogen en lang blond haar.

(The girls with whom/*that --- the BOY/MAN wants to dance all have blue eys and long blond hair.)

De vrouw/*vrouw de --- voor wie de MAN/JONGEN een grote bos bloemen heeft gekocht ziet er erg mooi uit.
(The woman/*woman the --- for whom the MAN/BOY has bought a big bush of flowers is looking very beautiful.)

De ouderen voor wie/*wat --- de muzikant FLUIT/PIANO speelt klappen heel enthousiast in hun handen.
(The elderly for whom/*what --- the musician plays FLUTE/PIANO clapped their hands very enthusiastically.)

De meisjes waarmee/*waaraan hij --- praat eten de BANAAN/APPEL die ze bij de groenteboer gekocht hebben.
The girls with whom/to whom he --- talks eat the BANANA/APPLE that they have bought at the grocer.)

De vrouw naast/*goed wie zij lopen draagt --- een JURK/ROK me blauwe strepen en roze bloemen.
(The woman near/*good whom they walk wear --- a DRESS/SKIRT with blue stripes and pink flowers.)

De klanten die --- de bakker vriendelijk begroet/*gegroet kopen een BROOD/TAART om in het weekend op te eten.
(The customers that --- the baker greets/greeted friendly buy a BREAD/PIE to eat during the weekend.)

De agenten door/*voor wie de dief gearresteerd wordt --- pakken hun PISTOOL/HANDBOEIEN meteen uit hun zak.
(The cops by/*for whom the thief is arrested --- take thier GUN/HANDCUFFS immediately from their pockets.)

Deze/*dit --- VROUWEN/MANNEN zien het kind dat huilt aan de overkant van de straat.
(These/*this --- WOMEN/MEN see the child that is crying on the other side of the street.)

Die/*dat --- jonge ARTS/DOKTER onderzoekt alleen patienten die heel hoge koorts hebben.
(That/that --- young PHYSICIAN/DOCTOR examines only patients that have very high fever.)

De --- zeer/*veel aardige ZUSTERS/VERPLEEGSTERS zingen een lied voor de kinderen die naar bed gaan.
(The --- very/*much nice NUNS/NURSES sing a song for the children that go to bed.)

De/*twee kok --- brengt de MANNEN/VROUWEN die lachen, een heel lekkere maaltijd.
(The/*two cook --- brings the MEN/WOMEN that laugh a very delicious meal.)

De jongens helpen/*geholpen --- de oude VROUW/MAN die de drukke straat over wil steken.
(The boys help/helped --- the old WOMAN/MAN that wants to cross over the busy street.)

De kapitein haat/*gehaat --- matrozen die hun BAAN/WERK niet serieus nemen en lui zijn.
(The captain hates/hated --- sailors that do not take their JOB/WORK seriously and are lazy.)

De/*a --- dokters ask the patient die veel VET/SUIKER eet om daar onmiddellijk mee op te houden.
(The/*a --- doctors ask the patient that eats a lot of FAT/SUGAR to immediately stop it.)

De leraar wenst/*gewenst --- de studenten die voor het VAK/DIPLOMA geslaagd zijn een succesvolle toekomst.
(The teacher wishes/wished --- the students that passed/received the COURSE /DIPLOMA a successful futer.)

De conducteur vertelt reizigers --- die daarom/*daarvan vragen in welke STEDEN/PLAATSEN de trein overal stopt.
(The conductor tells travelers -- that ask for/*from it in which CITIES/PLACES the train stops.)

De mensen op/*aan wie hij scheldt --- weten helemaal niet welke REDEN/AANLEIDING hij daarvoor zou kunnen hebben.
(The people at/to whom he curses --- do not know at all which REASON/IMMEDIATE CAUSE he could have for it.)

Chapter 5

The Production of Grammatical Morphology in Broca's and Wernicke's Aphasics: Speed and Accuracy Factors[1].

ABSTRACT

A group of Broca's aphasics (BA), Wernicke's aphasics (WA) and normal controls participated in a CLOZE experiment which required the oral production of various types of free and bound morphemes. Results provided support for the hypothesis that BA and WA share the same underlying impairment in the production of grammatical morphology. The relative difficulty of the various free and bound morpheme types was the same for BA and WA. This appeared to be the case not only in an analysis of the number of errors but also in an analysis of response times. The same analyses furthermore revealed no significant differences in the absolute levels of performance of BA and WA. Finally, it was found that BA and WA show the same relative contribution of within- and across-category substitutions of free morphemes. For bound morphemes, there was a slight difference between BA and WA, in that BA exclusively produced within-category substitutions while WA also produced some across-category substitutions.

5.1 INTRODUCTION

Most recent group studies directly comparing the grammatical problems of Broca's and Wernicke's aphasics (BA and WA, resp.) have focused on language reception (Ansell & Flowers, 1982; Blumstein, Goodglass, Stadlender & Biber, 1983; Blumstein, Katz, Goodglass, Shrier & Dworetsky, 1985; Caramazza, Berndt, Basili & Koller, 1981; Caramazza & Zurif, 1976; Friederici, 1981, 1982, 1983; Friederici & Graetz, 1987; Goodglass, Gleason & Hyde, 1970; Goodglass et al., 1979; Grossman & Haberman, 1982; Hagoort, 1989; Heeschen, 1980; Heilman & Scholes, 1976; Kolk & Friederici, 1985; Lesser, in Goodglass and Menn, 1985; Vermeulen, 1982). Relatively few studies comparing the grammatical problems of BA and WA have dealt with language production (Friederici, 1981, 1982; Kolk & Heeschen, in press; Von Stockert & Bader, 1976) (for case studies comparing BA and WA see Caramazza, Berndt, Basili, & Koller, 1981; Friederici & Schoenle,1980).

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[1] Haarmann, H.J., & Kolk, H.H.J. (1992). *Cortex, 28,* 97-112.

This is a rather unfortunate situation, since BA and WA show some typical grammatical differences in their spontaneous speech. Whereas the spontaneous speech of BA tends to be agrammatic, showing omissions of free and bound grammatical morphemes (i.e., function words and inflections), the spontaneous speech of WA tends to be paragrammatic, showing substitutions of free and bound grammatical morphemes. In addition, the agrammatic output of BA is produced in a context of slow, non-fluent speech, while the paragrammatic output of WA is produced in a context of fast, fluent speech (Goodglass & Kaplan, 1983).

Several investigators (Friederici, 1981, 1982; Von Stockert and Bader, 1976) have argued that Broca's agrammatism and Wernicke's paragrammatism reflect two different underlying impairments. Von Stockert and Bader (1976) administered a Sentence Order Test (SOT) to German BA and WA. The subject, verb and object of a simple declarative SVO sentence were written on three separate cards which had to be grouped together by the aphasic patient. A subpart of the material contained sentences each of which could be ordered in two different ways, either as a grammatically correct but semantically incoherent sentence or as grammatically incorrect but semantically coherent sentence. BA appeared to prefer grammatically incorrect but semantically coherent orderings, while WA appeared to prefer grammatically correct but semantically incoherent orderings. Based on these findings, Von Stockert and Bader (1976) argued that Broca's agrammatism reflects a grammatical impairment, while Wernicke's paragrammatism reflects a lexical-semantic impairment. However, this conclusion can be criticized on three grounds. To begin with, both Heeschen (1985) and Butterworth and Howard (1987) have pointed out that that the spontaneous speech of WA probably not only reflects lexical-semantic problems, that is, empty speech and verbal paraphasias, but also syntactic problems as revealed by phrasal misconstructions. One of the examples of phrasal misconstructions of German WA given by Heeschen (1985) is that of "subordination raising," that is, the incorrect use of the word order of the main clause in a subordinate clause by German Wernicke's. Two further criticisms of Von Stockert and Bader's (1976) result have been given by Goodglass and Menn (1985). These authors suggest that the BA in Von Stockert and Bader's (1976) study could have neglected grammatical errors in favor of a lexical strategy that allowed them to make sense out of the sentence, a strategy which Wernicke's additional lexical-semantic problem does not allow. In addition, Goodglass and Menn (1985) pointed out that a Wernicke aphasic studied in a case study by von Stockert (1972) failed to use grammatical cues to word order when a NP-VP sentence containing an embedding was used instead of just a simple NP-VP sentence. Thus, it is possible that the grammatical problems of WA reveal themselves as more complex grammatical material is used.

Support for the lexical-syntactic dichotomy came from studies by Friederici (1981, 1982). Like von Stockert and Bader (1976), Friederici (1981) directly compared the language production of BA and WA. She used a picture-description and sentence-completion task to elicit the oral production of prepositions. BA showed a mixture of within- and across-category substitutions, while WA showed only within-category substitutions. Friederici suggested that BA were insensitive to syntactic category due to a syntactic-constructional disorder. This insensitivity resulted in both within- and across-category substitutions. WA, on the other hand, would have a lexical-semantic selection disorder. They correctly assign syntactic category but have difficulties selecting the proper alternative. Friederici (1982) reported additional support for this interpretation. The results of the 1981 study were replicated. In addition, it was found that BA have more problems with syntactic-obligatory prepositions that are subcategorized for by the verb (as in "Peter hopes for the summer") than with lexical-semantic prepositions (as in "Peter stands on the chair"), while the reverse was true for WA. These studies, however, can be criticized on two grounds. First of all, BA and WA did not differ that much as far as type of error (i.e., within- versus between-category) was concerned. Across-category substitutions were indeed only found in BA and not in WA. However, the absolute numbers of across-category substitutions in BA were rather low (ranging from 0.2 to 1.58 substitutions). In fact, statistical testing in Friederici's 1981 study indicated no significant difference from zero. No such testing was reported in Friederici's 1982 study. Second, a point not mentioned in the discussion by Friederici (1982) is that WA, though having less problems with syntactic-obligatory prepositions than with lexical-semantic ones, still showed a rather substantial percentage of errors with the former type of preposition (i.e., 5 percent of omissions and 31 percent of within-category substitutions). Syntactic-obligatory prepositions bear no lexical-semantic content and have a purely grammatical function. A lexical-semantic impairment would therefore have no consequence for the production of this type of preposition. To account for Wernicke's problems with syntactic-obligatory prepositions, it seems therefore necessary to postulate some kind of grammatical problem also in WA.

If not only BA but also WA show grammatical problems in language production, the question becomes whether their underlying grammatical impairment is the same or not. Given the qualitative differences between the agrammatic speech output of BA and the paragrammatic speech output of WA it is tempting to assume that BA and WA have different grammatical impairments. Recent findings by Heeschen (1985) provide a challenge to the different-grammatical-impairment hypothesis. Heeschen (1985) observed that BA who show very few paragrammatic errors in their spontaneous speech, do make these errors in a constrained production task, that is, picture description. He reasoned that at least part of the differences between Broca's and Wernicke's problems in sentence production stem from the fact that Broca's avoid the production of grammatical morphology and Wernicke's do not (see also Kolk & Heeschen, 1990; Kolk & Heeschen, in press). This raises the possibility that the underlying impairment in the two groups is the same (see Goodglass and Menn, 1985 for a similar suggestion).

The purpose of the present study was to directly test the same-grammatical-impairment hypothesis. In order to counter the possibility of avoidance behavior, that is, in order to insure that all subjects have to construct the same underlying syntactic representation for each sentence, a CLOZE procedure was used which required Dutch BA and WA to speak aloud an obligatory grammatical morpheme which was missing from a sentence. It is important to realize that a CLOZE procedure does not just require the production of the missing grammatical morpheme but requires the construction of at least part of the sentence frame. A patient's CLOZE performance will therefore be disrupted by a grammatical impairment. Four different types of free grammatical morphemes, that is, determiner, preposition, pronoun and auxiliary verbs, and three different types of bound grammatical morphemes, that is, plural ending noun, adjective inflection and verb inflection had to be produced. Comparing BA and WA aphasics' response profiles on these different morpheme types would allow for a more precise test of the same-grammatical-impairment hypothesis. Based on an earlier CLOZE study by Goodglass and Berko (1960) involving the oral production of various types of inflectional endings by an undifferentiated group of aphasics, we expected the following order of difficulty (from easiest to most difficult): plural noun, adjective and verb inflection.

The same-grammatical-impairment hypothesis predicts qualitatively identical response profiles for BA and WA. It should be pointed out that the same-grammatical-impairment hypothesis does not prohibit quantitative differences in error rate to occur between BA and WA. Such quantitative difference could be the result of differences in severity of the syntactic impairment but also of differences in speed-accuracy trade-off (cf. Kolk and van Grunsven, 1985). As pointed out above, the agrammatic speech output of BA is usually non-fluent, while the paragrammatic speech output of WA is usually fluent. If it would be found that WA show a higher overall error rate than BA, than this could be due to a speed-accuracy trade-off with WA responding faster than BA. To check for the possibility of a speed-accuracy trade-off, it was decided to not only measure error rate but also response time. In the case of a speed-accuracy trade-off, one would not only expect a higher error rate but also faster responding.

5.2 METHOD

5.2.1 SUBJECTS

Three groups of right handed, Dutch subjects were selected for the experiment; (1) a group of 8 Broca's aphasics (BA), (2) a group of 5 Wernicke's aphasics (WA), and (3) a group of 6 healthy control subjects with no history of brain damage. BA and control subjects were matched for age (M = 54 years [23-70] and M = 55 years [35-71], respectively)(Mann-Whitney U-test, two-tailed, p=.85). Unfortunately, WA were older (M = 70 years [64 - 76]) than both BA and WA (Mann-Whitney U-test, two-tailed, p = .02 and p = .03, respectively) and comprised a smaller group than the BA because several WA did not fit the selection criteria for this study, that is reading ability and ability to comprehend the test requirements, or were to old to participate. Our samples of aphasic patients reflect what Harasymiw, Halper and Sutherland (1981) reported for a much larger sample of 358 aphasics in which there was a higher incidence of BA than WA and in which WA were older than BA, a trend which was significant for males (11.6 years older) but not nor females (6.2 years older). Patients were selected from the patient pool of the Max Planck Institute and had been administered a translated, Dutch version of the German Aachen Aphasia Test (AAT) (Graetz et al., 1991; Huber et al., 1983). Syndrom classification was unanimously reached by a team of three neurolinguists based on a recording and transcription of the spontaneous speech interview of the AAT. To be classified as BA, patients had to have non-fluent agrammatic language production with impoverished melodic line, disturbed articulatory agility, many phonematic paraphasias and only a few semantic paraphasias, while comprehension had to be relatively intact. To be classified as WA, patients had to have fluent, paragrammatic language production with a well preserved melodic line, undisturbed articulatory agility, many phonematic and verbal paraphasias and disturbed comprehension (Goodglass and Kaplan, 1972; Poeck et al., 1975). All patients had suffered from a right sided hemiplegia and had sustained left hemispheric damage with no previous history of neurological disease. With one exception, involving a a case of inflammatory meningites, all patients had sustained a cerebral vascular accident (CVA) involving the region of the left middle cerebral artery. Mean time post onset was 7 years and 5 months (range: 4 years and 8 months - 10 years and 11 months) for the BA and 2 years and 5 months (range: 4 years and 7 months - 5 months) for the WA. Additional patient characteristics are summarized in Table 1: age, sex, occupation, post onset time, etiology, Token Test, comprehension scores from the AAT and speech rate (i.e., number of words per minute spoken by a patient during the spontaneous speech interview of the AAT). As to be expected (see classification criteria), BA were significantly slower (M = 39 words/minute) than WA (M = 135 words/minute) (Mann-Whitney U-test, two-tailed, p =

TABLE 1

Patient Characteristics

Subject	Sex[a]	Age	Onset[b]	Occupation	Etiology	Speech type[c]	Speech rate[d]	TT[e]	Comprehension[f]
Broca's									
I	m	53	56	Mechanic	Occlusion L. artery carotis interna	3	37	17	105
II	f	33	124	Bank employee	Aneurysm	2	87	31	85
III	m	58	67	Municipal official	Infarct L. mid cerebral artery	1	28	2	104
IV	m	63	80	Construction worker	Same	1	47	46	90
V	m	70	74	Baker	Same	4	29	8	102
VI	m	63	131	Canteen chef	Same	2	40	4	102
VII	m	68	87	Teaching head	Occlusion L. artery carotis interna	4	52	2	105
VIII	m	23	94	None	Bacterial meningitis	2	23	34	100
Wernicke's									
IX	f	64	24	Housewife	Infarct L.mid cerebral artery	5	79	22	83
X	m	76	55	Bricklayer	Same	5	154	32	83
XI	m	72	48	Musician	Same	5	147	25	59
XII	f	66	12	Housewife	Same	5	137	19	66
XIII	f	75	5	Housewife	Same	5	157	32	81

Note. [a]m = male, f = female. [b]No. of months since onset. [c]Four types of agrammatic speech were discriminated: 1 = mainly one-word utterances, 2 = mainly telegraphic speech, 3 = mainly grammatically simple utterances, 4 = broken-off sentences. [d]No. of words spoken per minute during spontaneous speech interview of the Aachener Aphasietest. [e]No. of errors on the Token Test (maximum 50)(corrected for age). [f]Composite score (maximum 120) of four subtests: visual word, visual sentence, auditory word and auditory sentence comprehension.

.002) and BA also had significantly better comprehension scores (M = 99) than WA (M = 74) (Mann-Whitney U-test, two-tailed, p = .003). Scores on the the Token Test confirm the presence of aphasia and indicate different degrees of severity of aphasia (Huber et al., 1983).

5.2.2 MATERIALS

A CLOZE test was constructed which required subjects to supply four types of free grammatical morphemes, that is, determiner, preposition, pronoun and auxiliary, and three types of bound grammatical morphemes, that is, plural noun, adjective and verb inflection (see Table 2 for example sentences eliciting each morpheme type and see the Appendix for a complete listing of all experimental materials). Of each morpheme type there were six instances replicated two times in sentences with different semantics but identical syntax (see Table 3 for a listing of the particular grammatical morphemes elicited within each morpheme category). Thus, the CLOZE test included a total of 84 (7X6X2) experimental sentences. The syntactic structure of all sentences was kept as simple as possible. Moreover, only frequent, concrete and depictable content words were included. Since sentences containing bound versus free grammatical morphemes required different types of responses (see Table 2 and see also below), they were presented as separate blocks. Furthermore, for reasons that are of no concern here, the total experimental set was subdivided into two subsets containing two and four instances of each morpheme type, respectively. Each subset was preceded by a seven-item practice set containing one example of each grammatical morpheme type. Sentences within a block were then pseudo-randomized, with no sentences eliciting the same grammatical morpheme type immediately following one another.

All sentences were stored for bimodal presentation: on floppy disk for visual presentation on the CRT screen of an APPLE IIe computer and on cassette tape for binaural presentation through headphones. Bimodal presentation was chosen because a pilot experiment with one Broca and one Wernicke patient had shown that unimodal auditory presentation resulted in too many inadequate responses. Both patients filled in self-created gaps and the Wernicke patient sometimes responsed to free morpheme items as to bound morpheme items. To counteract this latter way of responding, bound morpheme items were clearly distinguished from free morpheme items not just by presenting them in separate blocks but also by visually highlighting the wordform to be inflected. This was done by inverting the screen background from dark to light. The cassette tape was prepared by means of a computerized speechlab. The sentences were recorded onto a cassette tape by a female reader at a moderate rate (approximately 130 words/minute). The reader was instructed to read them aloud using normal stress and intonation. However, the word, which was to be

TABLE 2

Example Sentences of CLOZE test[a]

Morpheme type	Dutch original	English translation
Free:		
Determiner	Opa geeft Tineke EEN zoen.	Grandfather gives Tineke A kiss.
Preposition	Oma schrijft MET een pen.	Grandmother writes WITH a pen.
Pronoun	Jan ziet Piet. Hij groet HEM.	John sees Pete. He greets HIM.
Auxiliary	Hans KAN goed zwemmen.	Hans CAN swim well.
Bound:		
Plural noun	Een ruit. Twee RUITEN.	One window. Two WINDOWS.
Adjective	De vrouw is klein, dus is het een KLEINE vrouw.	The woman is small; therefore, it is a SMALL woman.
Verb	Ik schrijf. Hij SCHRIJFT.	I write. He WRITES.

Note. [a]Words written in capitals were missing from the sentence and had to be spoken aloud by the subject.

elicited from the subjects, was marked by underlining and had to be read silently by the female reader. The resulting gap was substituted by a low tone, more specifically by a 333Hz, -6dB, 200ms sine wave, preceded and followed by a 300 ms silent pause. Each sentence was preceded (at 1.5 sec.) by two high-tone warning signals, more specifically by two 1000Hz, -6dB, 200ms sine waves separated by a 200 ms silent pause. Furthermore, the instructions "Please, fill in the missing word" and "Please, choose the correct form of the word" (read by a male) were added onto the tape immediately preceding the appropriate blocks.

In order to check for the understanding of all content words, that is, adjectives (6), verbs (26) and nouns (37) with the exception of person names (25), used in the CLOZE test, a pre-test was designed in which each content word was associated with a separate set of four black and white line drawings. One of these four line drawing pictures represented the content word. The other three line drawings were chosen at random to represent three other content words of the CLOZE procedure belonging to the same syntactic category. Subjects were required to choose one out of four pictures depicting the meaning of the word that was bimodally presented to them: written on a card and read aloud by the experimenter. The pre-test was administered to subjects during a separate session. Pre-test performance indicated near 100% correct understanding of the content words used in the CLOZE test.

TABLE 3.
Grammatical Morphemes Elicited within the Various Morphemic Subcategories and their Descriptions

subcategory	description	morpheme[a,b]
free:		
Determiner	article	
	indefinite	een (a)
	definite	de, het (the, non-neuter and neuter, resp.)
	possessive	
	pronoun	zijn (his), haar (her), hun (their)
Preposition	locative	in (in), op (on)
	directional	naar (to)
	instrumental	met (with)
	syntactic	aan, voor (to, dative)
Pronoun	nominative	hij (he), zij (she), het (it)
	accusative	hem (him), haar (her), ons (our)
Auxiliary	3rd. singular	kan (can), laat (lets), zal (will), heeft, is (has, perfect tense) wordt (passive be)

5.2.3 PROCEDURE

The CLOZE procedure was administered individually to subjects during one session of approximately 45 minutes. The experimental equipment consisted of two Uher stereo recorders (CR 210, CR 240), one Uher remote control (F112), a Sennheiser microphone, a Sennheiser headphone (HD400) and an Apple IIe microcomputer with CRT screen. The presentation of sentence trials was experimenter paced. By remote control the experimenter could trigger one of the two recorders to start the playing of each of the CLOZE sentences that were stored onto tape. Subjects heard these sentences over headphones as a binaural, monophonic signal. An inaudible pulse on the second channel of the tape coinciding with

Table 3 (continued)

Bound		
Plural noun	-en	stenen (stones), landen (countries), ruiten (windows), brillen (glasses), huizen (houses), neuzen (noses),
	-ien	knieen (knees), koeien (cows),
	-s	boys (jongens), meisjes (girls),
	strong	wegen (roads), schepen (ships).
Adjective	null [c]	groot (big), klein (small), mager (thin), slank (slim),
	-e [d]	grote (big), kleine (small), magere (thin), slanke (slim)
	-er (comparative)	slanker (slimmer), langer (taller)
	-est (superlative)	slankst (slimmest), langst (tallest)
Verb	Present	
	-t 2nd singular	schrijft (write), zwemt (swim), loopt (walk), kust (kiss)
	-t 3rd singular	huilt (cries), lacht (smiles)
	Past	
	-te 1st. singular	groette (greeted)
	-de 1st singular	huilde (cried)
	strong 1st sing	liep (walked), zwom (swam)
	strong 1st plur	liepen (walked), zwommen (swam)

[a]English translation between parentheses [b]For bound morphemes the whole word form is given [c]The null inflection for adjectives was elicited by a preceding indefinite article and a following neuter, singular noun [d]The -e inflection for adjectives was elicited by a preceding indefinite article and a following non-neuter, singular noun

the auditory onset of each sentence was fed to the computer and triggered the visual display of the entire sentence at the center of the CRT screen For the subject this had the effect of the sentence being read to him/her from left to right immediately after it appeared in its entirety on the CRT screen. Two short auditory warning signals preceded the auditory and visual onset of each sentence and both a low tone and line signalled the presence of the gap that had to be filled in. After the sentence had been thus presented to the subject, the experimenter used the remote control to stop the playing of the CLOZE tape. The second stereo recorder was used to record on one channel the auditorily presented sentence (over a wire connection from the first recorder) and on the other channel the spoken response of the subject (recorded by microphone). After a subject's response, the experimenter used the remote control to initiate presentation of the next trial.

In order to accomodate subjects with the procedure, they were first given the opportunity to practice without the use of the experimental apparatus. For this purpose, the experimenter presented seven practice items written on separate cards and read them aloud to the subject saying "hmmm" when the gap (a line) occurred. Subjects were instructed that there were two type of tasks. In the first type of task, they had to speak aloud a "little word" that was missing from the sentence. In the second type of task, they had to speak aloud the "right form" of the word mentioned in the previous sentence. Subjects were told that only one-word responses or omissions would be considered adequate. Subjects were furthermore instructed to respond as fast and accurately as possible. Also, it was indicated to subjects that they could give their answer as soon as they knew it. They did not have to wait until they had heard the entire sentence. In this way, the chance to discriminate fluent from non-fluent responders was increased. In order to go on with the experiment proper, subjects had to respond adequately, that is, with one-word responses or omissions, to all seven practice items in a row. In case of one or more inadequate responses or omissions, the experimenter presented the entire practice set again but no more than three times. Also, immediately after an inadequate response or omission, the experimenter re-emphasized the task requirements, supplied the correct answer and repeated the particular item. Except for one (sixth) Wernicke patient who failed to understand the task requirements, all subjects passed the criterion for the practice test. After subjects were thus acquainted with the task requirements, all CLOZE sentences, including the practice sentences, were presented bimodally by means of the experimental apparatus described in the previous paragraph.

5.2.4 ANALYSES

Both accuracy and response times of first and best attempts have been determined. Responses were categorized into several subcategories: correct, omission, within-category substitution (e.g., "on" for "with"), across-category substitution (e.g., "he" for "on") and inadequate response. The following criteria were used to score responses into these subcategories. No answers or answers consisting solely of secondary language usage, such as comments, stereotypes and negative reactions, and/or repetitions of part(s) of the stimulus sentence were scored as omissions. Otherwise, secondary language usage and repetitions of parts of the stimulus sentence were ignored (see exception below). Also, everything the subject produced after receiving feedback from the experimenter that the response was inadequate was ignored. With bound morphology items, stem reduction yielding an illformed sentence was scored as an omission, for example, "twee weg" ("two road") instead of "twee wegen" ("two roads"). Within-category substitutions were defined as substitutions of a grammatical morpheme by a grammatical morpheme belonging to the same subcategory, for example, the preposition "op" ("on") for the preposition "met" ("with)." Within-category substitutions also included mixtures of endings. To give an example, the ending -est supplied for an adjective requiring the superlative ending -st, was analyzed as a mixture of this latter ending and the one for the comparative -er. Across-category substitutions were defined as substitutions of a grammatical morpheme by a grammatical morpheme belonging to a different subcategory, for example, the preposition "on" for the auxiliary verb "lets." Across-category substitutions also included substitutions of free grammatical morphemes (function words) by content words. The following cases were treated as inadequate responses: a) exclamations such as hallo ("hello"), daag ("bye"). b) a repetition of part of the sentence (not the stem of a bound morpheme item, however) spoken as if it included the target morpheme. c) a more-word response, but only if it resulted in an ill-formed sentence. Paraphasias were not necessarily scored as incorrect. In case of free morpheme items, phonemic paraphasias were scored after reconstruction to their intended form, for example "naas" was scored as "naar" ("to"). In case of bound morpheme items, only the endings of paraphasias are taken into account. Stem substitutions were ignored, for example, "flink+e" ("big") instead of "dikk+e" ("fat"). Also in case of bound morpheme items, a paraphasic response consisting only of a stem was scored as an omission when its category was the same as that of the target morpheme, for example, the adjective "mager" ("thin") instead of the adjective "slank+st" ("slimmest"). The response time was defined as the time difference (in ms) between sentence onset and response onset. Response times were determined by means of a computerized speechlab which allows to place time-marks in a visual display of the speech waveform while receiving auditory feedback.

Since the control group scored near 100% correct on the CLOZE procedure their error data were not subjected to statistical analysis. Four different types of statistical analyses were conducted for free and bound morphemes separately. A first analysis assessed whether there were any differences between BA and WA in the relative contribution of substitutions and omissions. For this purpose, the 'substitution proportions' of BA and WA were compared by means of Chi-square test. 'Substitution proportion' was defined as the number of substitutions divided by the summed total of the number of substitutions plus omissions. A second analysis assessed whether there were any differences between BA and WA in the relative contribution of within- and across-category substitutions. For this purpose, the 'within-category proportion' of BA and WA were compared by means of Chi-square test. 'Within-category proportion' was defined as the number of within-category substitutions divided by the summed total of the number of within- and across-category substitutions. A third analysis used the number errors, that is, substitutions plus omissions, as a dependent variable, and assessed whether BA and WA differed in their absolute levels of performance and in their response profiles across the various morphemic subtypes. For this purpose, a mixed-factor 2 (Aphasic group: BA, WA) X 4 (Free morpheme type: determiner, preposition, pronoun, auxiliary) ANOVA and a mixed-factor 2 (Aphasic group: BA, WA) X 3 (Bound morpheme type: plural noun, adjective, verb) ANOVA were computed with aphasic group as between factor and free and bound morpheme type as within factors. A fourth analysis, finally, used response times for correct items as a dependent variable and assessed whether BA, WA and controls differed in terms of their absolute response times and response time profiles across the various morphemic subtypes. For this purpose, a mixed-factor 3 (Experimental group: BA, WA) X 4 (Free morpheme type: determiner, preposition, pronoun, auxiliary) ANOVA and a mixed factor 3 (Experimental group: BA, WA) X 3 (Bound morpheme type: plural noun, adjective, verb) ANOVA were computed with experimental group as between factor and free and bound morpheme type as within factors. The data entries for the ANOVAs were based on each subject's mean score for the relevant morphemic subcategory.

5.3 RESULTS

Since statistical analysis of first and best attempts showed the same results, only the results for best attempts are reported (see Table 4). For free morphemes, the percentages of inadequate responses (see previous section for definition) were 0 for controls, 5 for WA (Wernicke's aphasics) and 8 for BA (Broca's aphasics). For bound morphemes, the percentages of inadequate responses were 0 for controls, 0 for WA and 1 for BA.

Substitution proportion For free morphemes, WA showed a higher substitution proportion (.93) than BA (.82), not significantly higher, however, (Chi-square = 3.06, $p < .10$, df = 1, Yates' correction for continuity). For bound morphemes, BA and WA showed very similar substitution proportions (.83 and .81, respectively) (Chi-square = .0003, $p < 1$, df = 1, Yates' correction for continuity).

TABLE 4

Mean number of errors and Response Times

		MORPHEME TYPE[a]						
		FREE				BOUND		
		DET	PREP	PRON	AUX	PLUR	ADJ	VERB
No. of errors[b]								
Broca[c]	MEAN	1.13	2.75	3.88	4.13	1.50	2.75	4.00
	S.D[d].	1.13	1.83	2.17	2.59	1.69	2.19	4.57
Wernicke[e]	MEAN	2.00	2.60	3.20	4.20	1.00	2.00	4.40
	S.D.	3.39	2.30	2.68	2.77	1.73	1.58	3.85
Response time[f]								
Broca	MEAN	4229	6377	1180	9982	2365	3945	4050
	S.D.	1514	7712	6026	9525	567	2047	3035
Wernicke	MEAN	6121	6216	6795	9004	2939	6240	4322
	S.D.	4254	4533	2539	6037	1225	3638	879
Controls	MEAN	1684	1672	3483	3801	1936	3028	2592
	S.D.	310	196	797	1910	384	772	732

Note. [a]DET = determiner, PREP = preposition, PRON = pronoun, AUX = auxiliary verb, PLUR = plural noun inflection, ADJ = adjective inflection, VERB = verb inflection. [b]Since there were 12 items per morphemic category, the maximum error score equals 12. [c]N=8. [d]S.D . = standard deviation. [e]N = 5. [f]for correct items (in ms.).

Within-category proportion. For free morphemes, there was a nonsignificant tendency for BA to produce more within-category errors (Within-category proportion = .56) than WA (Within-category proportion = .39). (Chi-square = 3.17, $p < .10$, df=1, Yates' correction for continuity). This was true for all four free morpheme types. For bound morphemes, BA only produced within-category substitutions (Within-category proportion= 1) while WA also produced some across-category substitutions (Within-category proportion = .87) (Chi-square = 5, $p < .05$, df=1, Yates' correction for continuity). These across-category substitutions occurred for both plural noun and verb inflections.

= 5, p < .05, df=1, Yates' correction for continuity). These across-category substitutions occurred for both plural noun and verb inflections.

Errors. Collapsed over free and bound morphemes separately, BA and WA show the same absolute level of performance. The mean number of errors for free morphemes is 2.97 for BA and 3.00 for WA [F(1,11) = .00 , MSe = 13.29, p = .98], while the mean number of errors for bound morphemes is 2.75 for BA and 2.47 for WA [F(1,11) = .04, MSe = 16.87, p = .84]. In addition, there was a main effect of free morpheme type [F(3, 33) = 5.57, MSe = 2.81, p = .003] and of bound morpheme type [F(2,22) = 6.31, MSe = 4.32, p = .007] in the absence of an interaction between Aphasic group and Free morpheme type [F(3,33) = .45, MSe = 2.81, p = .72] and between Aphasic group and Bound morpheme type [F(2,22) = .26, MSe = 4.32, p = .77]. BA and WA show the same order of difficulty for the various free and bound morphemes. Going from the easiest to the most difficult grammatical morpheme, this order is determiner, preposition, pronoun and auxiliary for free morphemes and plural noun, adjective and verb inflection for bound morphemes (Figure 1).

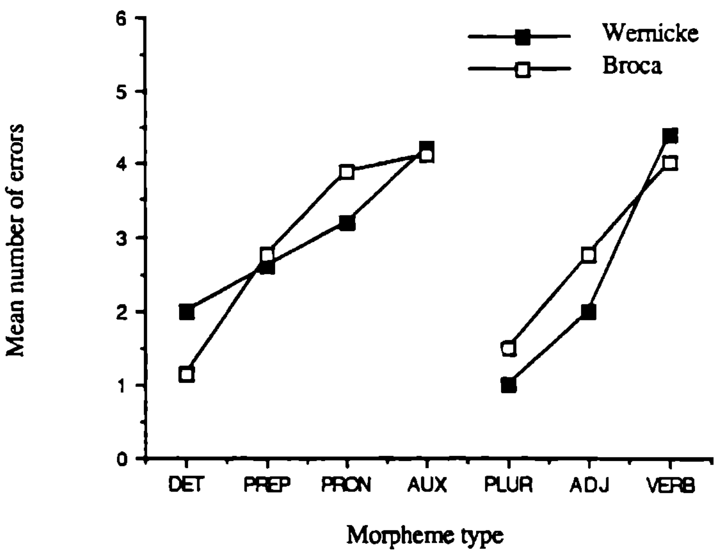

Figure 1.Mean percentage of errors as a function of morpheme type and aphasic group (DET = determiner, PREP = preposition, PRON = pronoun, AUX = auxiliary, PLUR = plural noun inflection, ADJ = adjective inflection, VERB = verb inflection)

Planned comparisons revealed that determiners (M=1.46) were significantly easier than prepositions (M=2.69), pronouns (M=3.61) and auxiliaries (M=4.15) and that prepositions were significantly easier than auxiliaries, while the differences between prepositions and pronouns and between pronouns and auxiliaries failed to reach significance. Planned comparisons furthermore revealed that plural noun endings (M=1.31) were significantly easier than adjective endings (2.46) and verb endings (4.15), while the difference between adjective and verb endings failed to reach significance.

Response times. The Experimental group X Free morpheme type ANOVA of response times revealed a main effect of Experimental group (BA,WA,controls) [$F(2,16) = 3.85$, MSe = 56105530, $p = .043$], a main effect of free morpheme type $F(3,48)=3.77$, MSe=16093922, $p=.016$] but no interaction between Experimental group and Free morpheme type $F(6,48) = 1.07$, MSe = 16093922, $p = .395$]. Planned comparisons of the three experimental groups collapsed over free morphemes revealed faster response times for Controls (M = 2260ms) than for both WA (M = 7034ms) and BA (M = 8117ms) [$F(1,9)= 10.59$, MSe = 4925535, $p = .01$ and $F(1,12) = 6.73$, MSe = 15179602, $p = .024$, respectively]. The response times of the latter two aphasic groups did not differ significantly [$F(1,11) = .18$, MSe = 80857891, $p = .681$] (Figure 2).

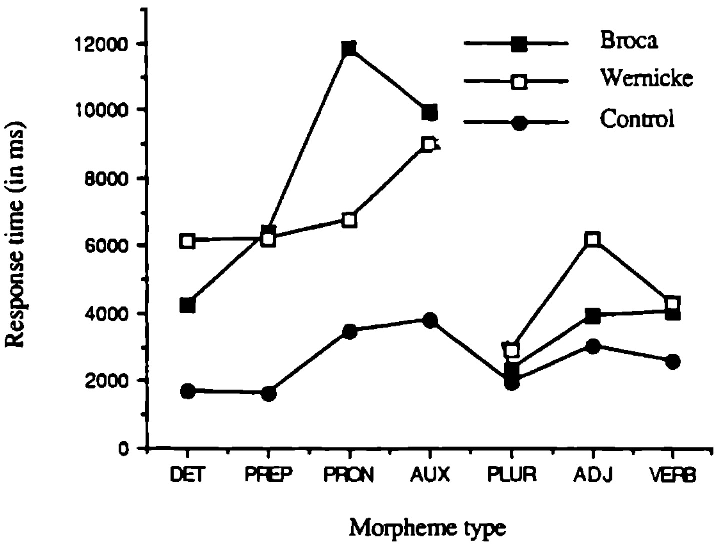

Figure 2. Response time as a function of morpheme type and aphasic group (DET =

determiner, PREP = preposition, PRON = pronoun, AUX = auxiliary, PLUR = plural noun inflection, ADJ = adjective inflection, VERB = verb inflection)

Planned comparisons of the four free morpheme types revealed that both pronoun (M=7890ms) and auxiliary items (M=7773ms) took a significantly longer time to be produced than both determiner (M=3923ms) and preposition items (M=4849ms), while there were no significant differences [F<1] between determiner and preposition items and between pronoun and auxiliary items, respectively [Fdet-pron = 10.23, MSe = 14609982, p = .005, Fdet-aux = 7.03, MSe = 20012340, p = .016, Fprep-pron = 4.20, MSe = 20929003, p = .05, Fprep-aux = 14.41, MSe = 5634036, p = .001, all with df = 1,18] (Figure 2).

The Experimental group X Bound morpheme type ANOVA of response times revealed a main effect of experimental group (BA, WA, controls) [F(2,16) = 3.62, MSe = 4446125, p = .05], a main effect of bound morpheme type [F(2,32)= 6.34, MSe = 2919634, p= .005] but no interaction between Experimental group and Bound morpheme type [F(4,32) = .89, MSe = 2919634, p = .483]. Planned comparisons of the experimental groups collapsed over bound morphemes revealed faster response times for controls (M = 2518ms) than for WA (M = 4500ms) [F(1,9) = 6.55, MSe = 1635489, p = .031], a trend towards faster response times for controls (M = 2518ms) than for BA (M = 3453ms) [F(1,12) = 3.49, MSe = 859865, p = .086] and similar response times for WA (M = 4500ms) and BA (M= 3453ms) [F(1,11) = 1.66, MSe = 2035232, p = .224] (Figure 2). Planned comparisons of the bound morpheme types revealed that plural noun inflections took less time to be produced (M = 2380ms) than both adjective (M = 4259ms) and verb (M =3661) inflections [F(1,18) = 15.25, MSe=2199131, p = .001 and F(1,18) = 8.06, MSe = 1933771, p = .011, respectively]. The response times of the latter two bound morpheme types did not differ significantly [F(1,18) = .75, MSe = 4516425, p = .397] (Figure 2).

5.4 DISCUSSION

The main result of our study is that BA and WA show the same relative difficulty in producing morpheme types, that is, both in terms of errors and in terms of responses times. This was confirmed by analyses of variance for both errors and response times which yielded main effects for free and bound morpheme type in the absence of an interaction between these morpheme types and aphasic group. Going from easiest to most difficult, the relative difficulty (as indicated by mean number of errors) was determiner, preposition, pronoun and auxiliary for free morphemes and plural noun, adjective and verb inflection for bound morphemes. Recall from the introduction that Goodglass and Berko (1960), also using a CLOZE test, found the same relative difficulty for bound morphemes for a a group of undifferentiated aphasics. Broca's and Wernicke's similar response profiles provide support for the hypothesis that at least one aspect of their grammatical impairment is the same, namely the one responsible for the production of morphological errors. This, of course, still leaves open the possibility that other aspects of the grammatical impairment, such as comprehension problems and syntactic-constructional errors (e.g., blends), are different in both patient types. In this study, we tried to minimize the disturbing effect that potential differences in comprehension abilities might have on patients' CLOZE performance by only presenting sentences that contained frequent, concrete and easy to understand (as assessed by pretest) content words embedded in simple syntactic constructions.

If, indeed, as we hypothesize, BA and WA suffer from the same impairment in producing grammatical morphemes, the question becomes as to what the precise nature of this impairment is. At the moment we can only speculate in this respect. We postulate a delay in the activation of syntactic categories in both Broca's (cf. Kolk and van Grunsven, 1985 and see Haarmann and Kolk, 1991b, for evidence from comprehension) and Wernicke's (cf. Kolk and Friederici, 1985). We will explain how such a timing disorder could disturb the production of grammatical morphemes and cause the within and across-category substitutions that were observed in similar amounts in both patient groups.

To start with the former type of error, one of our co-workers, Bison similated within-category substitutions for both free (unpublished data) and bound morphemes (1990) as the outcome of a delay in syntactic activation. In his competition based model, spreading activation from both semantic and grammatical features ensures that the target form of a word (e.g., sleeps) is initially higher activated than its incorrectly inflected competitors that are associated with the same lexical entry (e.g., sleep, slept). After a while, however, a passive decay process causes the activation of the target wordform to be no longer sufficiently distinguishable from the competitor wordforms. If there is no time delay in the construction of the phrase-structure representation, the correct target form is selected for insertion into the phrase-structure representation because its higher activation distinguishes it from competitor wordforms. If, however, there is a time delay in the construction of the phrase-structure representation, an incorrect competitor wordform might be selected for insertion into the phrase-structure representation because the activation of the target form is no longer distinguishable from that of the competitor wordforms. The longer it takes to complete construction of the phrase-structure representation, the more inflectional errors will result in this fashion. An interesting side-effect of this property is that Bison's model correctly simulates the order of difficulty for bound morphemes that was obtained by Goodglass and Berko (1960) and replicated in this study, with noun inflections being easier than adjective inflections than verb inflections. Noun, adjective and verb inflections require agreement in successively larger phrasal units which in Bison's model take an increasingly longer time to be constructed, so that more inflectional errors occur.

Not only within-category substitutions but also across-category substitutions can be explained as an outcome of a delay in the activation of syntactic categories. As explained above, a moderate delay may lead to a lack of synchrony between a phrase-structure representation and the lexical elements that have to be inserted into it (Bison, 1990). A more severe delay, however, may prevent syntactic categories from getting co-activated, so that they can not be assembled into a phrase-structure representation (see computer simulations by Haarmann and Kolk, 1991a and Kolk, 1987). Without a syntactic frame, the subject has no basis for deriving the syntactic category of the target morpheme that has to be supplied. Because sentences eliciting morphemes of different categories were not presentend as separate blocks but mixed together, the absence of a syntactic frame would leave our subjects with guessing the syntactic category of the target morpheme. This, in turn, may account for the occurrance of across-category substitutions that we observed in similar amounts in both BA and WA.

Continuation of this line of reasoning might give us a clue as to why BA and WA, in a study by Friederici (1981, 1982), made relatively few across-category errors in their CLOZE production of prepositions: on the average 3 and 0 percent for BA and WA, respectively, as compared to the 9 and 14 percent for BA and WA, respectively, that we obtained in our study. A difference in procedure may be responsible for this finding. Subjects in Friederici's study were presented with sentences eliciting prepositions only, whereas our subjects were presented with a mixed list of sentences eliciting also grammatical morphemes from other categories. Thus, subjects in our study, contrary to subjects in Friederici's study, had to determine for each sentence anew which morpheme category (e.g., determiner vs preposition) had to be supplied. As already pointed out above, it is quite conceivable that failures in this respect would have led to across-category substitutions. It should be noted that there was one subcategory of prepositions, that is, syntactically obligatory prepositions subcategorized for by the verb (e.g., "for" in "Peter hopes for the summer"), that were employed by Friederici (1982) but were not included in our material. On this subcategory, Friederici, observed her largest contrast between BA and WA in the number of across-category substitutions: 11 percent for BA and 0 percent for WA. Whether this difference is reliable remains to be established in future research. Since we did not study this subcategory, the possibility of a contrast between BA and WA in this respect remains.

Finally, we want to draw attention to our finding, that not only the performance profiles but also the absolute levels of performance, averaged over free and bound morphemes, respectively, were the same for BA and WA. For both free and bound morphemes, the analysis of variance of errors and the analysis of variance of response times yielded no main effect of aphasic group. The finding of a nonsignificant difference in the CLOZE production times of BA and WA deserves some more attention, since as to be expected, the spontaneous speech output of WA was produced significantly faster than that of BA. We would like to offer the following account for this apparent discrepancy. Kolk and van Grunsven (1985) suggested that during sentence production an aphasic patient with a grammatical impairment can react in two different ways when the formulator constructs an incomplete sentence representation. First, a patient could attempt to immediately realize this representation as a spoken sentence which would result in the fast and paragrammatic output typical of the spontaneous speech of WA. Second, a patient could attempt to covertly repair or reconstruct the sentence representation which would result in the slower and less paragrammatic output typical of the spontaneous speech of BA. Kolk and van Grunsven call this latter way of reacting "corrective adaptation." In terms of their proposal, it could be that not only BA but also WA applied corrective adaptation while performing the CLOZE procedure. Although Wernicke's spontaneous speech rate was 2,3 words per second, on average they required no less than 5,9 seconds to produce a particular grammatical morpheme on the CLOZE test.

What needs to be explained then is why WA applied corrective adaptation while performing the CLOZE procedure but not while engaged in spontaneous speech. Quite a different type of study, a syntactic judgement study by Heeschen (1992), might give a clue to the solution. Heeschen replicated the usual finding that the performance of WA is poorer than that of BA when the task is syntactic error detection, that is, deciding whether a sentence contains a syntactic error or not. This finding seems consistent with the commonly held view that WA are unaware of their errors. A lack of error awareness would explain why WA do not adapt correctively in their spontaneous speech. However, Heeschen also found that the performance of WA improved and equaled that of BA when the task is locating the syntactic error, that is, indicating where it occurs in the sentence after being told by the experimenter that every sentence contains an error. These findings suggest that the error awareness of WA is not complety lacking but can be enhanced in specific task situations which make it more clear to the patient that an error has occurred. In an analogous manner, our CLOZE procedure could have enhanced the error awareness of the WA and thereby their tendency to adapt correctively. To begin with, presentation of the sentences was experimenter-paced, so that the experimenter could have inadvertently given a patient error-feedback by initiating a trial more slowly in case of an error on a previous trial. In addition, sentences remained visible on the screen until the subject responded, so that the subject was provided with a permanent signal against which to check the response. If this is the proper picture, then both Heeschen's (1992) and our data suggest that the commonly supposed unawareness of WA is not an invariable property of these patients. While it is present in spontaneous speech, it can be overcome in specific task situations.

APPENDIX

CLOZE MATERIALS (WITH ENGLISH TRANSLATION)

Free morphemes

Determiner

Opa geeft Tineke EEN zoen. (Grandfather gives Tineke A kiss.)
Oma geeft Frans EEN hand. (Grandmother shakes Frans's [A] hand])
Frank veegt DE stoep. (Frank sweeps THE sidewalk.)
Annet doet DE afwas. (Annet does THE dishes.)
Hans schildert HET huis. (Hans paints THE house.)
Piet timmert HET hek. (Piet builds THE fence)
Jan zoekt ZIJN bril. (Jan looks for HIS glasses.)
Klaas snuit ZIJN neus. (Klaas blows HIS nose.)
Karin zoekt HAAR bril. (Karin looks for HER glasses.)
Maria snuit HAAR neus. (Maria blows HER nose.)
Thea en Jos snuiten HUN neus. (Thea and Jos blow THEIR nose.)
Ineke en Frans wassen HUN handen. (Ineke and Frans wash THEIR hands.)

Preposition

De man zit IN de auto. (The man sits IN the car.)
De baby ligt IN de wieg. (The baby lies IN the crib.)
Oma schrijft MET een pen. (Grandmother writes WITH a pen.)
Opa loopt MET een stok. (Grandfather walks WITH a cane.)
Het kopje staat OP de tafel. (The cup is ON the table.)
De duif zit OP het dak. (The dove sits ON the roof.)
Hans loopt NAAR school. (Hans walks TO school.)
Brigite loopt NAAR huis. (Brigite walks TO her house.)
De jongen bedankt VOOR het geschenk. (The boy gives thanks FOR the gift.)

De dief vlucht VOOR de agent. (The thief flees FROM the cop.)
Vader geeft een plant AAN moeder. (Father gives a plant TO mother.)
Jaap schrijft een brief AAN Marleen. (Jaap writes a letter TO Marleen.)

Pronoun

Piet is groot. HIJ is al een man. (Piet is big. HE is already a man.)
Hans is klein. HIJ is nog een kind. (Hans is small. HE is still a child.)
Maria is groot. ZIJ is al een vrouw. (Maria is big. SHE is already a woman.)
Ans is klein. ZIJ is nog een kind. (Ans is small. SHE is still a child.)
John leest een boek. HET is spannend. (John reads a book. IT is exciting.)
Petra eet een ijsje. HET is lekker. (Petra eats an ICE CREAM. IT is delicious.)
Karin ziet Annet. Zij groet HAAR. (Karin sees Annet. She greets HER.)
Jos groet moeder. Hij kust HAAR. (Jos greets mother. He kisses HER.)
Loes groet vader. Zij kust HEM. (Loes greets father. She kisses HIM.)
Frank ziet Hans. Hij groet HEM. (Frank sees Hans. He greets HIM.)
Oma groet Maria en mij. Zij kust ONS.
(Grandmother greets Maria and me. She kisses US.)
Opa ziet Ans en mij. Hij groet ONS. (Grandfather sees Ans and me. He greets US.)

Auxiliary

Opa KAN slecht lopen. (Grandfather CAN hardly walk.)
Hans KAN goed zwemmen. (Hans CAN swim well.)
John IS mager geworden. (John HAS become thin.)
Jan IS dik geworden. (Jan HAS become fat.)
Maria WORDT door Piet begroet. (Maria IS greeted by Piet.)
Ans WORDT door Jan gekust. (Ans IS kissed by Jan.)
Peter HEEFT Ria begroet. (Peter HAS greeted Ria.)
Jaap HEEFT Loes gekust. (Jaap HAS kissed Loes.)
De agent LAAT de dief ontsnappen. (The cop LETS the thief escape.)
Het kind LAAT de duif vliegen. (The child LETS the dove fly.)
Het water ZAL dadelijk stromen. (The water WILL soon flow.)
De ruit ZAL dadelijk breken. (The window WILL soon break.)

Bound morphemes

Plural noun

Een huis. Twee HUIZEN. (One house. Two HOUSES.)
Een ruit. Twee RUITEN. (One window. Two WINDOWS.)
Een bril. Twee BRILLEN. (One pair of glasses. Two PAIRS OF GLASSES.)
Een neus. Twee NEUZEN. (One nose. Two NOSES.)
Een steen. Twee STENEN. (One stone. Two STONES.)
Een land. Twee LANDEN. (One country. Two COUNTRIES.)
Een jongen. Twee JONGENS. (One boy. Two BOYS.)
Een meisje. Twee MEISJES. (One girl. Two GIRLS.)
Een weg. Twee WEGEN. (One road. Two ROADS.)
Een schip. Twee SCHEPEN. (One ship. Two SHIPS.)
Een knie. Twee KNIEEN. (One knee. Two KNEES.)
Een koe. Twee KOEIEN. (One cow. Two COWS.)

Adjective

Het kind is groot. Dus is het een GROOT kind.
(The child is big. Thus, it is a BIG child.)
De man is groot. Dus is het een GROTE man.
(The man is big. Thus, it is a BIG man.)
Het meisje is klein. Dus is het een KLEIN meisje.
(The girl is small. Thus, it is a SMALL girl.)
De vrouw is klein. Dus is het een KLEINE vrouw.
(The woman is small. Thus, it is a SMALL woman.)
Het kind is mager. Dus is het een MAGER kind.
(The child is thin. Thus, it is a THIN child.)
De man is mager. Dus is het een MAGERE man.
(The man is thin. Thus, it is a THIN man.)
Het meisje is slank. Dus is het een SLANK meisje.
(The girl is slim. Thus, it is a SLIM girl.)
De vrouw is slank. Dus is het een SLANKE vrouw.
(The woman is slim. Thus, it is a SLIM woman.)
Dit meisje is slank, maar dat meisje is SLANKER.
(This girl is slim, but that girl is SLIMMER.)
Deze man is lang, maar die man is LANGER.

(This man is tall, but that man is TALLER.)
Dit meisje is slank, maar dat meisje is het aller SLANKST.
(This girl is slim, but that girl is the SLIMMEST.)
Deze man is lang, maar die man is het aller LANGST.
(This man is tall, but that man is the TALLEST.)

Verb
Ik schrijf. Jij SCHRIJFT.
(I write. You WRITE.)
Ik kus. Jij KUST.
(I kiss. You KISS.)
Ik zwem. Jij ZWEMT.
(I swim. You SWIM.)
Ik huil. Hij HUILT.
(I cry. He CRIES.)
Ik lach. Hij LACHT.
(I laugh. He LAUGHS.)
Ik loop. Jij LOOPT.
(I walk. You WALK.)
Vandaag huil ik. Gisteren HUILDE ik.
(Today I cry. Yesterday I CRIED.)
Vandaag loop ik. Gisteren LIEP ik.
(Today I walk. Yesterday I WALKED.)
Vandaag groet ik. Gisteren GROETTE ik.
(Today I greet. Yesterday I GREETED.)
Vandaag zwem ik. Gisteren ZWOM ik.
(Today I swim. Yesterday I SWAM.)
Vandaag lopen wij. Gisteren LIEPEN wij.
(Today we walk. Yesterday we WALKED.)
Vandaag zwemmen wij. Gisteren ZWOMMEN wij.
(Today we swim. Yesterday we SWAM.)

Chapter 6

General Discussion

In this final chapter, the main conclusions of the research presented in this dissertation will be reiterated. Furthermore, previously unmentioned methodological and theoretical implications for research on Broca's aphasia will be discussed, as well as some of the limitations of the reported research in order to delineate new lines for future research. In particular, the implications and limitations of the computer simulation study (chapter 2) will be addressed first, followed by a renewed discussion of the discrepancy in the findings of the syntactic priming experiment, suggesting slow activation (chapter 3) and the monitoring study (chapter 4), suggesting fast decay. Finally, the question of whether a common syntactic deficit underlies both Broca's agrammatic and Wernicke's paragrammatic language output is re-addressed.

6.1 COMPUTER SIMULATION STUDY

The computer simulation study of agrammatic comprehension was conducted in an attempt to further formalize Kolk and van Grunsven's (1985) timing deficit theory of Broca's aphasia. The major insights derived from this study will be discussed first, followed by a discussion of some of the model's limitations that need to be addressed in future research.

Several major insights were derived from the computer simulation study. First, the sentence-picture matching data (i.e., the combined effects of sentence complexity and degrees of severity obtained by Schwartz et al., 1980, and Kolk and van Grunsven, 1985) could only be correctly simulated when the timing disorder was assumed to affect syntactic phrasal categories but not when it was assumed to affect function word categories. When phrasal categories were involved, the fit was not much affected, whether the damage was assumed to slow down the time for an element to be retrieved, or to decrease the time for an element to remain available. Thus, as far as the What-aspect of the processing disorder is involved, the simulation results suggest that minimally the timing disorder has to affect sentence-representational elements at a truly syntactic-structural (i.e., phrasal) level. Furthermore, as far as the How-aspect of the processing disorder is involved, the simulation results suggest that Broca's aphasics could be either suffering from a too-fast decay rate (i.e., decrease in memory time) or from a too-slow activation rate (i.e., increase in retrieval time). The syntactic priming experiment (chapter 3) and the word monitoring study (chapter 4) were conducted in order to find supporting empirical evidence for either one of these two temporal changes. There results are discussed (again) further below.

It should be pointed out that locating the deficit at the level of phrasal syntax does not imply that one needs an additional theory in order to account for Broca's aphasics' problems with closed class elements which encompass both function words and inflections. Both are dependent upon the integrity of the phrasal structure in order to receive their proper form and position in the sentence. Co-activation problems at the level of phrasal syntax might therefore be expected to result in problems with the processing of function words. The empirical research reported in this dissertation provides support for the hypothesis that problems with grammatical morphemes may arise from co-activation problems at the level of phrasal syntax. In the monitoring study (chapter 3, experiment 1), it was found that Broca's aphasics' sensitivity to a violation in bound grammatical morphology, in particular a violation in subject-verb agreement, was dependent on the syntactic complexity of the sentences in which these violations were couched. Broca's aphasics only showed sensitivity to subject-verb argreement violations in syntactically simple sentences but not in complex ones. In the CLOZE study (chapter 5), it was found that Broca's aphasics had more problems with the production of bound grammatical morphemes that required a more complex syntactic frame for their agreement computation, in particular, it was found that Broca's had more problems with verb inflections than with adjective inflections than with plural noun inflections. Bison (1990) simulated this order as a function of the time it took to activate the corresponding syntactic frames that these elements need for their agreement computation. Further support that problems with grammatical morphemes may arise from co-activation problems at the level of phrasal syntax comes from an off-line acceptability judgement task by Grossman and Haberman (1982). They found Broca's aphasics' sensitivity to several types of pronoun-verb agreement violations to be dependent on the syntactic complexity of the sentence frames in which they were couched.

More in general, the phrasal-syntax hypothesis makes the rather strong prediction that in any configurational language grammatical morphemes will be more difficult to process when embedded in a more complex syntactic frame. Especially, studies of Broca's aphasia in highly inflected languages like Finnish, Polish, Serbo-Croatian, Icelandic, and Turkish, would provide an ideal database against which to verify this prediction. Current descriptions of Broca's aphasics in these languages (see Menn and Obler, 1990, and also Slobin, 1991), however, do not provide the necessary data to do so. They have focussed instead on the relatively preserved ability of Broca's aphasics in highly inflected languages to produce grammatical morphemes and the contrast this provides with the typical pattern of omissions found for Broca's aphasics in less highly inflected languages like English.

A second major insight derived from the computer simulation study is that it is the hierarchical nature of a phrase-structure representation that makes its buildup especially vulnerable to slow activation. A typical phrase-structure representation can be represented as a tree of syntactic nodes with branches of different depth. Depth is defined here as the number of sub-branches a particular daughter category has in the vertical direction. An increase in retrieval time does not necessarily affect all branches equally, and may therefore have a more disruptive effect than just a delay in the availability of the end-result of parsing. The reason is that deeper branches are more affected by an increase in retrieval time (i.e., slow activation) than less deep ones because each sub-branch takes a certain time to be retrieved and because delays in retrieval accumulate across sub-branches. The lack of synchrony between daughter categories is caused because under conditions of a syntactic delay, daughter categories with deeper tree branches may get constructed much later than daughter categories with less-deep tree branches. In that case, there is a high probability that the memory time of daughter categories with the less-deep tree branches has already been counted down (with a normal rate), so that these less complex daughter categories are no longer available for parsing when the later arriving more complex daughter categories get retrieved. Hence the representations of the simple and more complex daughter categories will not be co-active and the model's requirement of computational simultaneity will be disturbed. The fact that increases in retrieval time accumulate more across deeper syntactic tree branches (called "accumulative effect" below) not only explains the disruption of co-activation within a sentence, but also explains the sentence-complexity effect across sentences: the phrase-structure representations of syntactically complex sentences tend to contain tree branches that are deeper than those found in syntactically more simple sentences. The accumulative effect also gives a clue as to why an increase in the retrieval time of phrasal nodes yields the best simulation results, that is, in terms of the desired syntactic complexity effect. Across deep syntactic tree branches, the accumulative effect of an increase in the retrieval time of phrasal categories adds up more than the accumulative effect of an increase in the retrieval time of lexical categories (i.e., of content words, function words, or both). In vertical direction, there can be more phrasal categories but only one lexical category.

There is an interesting difference between the effects of an increase in retrieval time and a decrease in memory time. Both types of temporal changes produce variations in the likelihood that one constituent will still be available when another becomes available and both types of temporal changes will therefore disrupt computational simultaneity in a similar manner. However, the results will not be exactly equivalent. Two reasons for this were already mentioned in section 2.4.1. First, in the determination of computational simultaneity, it is critical that the offset of the first retrieved daughter category occurs after the onset of the last retrieved daughter category. Both these points in time are affected by variation in retrieval time, whereas only the first point is affected by variation in memory time. Second, in a hierarchical phrase-structure representation, the effects of an increase in retrieval time accumulate across different levels, whereas the effects of a decrease in memory time do not accumulate across different levels (for explanation see section 2.4.1). Nevertheless, not only in the case of an increase in retrieval time, but also in the case of a decrease in memory time, computational simultaneity will be more difficult to achieve as the hierarchical depth of a syntactic tree branch increases. The deeper the syntactic tree branch, the more often co-activation has to be achieved (i.e., at each tree level encompassing more than one daughter category) and also the longer already retrieved daughter categories from other syntactic tree branches have to remain in an active state. There is a third, previously unmentioned reason why a decrease in memory time may produce results that are slightly different from an increase in retrieval time. Unlike an increase in retrieval time, a decrease in memory time may disturb co-activation in phrase-structure representations with syntactic tree branches of equal depth. The faster the decay of the already retrieved tree branches, the greater the chance that they will no longer be available for further phrasal integration when later arriving tree branches get retrieved (at a normal rate). This disruptive effect is enhanced as a phrasal category has more immediate daughter categories separating the first and last retrieved daughter category (both critical for the determination of computational simultaneity) in time.

A third major insight derived from the computer simulation study pertains to within-subject stochastic variability. This stochastic variability will be explained here by reference to the manipulation of the retrieval time parameter. Suppose that within a subject retrieval time has a constant value. In a certain fast range this value will be such that for a given sentence structure computational simultaneity will always be achieved and in a certain slow range it will be such that for a given sentence structure computational simultaneity will never be achieved. The consequence is that a constant retrieval time within a subject will on a given sentence type cause parsing to either always succeed or always fail. This in turn implies that one cannot simulate the finding that on a given sentence structure a subject may perform above chance level and that different subjects may do so with different percentages correct (i.e., degrees of severity). In the computer simulation study, it was therefore decided to let retrieval time fluctuate stochastically within a patient. This has the effect that the retrieval time will sometimes be in the range of computational simultaneity and sometimes not, so that a patient's repetitive parsing of a given sentence structure will sometimes succeed and sometimes not. By varying the mean of a patient's retrieval time distribution, different degrees of severity (i.e., percent correct) were successfully simulated.

Within-subject variability in retrieval time had an interesting side-effect. This variability was such that, for a particular simulated patient, on occasion (i.e., 3 of 16 patients), deviations from the group pattern of sentence complexity were obtained. A comparable number of deviations (i.e., 4 of 16 patients) was obtained in the empirical studies. This simulation result suggests the possibility that individual variation in the sentence-complexity effect may be attributed to within-subject variability in retrieval and/or decay time rather than to qualitatively different comprehension deficits. Indeed, the large across-subject variation in priming pattern that was obtained in the syntactic priming study might be a reflection of such within-subject variability in the underlying syntactic impairment. However, this remains only a speculative suggestion as repeated testing is necessary in order to establish the extent of within-subject variability in priming pattern in Broca's aphasics. This clearly is an issue that should be examined in future studies. In such studies, it might be found that the average performance profile for a group of Broca's aphasics remains relatively stable across different test admininstrations, while the test-retest reliability may be low due to within-subject variability. If stable group, but variable individual performance would indeed be obtained, then this would have both an important methodological and theoretical implication. To begin with the methodological implication, in order to get a reliable impression of the nature of the impairment, one either has to test one patient repeatedly or one has to pool the results of a single test administration across patients. The latter alternative is clearly to be preferred as one naturally wants to generalize across patients and developing task strategies will affect a single test administration less than a multiple one (Zurif, Gardner, & Brownell, 1989). A theoretical implication would be that across-subject variability in performance pattern does not necessarily have to be attributed to qualitatively different deficits as the same variability in peformance pattern would also occur within a single patient.

At this point, another reason for not immediately attributing across-subject variability in performance pattern to qualitatively different deficits should be mentioned. Such variability may sometimes be the outcome of quantitative variation in the same qualitative processing aspect (e.g., retrieval and/or memory time). Consider, for example, both the simulated and obtained sentence-picture matching data reported in chapter 2. These data seem to show an interaction between the degree of severity of the impairment and syntactic complexity (see e.g., figure 3c). For the less disturbed Dutch patients in Kolk and van Grunsven's (1985) study, the locative and passive were equally difficult to comprehend. For the more disturbed English patients in Schwartz et al.'s study, however, the passive seemed to evoke somewhat more errors in the locative. Thus, one could argue that the Dutch patients show a different performance pattern than the English patients and, therefore, suffer from a qualitatively different deficit. However, as the model's results indicate, the obtained data can be simulated when assuming only quantitative variation in the same qualitative processing aspect. How was the interaction between sentence complexity and severity obtained? As already mentioned before, in SYNCHRON, syntactic complexity effects arise because the effects of an increase in retrieval time or a decrease in memory time are more likely to disrupt co-activation in syntactically complex sentences than in simple ones. Whether a syntactic complexity effect indeed occurs is a function of the severity of the increase in retrieval time or decrease in memory time. The larger these two temporal changes are, the more likely it is that a syntactic complexity effect will appear and the more likely the syntactic complexity effect will be large.

The SYNCHRON model was used in the first quantitative simulation of agrammatic comprehension. The model must be viewed as a first attempt to model this phenomenon. In this respect it should not come as a surprise that the model suffers from certain limitations that need to be addressed in future research. A few limitations pertaining to the definition of the requirement of computational simultaneity were already discussed in section 2.4.2. Here some other limitations are discussed.

To begin with, SYNCHRON does not include a thematic role assignment process. It only makes assumptions about the time course of a phrase-structure building process. It might be important, however, to add a thematic role assignment process. In SYNCHRON, it is assumed that thematic role assignment fails in the case the increases in retrieval time or the decreases in memory time have prevented the buildup of a complete phrase-structure representation. However, thematic role assignment might fail for another reason which was not modelled in SYNCHRON. It may be that moderate changes in retrieval or memory time at the syntactic level, while not preventing the buildup of a complete phrase-structure representation, do disrupt co-activation at a point in time when phrase-structure representations and thematic-role representations interface. This may help to explain the well-known advantage of syntactic judgement over sentence-picture matching (Linebarger et al., 1983). Contrary to syntactic judgement, sentence-picture matching not only requires co-activation at the level of phrase-structure representations, but also co-activation at the level where phrase-structure and thematic-role representations interface. This may make sentence-picture matching more vulnerable to changes in syntactic retrieval and/or memory time than syntactic judgement. It is not clear how the current version of SYNCHRON would explain the contrast between relatively preserved syntactic judgement and poor syntactic comprehension.

Another reason to include a thematic-role assignment process is that it forces one to make explicit assumptions about how much of a syntactic tree needs to be represented in order for thematic roles to be derived. It might be possible to assign thematic roles on the basis of an incomplete syntactic tree representation. To give an example, suppose subjects have to interpret a simple active SVO sentence like "The man greeted the woman" and suppose subjects succeed in representing the verb phrase (VP) "greeted the woman" but fail to integrate it with the subject noun phrase (NP) into a sentence node (S). Then subjects might assign the theme role to the NP "the woman" on the basis of the VP representation and conclude with the help of the picture alternatives that the remaining NP "the man" must be the actor. In the current version of SYNCHRON, however, the rather strong assumption was made that a complete syntactic tree was needed in order to assign thematic roles. This may have led to an overestimation of the syntactic complexity effect. The VPs of the locative and passive sentence types take longer to build than the VP of the active sentence type and therefore will be more difficult to integrate with the subject NP into an S node.

Another limitation of the SYNCHRON model was already discussed in section 2.4.2.2. There we pointed out that the model may produce unwanted phrase-structure complexity effects in that the model will not always make more errors on sentences that are syntactically more complex. Specifically, when a phrasal category in the surface representation of a sentence is preceded by a more complex phrasal category, co-activation may be easier to fulfill than when it is preceded by a more simple phrasal category (for an explanation see section 2.4.2.2). It was suggested that such an effect can be prevented by changing the definition of the requirement of computational simultaneity to not only include the immediate daughter categories of a phrasal category, but all of its daughter categories. However, there is no absolute guarantee that this solution will always work. A different solution is to assume a continuous activation model of parsing (e.g., Just and Carpenter, 1992; Waltz and Pollack, 1985) in which added syntactic complexity always works against synchrony. This could be achieved by assuming that phrase-structure nodes have to share a finite amount of activation (cf., Just and Carpenter, 1992), so that syntactic representations which consist of more nodes (i.e., the complex ones) will be more difficult to keep activated. Another way to make sure that added syntactic complexity always works against synchrony is to spread only a proportion of the activation of a syntactic node to each connected node in a network of nodes representing phrase-structure (see e.g., Waltz and Pollack's, 1985). The nodes in complex syntactic representations will be more difficult to activate under these circumstances because a node will receive less activation from source nodes as more nodes intervene (i.e., in vertical direction). A continuous activation approach is beyond the current version of SYNCHRON because it models retrieval time and memory time in a discrete, all-or-none manner. In particular, a syntactic tree element either is inactive, active (i.e., in its memory time phase), or in the state of being retrieved (i.e., in its retrieval time phase).

A final limitation of SYNCHRON is that it makes only predictions about the end-result of parsing, that is, whether the sentence can be interpreted or not. About on-line properties, such as the time course of activation (i.e., the extent of activation over time) of individual word representations during sentence input, SYNCHRON has nothing to say because of its discrete nature. Such on-line properties may however provide an important source of constraint in the development of a processing theory of the syntactic deficit of Broca's aphasics and should therefore fall under the scope of a simulation model. Though, so far only applied to account for the time course of activation during sentence parsing in normals, the recent CC READER model of Just and Carpenter (1992) may help to illustrate this point. This model makes the prediction that the time it takes to process a word (e.g., in a reading task) is dependent on the complexity of the immediate syntactic context in which the word occurs. Because in CC READER the same resources are shared for lexical and syntactic processing, the more complex the syntactic context, the more time it takes to process the word. One might expect this to be the case especially for Broca's aphasics because of their greater limitation in parsing resources. The validation of such a prediction would have important consequences for a processing theory of Broca's aphasics' syntactic deficit.

6.2 CAPACITY VERSUS EFFICIENCY

The results of the computer simulation study (chapter 2) showed that the sentence-picture matching data of Schwartz et al. (1980) and Kolk and van Grunsven (1985) could be simulated under both the slow activation and fast decay hypothesis. Both the syntactic priming (chapter 3) and word monitoring study (chapter 4, experiments 1 and 2) were conducted in an attempt to obtain supporting evidence for either one of these hypotheses. The results of the syntactic priming study seem to support the slow activation hypothesis (Friederici and Kilborn, 1989; Gigley, 1983; Huber, Cholewa, Wilbertz and Friederici, 1990; Kolk and van Grunsven, 1985) in that Broca's aphasics, unlike normal controls, did not show significant priming at all three prime-target SOAs (i.e., 300, 700, and 1100 ms), but only at the largest SOA. The results of monitoring experiment 1, on the other hand, seemed to contradict the slow activation hypothesis in that Broca's aphasics showed sensitivity to subject-verb agreement violations in simple, conjoined sentences in spite of the fact that the target noun followed the syntactic frame containing these violations almost immediately (i.e., after 229 ms). Because the detection of the subject-verb agreement violations required the analysis of a (7 word long) syntactic frame preceding the target, it was concluded that sensitivity to subject-verb agreement violations under these conditions reflected relatively fast syntactic processing in the Broca's aphasics that were tested. Moreover, it was found that, contrary to normal controls, Broca's aphasics no longer showed sensitivity to subject-verb agreement violations in simple, conjoined sentences when the presentation of the noun target was delayed by 750 ms. In addition, going from experiment 1 to 2, the grammaticality effect in filler sentences disappeared in Broca's aphasics but not in normal controls, even though in experiment 1 the grammaticality effect for filler sentences in Broca's aphasics was almost twice as large and somewhat more significant as that in normal controls. The latter two findings were interpreted as suggesting that syntactic information in Broca's aphasics is decaying at a faster than normal rate (Friederici and Kilborn, 1989; Hagoort, 1989; Kolk and van Grunsven, 1985). The hypothesis that Broca's aphasics' syntactic processing deficit is due to a reduced capacity of a syntactic buffer (Caplan and Hildebrandt, 1988; Kolk and van Grunsven, 1985) cannot explain the disappearance of these patients' sensitivity to grammatical violations due to a delay in the presentation of the target noun. The same materials were used in both experiment 1 and 2, and a reduced buffer capacity should, therefore, have produced the same results in these experiments. Of course, one could argue that the results do not necessarily invalidate the reduced-buffer-capacity hypothesis because it is possible that the materials for which Broca's aphasics showed grammaticality effects in experiment 1 were syntactically not complex enough to surpass the capacity of the syntactic buffer. This seems implausible, however, because the conjoined sentences, though 'syntactically simple', were still rather long (i.e., 7 words), and because in the filler sentences complex syntactic constructions often preceded the target (e.g., center embedded relative clauses). Moreover, a processing theory of Broca's aphasics' syntactic deficit should be able to acount for the finding that Broca's aphasics may have syntactic problems with even simpler and shorter sentences than ones that were used in the word monitoring study, such as the reversible active SVO sentences of only 5 words long that were used by both Schwartz et al., (1980) and Kolk and van Grunsven (1985).

The major question addressed in the discussion of the monitoring results (chapter 4) was how to reconcile the seemingly contradictory findings from the syntactic priming study (chapter 3), suggesting slow syntactic activation, with those from the monitoring study, suggesting normally rapid syntactic activation, and moreover, though not necessarily contradictory[1] , fast syntactic decay. It was suggested that these contradictory findings could be reconciled within the framework provided by CC READER, that is, Just and Carpenter's (1992) recent activation-based model of parsing in normals. Specifically, it was suggested that the primary syntactic processing deficit of Broca's aphasics could be due to a capacity reduction or, alternatively in terms of CC READER, to a reduction in the total amount of activation available for maintenance and propagation. Here, we will briefly reiterate the rationale behind this account. However, we will also, within the framework of the same model, suggest a different account which postulates that Broca's suffer from a reduction in the efficiency by which activation is propagated during sentence parsing rather than from a capacity reduction in the total amount of available activation. The advantage of an efficiency based account over a capacity based account will be outlined.

In CC READER, parsing is implemented by a set of production rules (i.e., conduction - action rules consisting of source and target elements) whose application is activation driven. Activation is used to perform two functions, propagation and maintenance. Propagation refers to the spreading of activation from the source (condition) elements to the target (action) elements of a production rule and determines the processing speed. The more activation available for propagation, the faster the target elements surpass a certain threshold above which they are available for the application of further production rules. Maintenance refers to the keeping active of target elements that have been activated above threshold by the application of production rules and determines the accuracy of processing. The more activation available for maintenance, the more target elements can be maintained active for further processing. A common pool of activation is used to perform both activation functions, that is, propagation and maintenance. As Just and Carpenter (1992) point out, this characteristic implies the possibility of trade-off between propagation and maintenance, or, to put it differently, between speed and accuracy of processing. Allocating, relative to the total demand for activation, proportionally more activation to propagation than to maintenance will result in fast but potentially inaccurate processing, while the reverse allocation policy will result in accurate but potentially slow processing (see figure 1).

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[1] The slow activation and fast decay hypotheses are not mutually exclusive because at least in theory Broca's aphasics may suffer from both temporal changes simultaneously. In that case one would expect not only a late appearance (i.e , at larger SOAs) of syntactic priming in Broca's but also an earlier disappearance. The latter possibility could not be verified as the syntactic priming study did not include SOAs larger than the SOA at which syntactic priming first became significant in the Broca's aphasics.

The CC READER model was developed in an attempt by Just and Carpenter to simulate their finding that the on-line performance characteristics of normal subjects differed both qualitatively and quantitatively as a function of the sentence memory span of the individual subjects. Sentence memory span refers to the maximum number of read sentences in a set for which all sentence-final words can be recalled. To mention a few results, compared to high span subjects, low span subjects read slower, made more comprehension errors, showed more pronounced reading time differences between syntactically simple and complex sentences, showed larger interference of external memory load on comprehension accuracy, appeared to make no use of pragmatic information during parsing[2], and were unable to maintain multiple representations of a verb. Just and Carpenter were able to simulate all of these differences by assuming that low span subjects have less activation available for propagation and maintenance than high span subjects.

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[2] I do not agree with Just and Carpenter's interpretation of this finding. Just and Carpenter contrasted subjects' reading of sentences with an animate subject noun (e.g., "the defendant examined by the lawyer shocked the jury") with nearly identical sentences containing an inanimate subject noun (e.g., "the evidence examined by the lawyer shocked the jury"). The question was whether subjects would use the inanimacy information of the subject noun to syntactically disambiguate the following verb, that is, to reject its main verb interpretation and choose its relative clause past participle interpretation. It was reasoned that this should become apparent from faster reading times in the inanimate than animate condition. The reason is that the incorrect main verb interpretation with the subject noun as agent is temporarily sustained in the animate but not in the inanimate condition (cf. "the evidence examined ..." and "the defendant examined ...") and would have to be undone in the animate condition when the by-phrase is encountered. Reading times were indeed faster in the inanimate condition than in the animate one, however, only in the high span subject, but not in the low span subjects. Just and Carpenter interpreted this finding as suggesting that parsing is modular, in particular, informationally encapsulated in low span but not in high span readers due to their extra capacity to maintain pragmatic information (e.g., about animacy). However, in my view, the animacy effect in high span subjects does not necessarily have to be interpreted as suggesting non-modularity of parsing in these subjects. It seems possible that the larger reading times in the animate than inanimate condition are due to the fact that the process of thematic-role assignment is more difficult in the former condition because from the viewpoint of verb semantics there is more than one plausible agent in that condition, irrespective of whatever disambiguating information syntax provides. This latter interpretation is supported by Just and Carpenter's own finding that the size of the inanimacy effect in high span subjects remains the same when unreduced relatives are used (e.g., "the defendant that was examined by the lawyer shocked the jury"), suggesting that animacy has an effect independent of syntactic ambiguity. Note that the main verb interpretation is syntactically not possible in the unreduced condition.

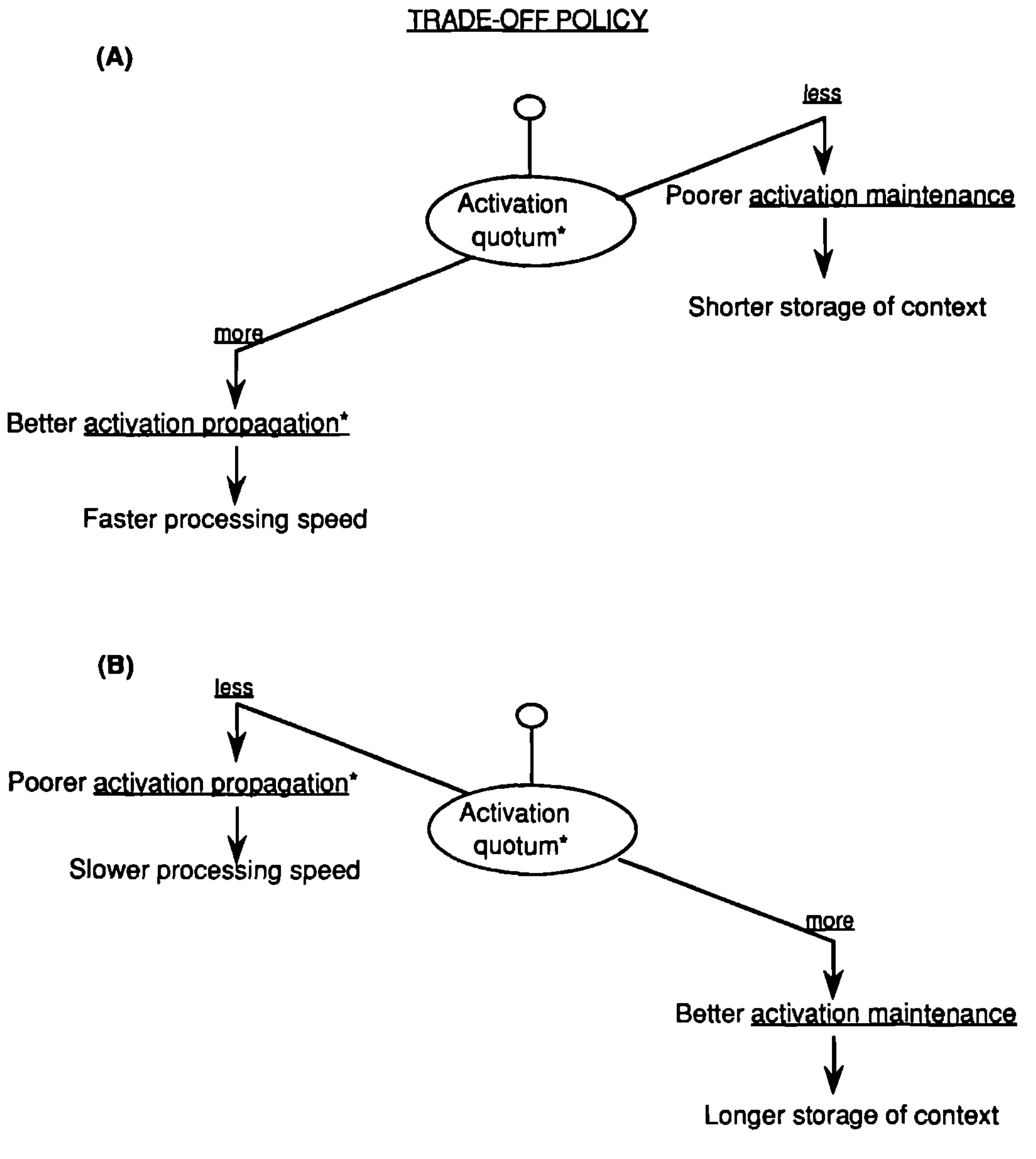

Figure 1. A schematic (balance) representation of the propagation/maintenance trade-off mechanism implemented in Just and Carpenter's (1992) CC READER model of sentence comprehension.In order to meet task demands, agrammatic aphasics are hypothesized to be in **situation A** during a word monitoring task (Haarmann and Kolk, submitted) and in **situation B** during syntactic priming involving a lexical decision task (Haarmann and Kolk, 1991b). For further explanation see text. The two stars (*) in each subfigure indicate two possible loci for the underlying impairment in agrammatic aphasia which are discussed in the text: (1) reduced capacity (i.e., reduced activation quotum) or (2) reduced efficiency (i.e., reduced activation rate during propagation).

In line with this proposal, it might be hypothesized that Broca's aphasics' agrammatic comprehension might be due to an even larger, pathological reduction in the activation available for propagation and maintenance. As previously mentioned (see section 4.4), the contradictory findings of the syntactic priming study and the word monitoring study may be reconciled if one assumes that in word monitoring Broca's aphasics' emphasis is on activation propagation at the expense of activation maintenance, whereas in syntactic priming their emphasis is on activation maintenance at the expense of activation propagation. The first type of emphasis, while resulting in the fast buildup of a syntactic representation, would shorten its lifespan. The second type of emphasis, while resulting in the maintenance of already activated syntactic representations, would slow down their completion. In section 4.4., possible reasons for such an emphasis were suggested (for details see that section). Briefly, it was suggested that the appearance of syntactic priming in Broca's aphasics at the 1100 ms SOA largely reflected these patients' strategic use of syntactic contextual information (in particular, its grammaticality) in order to facilitate their lexical decision response. In terms of CC READER, such a strategic use of contextual information would imply an emphasis on activation maintenance at the expense of activation propagation, thus effectively slowing down syntactic processing[3] . It was furthermore suggested that the strategic use of contextual information in word monitoring would be of much less benefit to the patient because the grammaticality of the sentence context provides no information to assist detection of an upcoming target and because the word monitoring task requires the rapid detection of a word

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[3] One might criticize the proposal that Broca's aphasics attempt to facilitate their lexical decision response by making strategic use of syntactic, contextual information because the application of that very same strategy leads to a delay in the availability of the requested syntactic information (due to the hypothesized propagation/maintenance trade-off mechanism). My response to this criticism is that patients have nothing to lose by attempting to use syntactic, contextual information to facilitate their lexical decision. If this information comes in time, then it will on average facilitate patients' lexical decision. If it does not come in time, then the lexical decision will simply proceed on the basis of non-syntactical lexical information. The assumption here is that the strategic use of syntactic, contextual information does not draw away processing resources, which are needed for the activation of non-syntactical lexical information. Whether and how often syntactic contextual information comes in time will be determined partially by probability factors affecting the syntactic processing times and by the inter stimulus interval (ISI) between the prime fragment and the target string. Larger ISIs probably result in more activation buildup of the syntactic representation of the prime fragment and, therefore, reduce the amount of activation that is needed to maintain this representation at a certain minimum threshold level which determines its availability. Due to the assumed trade-off mechanism this will free up activation for syntactic propagation so that information about prime-target congruency is more likely to become available early enough to bias the lexical decision.

that can appear anywhere in the sentence. In CC READER, such an emphasis on speed of processing would imply allocating more activation to propagation at the expense of activation maintenance, causing rapid decay.

In terms of the above proposal, neither fast decay nor slow activation reflect the primary syntactic processing deficit in Broca's aphasics. Rather, both of these temporal changes are the result of a deeper underlying syntactic processing deficit, in particular, a pathological reduction in the amount of processing resources, or more specifically, a pathological reduction in the amount of activation that is available for maintenance, determining the decay rate and propagation, determining the processing speed. Staying within the confines of the CC READER model, it is however possible to characterize the primary syntactic processing deficit in a slightly different manner, in particular, involving a reduction in the efficiency of activation propagation. As will become clear, under this account rapid decay is viewed as the result of a compensatory reaction to this efficiency problem. This different characterization of Broca's aphasics' syntactic processing deficit, as well as its major advantage, is outlined next.

A key property of the CC READER model is that parsing operations are not applied in a single time step, but instead last for the time that it takes to propagate activation (A) from a source element to a goal element of a condition-action rule until the goal element surpasses some fixed threshold. This duration aspect of production rule application is implemented by spreading the activation of a source element to a goal element not all at once, but rather by spreading at each time step only a proportion of the activation, determined by a a weight factor. In this manner, the weight factor directly determines the rate of activation propagation. The weight factor can be viewed as determining the efficiency by which activation is propagated and consequently, the efficiency by which the capacity of the parser (i.e., total amount of activation available) is used. A fixed amount of activation will be propagated more quickly in case efficiency is high causing an increase in processing speed. Now, an alternative account of Broca's syntactic processing deficit is that the efficiency of propagation (as determined by the weight factor) and, thereby, its speed has slowed down. A subject may try to compensate for the reduced efficiency in activation propagation by allocating more activation to propagation. The fact that a reduced proportion of activation is spread during each time unit has a less-reducing effect on processing speed when more activation is fed into the spreading activation process[4]. However, allocating more activation to propagation to keep up

[4] To see this, consider the formula giving the amount of activation propagated from a source element to a goal element, A x E, where A stands for the activation level of a source element and E (for efficiency) stands for the proportion of A that is being spread to a goal element. In the case E is low, the same amount of activation

processing speed, as was hypothesized to be the case for word monitoring will go at the expense of activation maintenance, resulting in a faster decay of already activated syntactic representations. In a complementary fashion, allocating more activation to maintenance in order to counteract decay, as was hypothesized to be the case for syntactic priming with lexical decision will go at the expense of processing speed. In this way, not only a capacity account, but also an account in terms of reduced efficiency of activation propagation can account for the discrepant findings of the syntactic priming and word monitoring study. But what is the major advantage over a capacity based account?

The answer is parsimony. As listed above, Just and Carpenter's capacity theory can account for an impressive number of differences in the on-line parsing performance of low and high span subjects. However, as they admit, individual differences based on different amounts of practice are not easily explained in terms of differences in capacity because one would have to make the implausible assumption that "the practice would have to recruit more activation and/or additional processes and structures, quite apart from producing any efficiency gain in the originally targeted processes" (p. 33, 1992). Rather it seems that more practice goes together with more efficiency (cf. Cohen, Dunbar, and McClelland, 1990) in that less activation/capacity is needed to achieve the same processing speed (see note 3 for an explanation), as seems to be indicated by the results of pupillometry (e.g., Beatty, 1982) and glucose studies (Haier et al., 1988) which suggest that more practiced subjects perform a task with less effort (i.e., a possible indicator of activation). Just and Carpenter prefer a capacity account for most of the individual differences they obtained, but an efficiency account for practice effects. A more parsimonious approach, however, would be to account for all individual differences in parsing in terms of differences in efficiency of activation propagation, including differences involving the degree of severity of agrammatic comprehension. According to an efficiency based account high span readers would differ from low span readers in that they are more efficient in their activation propagation and, therefore, have a faster processing rate and more capacity left over for activation maintenance.

Both under a capacity and efficiency based account of Broca's aphasics' syntactic deficit, the assumption was made that these patients have somehow the ability to strategically influence the scheme by which activation is allocated to propagation and maintenance,

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can still be spread each time unit by increasing A, the activation that is fed into the goal element. In Just and Carpenter' (1992) terminology E is called the "weight factor." It has a uniform value throughout their model. Note that the term efficiency is not used here to refer to the task approach of a subject but instead to refer to a property of the functional architecture of the parsing module.

emphasizing the first more than the other, or vice versa. However, parsing is probably a highly modular process whose internal functioning is not penetrable by central strategic control (e.g., Fodor, 1983, Ferreira & Clifton, 1986, see also note 3), at least in normals. Because it is a component of the parser one would expect the (propagation/maintenance) activation allocation scheme to be subject to the same impenetrability constraint. The question then becomes how an aphasic patient can nevertheless influence this activation allocation scheme. There are two fundamentally different ways to approach the answering of this question.

One approach is inspired by the findings of a syntactic priming experiment conducted by Kilborn and Friederici (1989). As discussed in chapter four, they found that explicit instructions to ignore the prime context led to the disappearance of syntactic priming in Broca's, but not in normals. According to Kilborn and Friederici (1989), these findings suggest that due to brain damage the parser has lost its normal cognitive impenetrability and become cognitively penetrable in Broca's aphasics, that is, its internal functioning has become open to direct cognitive control. The emergence of a cognitively penetrable parser in Broca's aphasics, if indeed the case, would create a necessary condition for these patients to exert direct cognitive control over its internal activation allocation scheme. What in turn are the necessary conditions for changing a cognitively impenetrable parser into one that is cognitively penetrable? One condition probably involves a slowing of the parser's processing speed (e.g., due to less efficient activation propagation as claimed for Broca's aphasics in this chapter). Central cognitive control typically takes time and only has the potential of directly influencing the internal functioning of the parser if the speed of the parser itself has slowed down. The normally fast operating parser will allready have done its job before central cognitive control has had a chance to influence its internal workings. However, another condition for cognitive penetrability is less likely to be satisfied. The subject needs to have not only time to cognitively control the internal functioning of the parser but also knowledge to do so. Most relevant for the discussion here, the subject needs to have knowledge about the workings of the parser's (propagation/maintenance) activation allocation scheme. If such knowledge was not available before the brain damage occurred (which is likely because under normal circumstances there is no functional role for it), then it is unlikely to become available as a consequence of the brain damage. To conclude, it seems unlikely that brain damage changes a Broca's aphasic in such a way that direct cognitive control can be exerted over the activation allocation scheme internal to the parser.

Another approach to the question of how a subject exerts influence over the parser's activation allocation scheme avoids the assumption of cognitive penetrability, that is, it does not assume that there is direct central cognitive control over the parser's internal functioning. Instead this approach, which can be viewed as a refinement of Kolk and van Grunsven's (1985) notion of corrective adaptation (see introductory chapter section 1.3), assumes that a subject can indirectly control the activation allocation scheme by selectively attending in a certain way to the parser's input which is formed by auditory traces of the input words in verbal short-term memory. Depending on whether the task requirements stress propagation or maintenance, a subject could either choose to selectively attend (i.e., a centrally controlled process) to new input (i.e., the next word to be inputted) or to old input (words already inputted). The first strategy would speed up the processing of new input, leaving, however, less activation for the propagation and maintenance of old input. The second strategy would improve the propagation and maintenance of old input, but would slow down the propagation caused by new input. This account is slightly different from the one given before as it does not assume a direct trade-off between maintenance and propagation, but beween the maintenance and propagation caused by a new input word, on the one hand, and the maintenance and propagation caused by already presented input words, on the other hand. Under this account, the disappearance of syntactic priming in Broca's after explicit instructions to ignore the prime fragment as found by Friederici and Kilborn (1989) can be explained as resulting from the failure to direct selective attention to old input (i.e., the prime fragment). Without such selective attention the (already less efficient) propagation and maintenance caused by the prime fragment is likely to suffer.

Though speculative, the proposal that Broca's aphasics control resource allocation internal to the parser indirectly through selective attention to new versus old input words has certain implications which are clearly testable in future studies. It would be preferable to manipulate a subject's selective attention for new and old input in one and the same task involving the same group of Broca's aphasics. This would be a better way to contrast different activation allocation schemes than was possible (i.e., based on posthoc interpretation) in the present research which involved the use of different tasks (i.e., word monitoring versus syntactic priming with lexical decision), different materials, and slightly different groups of Broca's aphasics. To give a suggestion for a future study, one could use a syntactic priming paradigm in which the proportion of syntactically related stimuli is varied. Analogous to variation of the proportion of semantically related stimuli in a semantic priming task (Tweedy, Lapinsky, and Schwaneveldt, 1977), this manipulation should result in different tendencies to strategically use contextual information to facilitate the lexical decision response (cf. Seidenberg et al., 1984). In particular, with a high proportion of related trials, Broca's aphasics should show a strong tendency to use contextual information for strategic reasons, and in terms of the above account, there should be a strong tendency to propagate and maintain activation associated with old input words, hindering and slowing the propagation and maintenance of activation that is associated with new input words. Consequently, one would expect a late appearance of syntactic priming under those conditions. Conversely, with a low proportion of related trials, Broca's aphasics should show hardly any tendency to use contextual information for strategic reasons, and in terms of the above acount, they should show hardly any tendency to maintain and propagate old input words preventing the occurrence of syntactic priming at large SOAs. They might, however, still show syntactic priming at extremely short SOA's (e.g., at a 0 ms SOA, Friederici and Kilborn, 1989) because maintenance of the activation associated with the prime fragment is not yet as important at such short SOA's. In order to further test the notion that Broca's aphasics use selective attention to strategically control the parser's activation allocation scheme, the high proportion condition should also be administered under conditions that prevent selective attention by introducing distracting stimuli or a second task. Under such conditions, one would expect a strategically-based, late syntactic priming effect to disappear in Broca's aphasics. Studying Broca's sentence processing under conditions that involve distraction and divided attention could be of potential relevance for aphasic rehabilitation. Unlike the confines of a one-to-one relation with a clinician in a therapy room, in daily life the aphasic patient will typically be exposed to multiple distracting stimuli and conditions that divide attention, that is, circumstances that make it more difficult for the patient to compensate for a lack of efficiency in sentence processing by allocating central, selective attention[5]. The learning of strategies to allocate attention appropriately under such real-life circumstances could therefore benefit the well-being and communication abilities of the patient (cf. LaPointe & Erickson, 1991).

At the end of this section it should be pointed out that a reduction in propagation efficiency might not be limited to Broca's aphasics' syntactic processing but might encompass their lexical-semantic processing as well. A reduction in lexical-semantic propagation efficiency might be expected to slow down the rate by which a word's accessed lexical-

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[5] Based on their finding that a group of undifferentiated aphasics, unlike a group of normal controls, showed a significant drop in auditory vigilance (involving word identification) under a divided attention condition (involving simultaneous card sorting), LaPointe and Erickson (1991) proposed that aphasics have a non-linguistic attentional allocation deficit which is superimposed on the linguistic deficit. An alternative explanation of the same findings, however, might be that aphasics do not suffer from a non-linguistic attentional deficit, but rather use their normal capacity to allocate attention in order to compensate for the negative consequences of the pimrary linguistic deficit, for example, less efficient activation propagation as is proposed in this dissertation. Such a compensatory use of attention is likely to be interfered with under conditions that divide attention.

semantic information is integrated with the preceding lexical-semantic context. As might be recalled from the general introduction (chapter 1), Hagoort's (1990) finding of a delayed context selection effect for the subordinate meaning of an ambiguous prime word provided direct evidence for a slowing down in lexical integration and also the absence of semantic priming at a large ISI of 1250 ms seemed to indicate such a slowing down. According to Hagoort, this slowing down is due to a lack of computational resources available for lexical integration. When writing "Computational resources are invested in retaining the context representation and in the process of integrating the lexical information into this higher-level representation" (p. 177), Hagoort seems to have in mind the same activation functions which Just and Carpenter (1992) call maintenance and propagation, respectively. Hagoort, however, is not very specific about how to view Broca's reduction in computational (lexical-intergration) resources (cf. chapter 1). The advantage of Just and Carpenter's CC READER model (1990) is that it allows for a formal specification of the rather vague concept of computational resources, so that unambiguous predictions can be made about subjects' on-line parsing properties. As indicated above, within this framework, Broca's aphasics' reduction in computational resources can be viewed as the outcome of either a reduction in capacity (i.e., a reduction in the total amount of activation that is available per time unit for maintenance and propagation) or a reduction in the efficiency of propagation (i.e., proportion of activation spread from source to goal elements). For reasons of parsimony (see above) the latter alternative, a reduction in propagation efficiency, is preferred here. Such a reduction will slow down processing (i.e., propagation) and indirectly hinder maintenance. Because syntactic representations are more hierarchical and, therefore, deeper and more order dependent than lexical-semantic representations, they require that processing is carried out quickly in order to prevent premature decay of already activated representational elements, as suggested by the SYNCHRON model (chapter 2). Therefore, a reduction in propagation efficiency can be expected to have more disruptive effects on syntactic than on lexical-semantic integration. This may help to explain the common finding that Broca's have less comprehension problems with irreversible than reversible sentences in which interpretation critically depends on syntactic information (e.g., Kolk and Friederici, 1985).

6.3 BROCA'S VERSUS WERNICKE'S

The syntactic priming and word monitoring study reported in chapters 3 and 4, respectively, investigated only one type of aphasics, that is, Broca's aphasics. It remains therefore an open question to what extent other major aphasic syndrome types, in particular, Wernicke's and Conduction aphasics suffer from similar receptive syntactic processing problems. As far as language production is concerned, the results of the CLOZE study (chapter 5) suggested that Broca's and Wernicke's aphasics may suffer from the same underlying morpho-syntactic impairment in language production. These two patient types showed very similar performance profiles (i.e., similar order of difficulty) on response time and accurracy measures when producing several types of free and bound grammatical morphemes.

As was pointed out above, the timing deficit theory predicts especially problems with phrasal integration in the case of syntactically complex sentences. Of particular importance, therefore, is the question of whether Broca's and Wernicke's aphasics' language production is affected in the same way by an increase in the syntactic complexity of the sentences to be produced. In the discussion of the CLOZE data (chapter 5), the tentative conclusion was reached that such is indeed the case. Bison's (1990) model of paragrammatism appeared to be capable of producing the obtained order of difficulty for different types of bound morphemes (i.e., more errors for verb inflections than for adjective than for plural noun inflections) as a function of the complexity of the minimal syntactic frame that these different morphemes need for their agreement computation. Especially in the case of a syntactic delay, more complex syntactic frames take more time to construct and are therefore more likely to be out of synchrony with (normally) activated lexical information about wordform that needs to be inserted into the syntactic frame.

Though the CLOZE data are consistent with the syntactic-complexity hypothesis, a more direct test of this hypothesis would be to test the prediction that one and the same type of grammatical morpheme should become more difficult to produce as the syntactic complexity of the sentence frame of which it is part increases. In case Broca's and Wernicke's suffer from the same underlying syntactic impairment in language production, then they should be similary affected by such a manipulation. In evaluating the results of such research it will be important to take into account the degree of severity of the syntactic impairment. Considering their rather complex syntactic constructions in spontaneous speech, it is likely that Wernicke's aphasics suffer from a less severe syntactic deficit than Broca's aphasics. As was pointed out for comprehension (see section 6.1 above), the degree of severity of the syntactic deficit may interact with the sentence-complexity effect in that certain complexity contrasts (e.g., between locative and passive sentences) will only become significantly different as the severity of the syntactic timing deficit increases. In order to demonstrate the negative effects of an increase in syntactic complexity on the production of grammatical morphemes, it will therefore be necessary to include rather complex constructions so that such effects will also become apparent in the syntactically, less-severily disturbed aphasics, most likely, the Wernicke's aphasics.

An alternative way to reveal syntactic complexity effects in Wernicke's aphasics is to have them engage in a secondary task that demands selective attention. In this way, potential effects of syntactic complexity on grammatical morpheme production are less likely to become masked by what Kolk and van Grunsven (1985) termed corrective adaptation (cf. section 1.3). In corrective adaptation, a subject repeatedly inputs the same conceptual message into the formulator. It is assumed that with each re-inputting cycle, there is a higher chance that phrasal co-activation succeeds because of rest-activation left from the previous cycle, especially when the syntactic impairment is mild as is most likely to be the case for the Wernicke's aphasics. In the discussion of the CLOZE data, it was suggested that when the task requirements emphasize correct production, such as in the CLOZE test, that not only Broca's aphasics, but also Wernicke's aphasics might engage in corrective adaptation. Corrective adaptation, however, is a compensatory reaction which requires selective attention. Engaging Wernicke's in a secondary task that divides attention, will make them less likely to adapt correctively and will therefore bring the potentially disruptive effects of increased syntactic complexity more easily to the foreground.

In the preceding section, Kolk and van Grunsven's temporal deficit theory was restated in terms of the activation dynamics, which are assumed in Just and Carpenter's (1992) model of sentence comprehension. An interesting remaining question is whether this proposal can be extended to the area of language production. In particular, one can ask whether the proposal is compatible with the normally observed difference in the spontaneous speech output of Broca's and Wernicke's aphasics which is agrammatic and paragrammatic, respectively. And furthermore, one can ask how the proposal relates to the absence of this difference in the CLOZE study.

To begin with the first question, during spontaneous speech both the propagation and maintenance of activation are important for the buildup of a syntactic frame. If our above proposal is correct, then both Broca's and Wernicke's aphasics suffer from a reduction in the efficiency by which syntactic activation is propagated. Because of the relative importance of activation maintenance during speaking, the lack of efficiency in activation propagation cannot be compensated for. The outcome is a decrease in the speed of syntactic processing. As Bison's (1990) model of paragrammatism suggests, a decrease in syntactic processing speed can lead to a temporal mismatch between phrase-structure and wordform information causing substitutions of grammatical morphemes. Due to a decreased error awareness (cf. chapter five) or press of speech (Kolk and Heeschen, 1992) Wernicke's aphasics might not be inclined to correct such morphological errors. This could explain their relatively fast[6] and paragrammatic speech output. Broca's aphasics, on the other hand with a relatively intact error awareness and no press of speech might be inclined to apply what Kolk and van Grunsven (1985) have termed preventive adaptation and corrective adaptation, respectively.

In preventive adaptation, subjects simplify the messages that form the conceptual input to the sentence formulator. Simplified messages will be realized through utterances with a more simple syntactic, often elliptical structure. Therefore, preventive adaptation indirectly causes a reduction in syntactic load which makes both syntactic activation propagation and maintenance easier. More activation will be available to compensate for the pathological reduction in syntactic processing rate so that, according to Bison's model, there will be less (or even no) substitutions of grammatical morphemes. Altogether, the speech output will be that of a typical Broca's aphasic, that is, agrammatic (i.e., syntactically simple and often elliptical) with little or no paragrammatic morpheme substitutions and, moreover, non-fluent due to the time consuming nature of adaptive strategies.

In corrective adaptation, a message fragment is re-inputted into the formulator. Every re-inputting cycle, propagation will start to build up from a higher initial level due to rest activation left from the previous cycle. The higher the initial level from which activation builds up, the faster the threshold level is reached at which syntactic information becomes available for further processing. In other words, re-inputting can be expected to cause an increase in syntactic processing speed and thereby compensate for the reduced efficiency in syntactic activation propagation. Again, as was also the case for preventive adapation, Bison's (1990) model would predict a reduction in or complete disappearance of substititions of grammatical morphemes. The overt and covert attempts to re-input message fragments would result in the many pauses and self-corrections that are typical of Broca's aphasics' agrammatic speech output.

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[6] The claim that in spontaneous speech Wernicke's suffer from a reduced syntactic speed but nevertheless have a fluent speech output may seem contradictory. However, this need not be the case because the overt speech rate (i.e., number of words produced per minute) is not necessarily a direct outcome of the processing speed of the syntactic module. Especially in the case of aphasics, the degree to which adaptative strategies such as corrective adaptation (see text) are applied might be a much more important factor in determining the overt speech rate. Following Kolk and van Grunsven (1985), Wernicke's aphasics are assumed to apply time-consuming corrective adaptation in their spontaneous speech not at all or to a much lesser degree than Broca's aphasics. This would explain why Wernicke's aphasics have a faster speech output than Broca's aphasics (see text).

In the CLOZE test, both the agrammatic/paragrammatic and nonfluent/fluent distinction between Broca's and Wernicke's aphasics disappeared and both patient types became paragrammatic and equally slow. As already suggested in chapter five, this might indicate that both patient types applied corrective adaptation while performing the CLOZE test: corrective adaptation costs time and, while reducing the number of morphological errors (as explained above), corrective adaptation cannot guarantee their complete disappearance, especially because the CLOZE test does not allow a patient to select a particular sentence frame as freely as during spontaneous speech. Why would Wernicke's aphasics change from no adaptation in spontaneous speech to corrective adaptation in the CLOZE test? As already explained in chapter five, certain procedural details of the CLOZE test administration (i.e., the bimodal and experimenter-paced presentation of the sentence material) may have enhanced the impaired error awarenss of the Wernicke's aphasics causing them to correct morphological errors by means of corrective adaptation.

6.4 FINAL REMARK

Most of the current research with Broca's aphasics, including most of the research reported in this dissertation deals with the syntactic and semantic processing problems that these patients experience in language reception. Such problems require carefully controlled formal psycholinguistic testing in order to be observed. The ultimate goal of any theory of Broca's aphasia, however, should also be to explain those features of the syndrome which are clinically most striking and can be readily observed without formal testing. One of those features undoubtedly is agrammatic language production. The challenge for future research will be to apply the temporal framework that was advocated in this dissertation to the area of language production. More specifically, there is a need for on-line methods that allow one to probe into the time course of syntactic planning during sentence production. Unfortunately at present, such methods are not available as hardly any research has been conducted along these lines involving normal, non-aphasic subjects (for an exception see Schriefers, in press). It can only be hoped that the need to study the nature of Broca's processing deficit not only in comprehension, but also in production will stimulate the development of methods that allow one to probe into the time course of syntactic planning in both normal subjects and Broca's aphasics. Just as the imaginary programmer that was brought to the forefront in the introductory chapter of this dissertation, the investigator carrying out such research will probably begin to marvel at how any symbol manipulating system that operates under tight temporal constraints succeeds in even coming close to functioning normally.

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SUMMARY

The central goal of the research reported in this dissertation was to develop and test the theory proposed by Kolk and colleagues (Kolk and van Grunsven, 1985; Kolk et al., 1985; Kolk, 1987) that the syntactic problems of Broca's aphasics are caused by a timing deficit involving either a too slow activation or too fast decay of sentence representational elements.

Chapter 1 provides a general introduction to the research. The syndrome of Broca's aphasia is defined with an emphasis on one of its main features, agrammatism in spontaneous speech. It is pointed out that agrammatism, defined as a tendency to use a rather simplified syntactic repertoire with many function words and inflections missing, is often parallelled in comprehension. When sentence understanding is crucially dependent on the proper use of syntactic cues, Broca's aphasics are typically impaired. After having introduced the syndrome of Broca's aphasia, several types of evidence from modern psycholinguistic studies are discussed indicating in a rather straightforward manner that Broca's syntactic deficit does not involve a loss of syntactic knowledge but rather a problem in the processing of this type of knowledge. Then, Kolk's timing deficit theory of Broca's aphasia is introduced within a theoretical framework that outlines various alternative ways to specify the nature of Broca's syntactic processing deficit (i.e., the How-aspect of the syntactic processing impairment) as well as the type of linguistic elements that are affected by this deficit (i.e., the What-aspect of the syntactic processing impairment). As far as the How-aspect is concerned, three metaphors for specifying Broca's syntactic processing impairment in terms of a pathological resource restriction are outlined, involving a temporal (i.e., time), spatial, or energetic limitation. As far as the What-aspect is concerned, it is described that three candidate elements have been proposed in the literature, involving function words, higher-order phrasal information, and so-called 'traces' (left behind by a general constituent moving transformation). The theoretical framework describing the various alternative ways to specify the nature of Broca's syntactic processing deficit is followed by a review of several recently conducted on-line processing studies with Broca's aphasics. This review is intended to show that the studies conducted either do not allow one to distinguish between the various theoretical possibilities with respect to the How-aspect of the impairment or, though they seem to point to one specific type of resource restriction, have to be interpreted with caution because of the materials used. Chapter 1 ends with a general overview of the conducted research.

Chapter 2 describes a computer simulation study of Broca's agrammatic comprehension that uses a newly developed model, called SYNCHRON, that was designed in order to refine Kolk's timing deficit theory in a more formal manner. Within this model, the notion of slow activation is specified as the time it takes to retrieve a syntactic tree element from memory (i.e., as determined by a retrieval time parameter), while the notion of fast decay is specified as the time an element remains available for further syntactic processing once it has been retrieved from memory (i.e., as determined by a memory time parameter). Both an increase in retrieval time and a decrease in memory time are shown to interfere with the co-activation of the daughter categories of a syntactic phrasal category preventing the buildup of a phrase-structure representation specifying the hierarchical relations among the constituents of a sentence. It is assumed that in sentence-picture matching with reversible sentences (i.e., sentences containing only syntactic cues to thematic-role assignment), the lack of a complete phrase-structure representation forces the subject to guess the correct picture alternative (i.e., the picture depicting the correct thematic role relations, e.g., woman = actor, man = theme) causing a potential comprehension error. The goal of the simulations that were conducted with the model was to simulate two very basic phenomena in agrammatic comprehension that had not received any formal treatment so far, that is, degrees of severity (i.e., indicated by between-subject differences in the percentages correct for a given sentence type) and the sentence-complexity effect (i.e., the finding that syntactically more complex sentences evoke more errors than syntactically more simple sentences). In order to simulate the above-chance performance of a single patient on a given sentence type, the assumption was made that either the retrieval time or memory time fluctuates stochastically from moment to moment within a patient. Degrees of severity corresponded with different increases in either mean retrieval or mean memory time, keeping the standard deviation of these parameters constant.The data that were simulated came from two sentence-picture matching studies with Broca's aphasics that had shown a similar effect of sentence-complexity, however, at different overall levels of severity. As far as the How-aspect of Broca's aphasics syntactic processing deficit was concerned, certain syntactic tree elements were either assumed to be selectively affected by an increase in retrieval time or by a decrease in memory time. As far as the What-aspect of the impairment is concerned, these elements were either assumed to involve the lexical-syntactic category that is associated with function words or so-called phrasal categories (i.e., syntactic categories of sentence constituents, such as noun phrase [NP]).

The simulation results showed that the combined effects of sentence complexity and degrees of severity obtained in the two empirical studies could only be correctly simulated when the timing disorder was assumed to affect syntactic phrasal categories but not when it was assumed to affect function word categories. Completely unexpected, counterintuitive results were obtained in the latter case, suggesting a role for computer simulation models as a means to compute through the often unpredictable consequences of the temporal assumptions of a linguistic processing theory. When phrasal categories were involved, the fit was not much affected, whether the damage was assumed to slow down retrieval time, or to decrease memory time. Thus, as far as the What-aspect of the processing disorder is involved, the simulation results suggest that minimally the timing disorder has to affect sentence-representational elements at a truly syntactic-structural (i.e., phrasal) level. Furthermore, as far as the How-aspect of the processing disorder is involved, the simulation results suggest that Broca's aphasics could be either suffering from a too-fast decay rate (i.e., decrease in memory time) or from a too-slow activation rate (i.e., increase in retrieval time). In the discussion of the computer simulation study, the slightly different mechanisms by which the temporal changes in retrieval and memory time prevent the buildup of a phrase-structure representation are described (see also chapter 6). Moreover, though the simulation results mimicked the empirically obtained pattern rather well, it was indicated that more complex sentences than the ones used in the simulation (i.e., simple active NP - V - NP sentences, their passive counterparts, and locative NP V NP PP sentences) would imply a change in the model's definition of co-activation, called the requirement of computational simultaneity. Specifically, it was indicated that future versions of the model should extend this definition to include not only the immediate daughter categories of a phrasal category but also the ones at deeper levels and, moreover, should allow pre-mature closure of phrasal category based on part-by-part parsing. Furthermore, it was suggested that future versions of the model might use a richer description of phrase-structure representations including co-activation assumptions for the abstract coindexed phrase-structure elements that have been proposed by Government and Binding theory.

In chapter 3, a syntactic priming experiment with Broca's aphasics and normal controls is presented. The experiment was designed to find empirical evidence supporting either the slow activation or fast decay hypothesis. Broca's aphasics had to give lexical decisions to targets that in the word condition either formed a syntactically appropriate or inappropriate continuation of a preceding two-word prime fragment. Both response latencies and accuracy were recorded. The critical manipulation involved the stimulus onset asynchrony (SOA) between the prime fragment and the target, that were both visually presented on a computer screen. The SOA was 300, 700, or 1100 ms long. Specifically, the predicition was made that, in the case of slow syntactic activation, Broca's aphasics should show a later (in terms of the SOA size) appearance of syntactic priming (i.e., significantly faster response latencies in the grammatical than in the ungrammatical condition) than the normal controls, while, in the case of fast syntactic decay, they should show an earlier disappearance of syntactic priming than the normal controls. A combination of these priming patterns, that is, later appearance and earlier disappearance of syntactic priming, was expected in the case Broca's aphasics would suffer from both pathological temporal changes. The results turned out to support the slow activation hypothesis, while leaving open the possibility of a fast decay. Contrary to normal controls who showed syntactic priming at all three SOAs, Broca's only showed priming at the largest SOA of 1100 ms.

In chapter 4, the timing deficit theory of Broca's aphasia is further tested by means of a different task paradigm, in particular, identical word monitoring. Subjects, that is, Broca's aphasics and normal controls, were given a pre-specified target noun and were asked to press a button as soon as they heard this target noun in a spoken sentence. In critical sentences, the target noun was preceded by a syntactic frame which either did or did not contain a subject-verb agreement violation. Subjects' on-line sensitivity to these agreement violations was assessed by observing whether the monitoring latencies to target nouns were significantly slower in the non-agreeing than agreeing condition. The results of a first experiment revealed that Broca's aphasics, contrary to normal controls, only showed on-line sensitivity to subject-verb agreement violations when these violations were couched in a simple syntactic frame conjoining two verb phrases, but not when these violations were couched in a complex syntactic frame embedding one of the two verb phrases in a subject-relative clause. These results were interpreted as support for the hypothesis that Broca's aphasics suffer from a pathological limitation in the amount of syntactic processing resources that they can bring to the task of phrase-structure construction (cf. Frazier and Friederici, 1991; Friederici and Frazier, 1992). Furthermore, the occurrence in Broca's aphasics of an agreement effect in syntactically simple sentences seemed to contradict the findings of the syntactic priming experiment (suggesting slow activation, chapter 3), because this agreement effect was obtained under conditions that implied that syntactic activation must have been relatively fast. Fast syntactic activation was specifically suggested by the fact the agreement effect for simple sentences was obtained in spite of the fact that the monitoring target followed the critical syntactic frames containing the agreement violations almost immediately (i.e., on average after 229 ms) and in spite of the fact that the detection of the agreement violation required the analysis of a rather long sentence fragment consisting of 7 words. The results of a second word monitoring experiment suggested that Broca's aphasics suffer from a pathologically increased rate of syntactic decay because, contrary to normal controls, the same Broca's aphasics that had shown an agreement effect for syntactically simple sentences in experiment 1 no longer showed this agreement effect when the presentation of the monitoring target was experimentally delayed with 750 ms. Also, the finding that Broca's aphasics, contrary to normal controls, were under these conditions no longer sensitive to grammaticality violations in filler sentences suggested a pathologically increased rate of syntactic decay. The major question addressed in the discussion of the monitoring results (chapter 4) was how to reconcile the seemingly contradictory findings from the syntactic priming study (chapter 3), suggesting slow syntactic activation, with those from the monitoring study, suggesting normally rapid syntactic activation, and moreover, though not necessarily contradictory , fast syntactic decay. It was suggested that these contradictory findings could be reconciled within the framework provided by CC READER, that is, Just and Carpenter's (1992) recent activation-based model of parsing in normals. Specifically, it was suggested that the primary syntactic processing deficit of Broca's aphasics could be due to a capacity reduction or, alternatively in terms of the CC READER model, to a reduction in the total amount of activation available for propagation, determining the processing speed, and maintenance, determining the decay rate. Because both activation functions, that is, maintenance and propagation, are fed from the same pool of activation there exists, according to Just and Carpenter, the possibility of a trade-off between both functions where emphasizing one function will go at the expense of the other function. Consistent with these assumptions, it was proposed that in syntactic priming subjects try to strategically use contextual information (i.e., about syntatic appropriateness) in order to facilitate the lexical decision response and, accordingly, try to maintain this type of information going at the expense of propagation. The reduction in processing speed, which results when less activation is allocated to propagation, causes late syntactic priming. In a complementary fashion, it was proposed that the task requirements in word monitoring do not cause an emphasis on maintenance because contextual information (i.e., about syntactic appropriateness) does not help to predict the upcoming of a target, but rather cause an emphasis on processing speed because every next word is a potential target. Consequently, in word monitoring, a subject will allocate more activation to propagation, speeding up processing, at the expense of the maintenance function, causing rapid decay.

In chapter 5, the focus of attention is switched from Broca's aphasics' language reception to their language production. Broca's aphasics' agrammatic spontaneous speech output is often contrasted with Wernicke's aphasics' paragrammatic spontaneous speech output. Whereas Broca's aphasics tend to omit grammatical morphemes in the context of non-fluent, syntactically simple speech production, Wernicke's aphasics tend to substitute grammatical morphemes in the context of more fluent, syntactically complex speech production. Because of these qualitative differences, it is tempting to assume that Broca's and Wernicke's aphasics have a different underlying grammatical impairment. Kolk and colleagues (Heeschen, 1985; Kolk and van Grunsven, 1985; Kolk and Heeschen, 1992; Kolk et al., 1985), however, have suggested the possibility that agrammatism and paragrammatism might be the result of a different reaction to the same underlying grammatical impairment. Specifically, these researchers proposed that agrammatism in Broca's aphasics results from the strategic use of elliptical utterances that helps to reduce syntactic complexity and, hence, makes the corresponding syntactic representations less susceptible to a timing deficit. On the other hand, they have suggested that Wernicke's aphasics try to produce the same complex sentence constructions as these patients did pre-morbidly. Under such syntactically more demanding conditions, the timing deficit is more likely to result in the pre-mature disintegration of a sentence-representation causing it to be incomplete, so that paragrammatic substitutional errors and misconstructions might result. The same-grammatical-impairment hypothesis is supported by the finding that Broca's aphasics can be made to change their speech output from agrammatic to more paragrammatic under conditions, such as picture description (Heeschen, 1985; Hofstede, 1992), which force the subject to select more complex sentence frames. In chapter five, an experiment is reported that was designed as a direct test of the same-grammatical-impairment hypothesis. In order to counter the possibility of avoidance behavior, that is, in order to insure that all subjects have to construct the same underlying syntactic representation for each sentence, a CLOZE experiment was conducted which required Dutch Broca's and Wernicke's to speak aloud various types of free and bound grammatical morphemes that were missing from a sentence. The results provided support for the same-grammatical-impairment hypothesis in that the response profiles of Broca's and Wernicke's aphasics were very similar on both error and response time measures. In the discussion of the CLOZE data, Bison's (1990) recent model of paragrammatism is used to explain the obtained order of difficulty for bound morphemes. There are two characteristics of Bison's model that make it the production analogue of the theory of Broca's receptive syntactic processing that is advocated in this thesis, namely, (1) that errors arise as a consequence of a pathological change in the temporal availability of syntactic information, and (2) that the difficulty of a particular morpheme is dependent on the complexity of the syntactic context that this morpheme requires for its agreement computation.

In the 6th and final chapter, the main conclusions of the research reported in chapters 2 to 5 are reiterated. Furthermore, previously unmentioned methodological and theoretical implications for research on Broca's aphasia are discussed, as well as some of the limitations of the reported research in order to delineate new lines for future research. As far as the computer simulation model was concerned it is pointed out that it is especially the hierarchical nature of a phrase-structure representation which makes syntactic processing vulnerable to increases in retrieval time and decreases in memory time, in particular, when phrasal elements, that is, the elements most central to this representation are affected. Furthermore, the theoretical and methodological implications of the model's stochastic nature were addressed. And, finally, it was argued that future versions of the model should (1) include co-activation demands not only at the level of phrasal syntax itself, but also at the interface of this level with the semantic process of thematic-role assignment, and should (2) use a continuous

metaphor of activation in order to model syntactic complexity effects in a better way and in order to make predictions not only about the end-result of parsing but also about its on-line properties. The final chapter also provides a renewed discussion of the discrepant findings that were obtained in the syntactic priming (chapter 3) and monitoring study (chapter 4). Staying within the confines of Just and Carpenter's (1992) parsing model, it is argued that Broca's aphasics' syntactic processing deficit cannot only be explained in terms of a capacity based account, but also in terms of an efficiency based account. In an attempt to further refine Kolk and van Grunsven's notion of corrective adaptation, it is furthermore argued that patients can adapt in basically two ways to their receptive impairment by focussing their selective attention to word input, either on old, previously already activated input, or on new input. In syntactic priming, the first strategy, that is, selectively attending to old input enables the strategic use of contextual information at the expense of processing speed. In monitoring, the second strategy, that is, selectively attending to new input, speeds up processing but causes a faster decay of contextual information. Finally in chapter 6, the question of whether a common syntactic deficit underlies both Broca's agrammatic and Wernicke's paragrammatic language output is re-addressed.

In deze dissertatie staan de syntactische (d.w.z, zinsbouw) problemen van Broca's afatici centraal. De primaire doelstelling van het gerapporteerde onderzoek was om een door Kolk en collega's (Kolk en van Grunsven, 1985; Kolk et al., 1985; Kolk, 1987) voorgestelde theorie omtrent de oorzaak van deze problemen verder te ontwikkelen en voor het eerst direct te toetsen. Volgens deze theorie zijn de syntactische problemen van Broca's afatici het gevolg van een timing stoornis, die omschreven kan worden als een te trage opbouw en/of te snel verval (decay) van het activatienivo van zinsrepresentationele elementen.

In hoofdstuk 1 wordt het uitgevoerde onderzoek algemeen ingeleid. Een nadere omschrijving van het syndroom van Broca's afasie maakt duidelijk dat agrammatisme in de spontane spraak een van de voornaamste definierende kenmerken van deze vorm van afasie vormt. Er wordt op gewezen dat agrammatisme in de spontane spraak, gedefinieerd als een neiging van de patient om zich te uiten in syntactisch eenvoudige zinnen waaruit funktiewoorden en inflecties vaak zijn weggelaten, meestal samengaat met agrammatisch zinsbegrip. Broca's afatici blijken vaak problemen te hebben met zinsbegrip wanneer dit begrip cruciaal afhankelijk is van een correct gebruik van syntactische informatie. Na het syndroom van Broca's afasie ingeleid te hebben, worden de bevindingen van een reeks recente psycholinguistische studies besproken waaruit op een nogal eenduidige wijze blijkt dat de syntactische problemen van Broca's afatici niet zozeer het gevolg zijn van een verlies van syntactische kennis, als wel van een probleem in de verwerking van dit soort kennis. Vervolgens wordt de bovengenoemde theorie van Kolk en collega's besproken volgens welke de syntactische problemen van Broca's afatici het gevolg zijn van een timing stoornis. Dit gebeurt aan de hand van een theoretische kader dat aangeeft welke alternatieve manieren er zijn om de aard van de syntactische verwerkingsstoornis te beschrijven (i.e., het Hoe-aspect van de stoornis) alsmede het soort linguistische elementen waarop deze stoornis betrekking heeft (i.e., het Wat-aspect van de stoornis). Met betrekking tot het Hoe-aspect, worden drie metaforen genoemd die de syntactische verwerkingsproblemen van Broca's afatici achtereenvolgens aan een temporele, spatiele, of energetische rekenbeperking toeschrijven. Bovendien wordt opgemerkt dat er drie mogelijke kandidaat elementen bij een dergelijke verwerkingsstoornis betrokken zouden kunnen zijn, te weten, funktiewoorden, hogere-orde frasale informatie (i.e., informatie omtrent de categorie van constituenten), en zogenaamde 'traces', die het gevolg zijn van een constituent-verplaatsende transformatie. Na de beschrijving van het theoretische kader van het onderzoek volgt een bespreking van enkele recent uitgevoerde studies naar on-line verwerking bij Broca's afatici. Enerzijds blijken er studies te zijn die geen eenduidige conclusie toelaten met betrekking tot het hoe-aspect van de verwerkingsstoornis. Anderzijds blijken er studies te zijn. die een specifieke rekenbeperking suggereren, maar vanwege het gebruikte materiaal uiterst voorzichtig geinterpreteerd dienen te worden. Hoofdstuk 1 wordt afgesloten door een algemeen overzicht van het uitgevoerde onderzoek.

In hoofdstuk 2 wordt een computersimulatie van agrammatisch begrip bij Broca's afatici gerapporteerd. Deze computersimulatie werd uitgevoerd met een nieuw model, SYNCHRON genaamd, dat speciaal ontworpen werd om Kolk's theorie, volgens welke Broca's afasie het gevolg is van een timing stoornis in het activeren van zinsrepresentationele elementen, nader te formaliseren. Binnen dit model is activatiesnelheid geoperationaliseerd als de tijdsduur die nodig is om een syntactisch boomelement uit het geheugen op te halen (i.e., bepaald door een "ophaaltijd" parameter), terwijl decay snelheid geoperationaliseerd is als de tijdsduur gedurende welke een element beschikbaar blijft voor verdere syntactische verwerking, nadat het is opgehaald uit het geheugen (i.e., bepaald door een "geheugentijd" parameter). Gedemonstreerd wordt hoe zowel een selectieve toename in ophaaltijd als een selectieve afname in geheugentijd kunnen interfereren met de co-activatie van de dochtercategorieen van een syntactische frasale categorie en hoe beide temporele veranderingen daardoor de opbouw kunnen verhinderen van een complete zinsbouwrepresentatie, waarin de hierarchische relaties tussen de verschillende constituenten van een ingevoerde zin zijn specificeerd. Agrammatisch begrip wordt meestal getest door middel van zogenaamde "sentence-picture matching" taken waarin het subject bij een visueel of auditief gepresenteerde zin uit een reeks plaatjesalternatieven dat plaatje moet uitkiezen dat de betekenis van de zin weergeeft (i.e., het plaatje dat de juiste thematische rolrelaties aangeeft, bijv., vrouw = actor, man = thema). Een aanname van het model is dat tijdens sentence-picture matching met omkeerbare zinnen (i.e., zinnen waarvan het begrip cruciaal van een correcte syntactische analyse afhankelijk is) een incomplete zinsbouwrepresentatie het subject dwingt om het correcte plaatjesalternatief te raden, hetgeen mogelijkerwijs een begripsfout tot gevolg heeft. Het doel van de simulaties, die met het SYNCHRON model werden uitgevoerd, was om twee fundamentele kenmerken van agrammatisch zinsbegrip te simuleren, waarvoor nog geen formeel verklaringsmodel bestond, namelijk, ernstgraden in begrip (i.e., geindiceerd door tussen-subject verschillen in de percentages correct voor een bepaald zinstype) en het complexiteitseffect (i.e., het gegeven dat syntactisch complexe zinnen meer fouten oproepen dan syntactisch eenvoudigere zinnen). Om de bovenkans-presentatie van een enkele patient voor een gegeven zinstype te kunnen simuleren, werd de aanname gemaakt dat oftewel de ophaaltijd oftewel de geheugentijd stochastisch fluctueert binnen een patient en wel van moment tot moment. Ernstgraden kwamen overeen met verschillende toenames in de gemiddelde ophaal- of geheugentijd. De standaarddeviaties van beide temporele parameters werden daarbij constant gehouden. De data die gesimuleerd werden, waren afkomstig van twee sentence-picture matching studies met Broca's afatici. In beide studies werd eenzelfde effect van zinscomplexiteit gevonden, echter, op twee gemiddeld verschillende nivo's van prestatie. Met betrekking tot het Hoe-aspect van de verwerkingsstoornis werd aangenomen dat oftewel de ophaaltijd van bepaalde syntactische boomelementen selectief was toegenomen oftewel de geheugentijd ervan selectief was afgenomen. Met betrekking tot het Wat-aspect van de verwerkingsstoornis werd aangenomen dat oftewel de lexicaal-syntactische categorieen van funktiewoorden oftewel de frasale categorieen (i.e., de syntactische categorieen van zinsconstituenten, zoals naamwoordsgroep) door een van beide temporele veranderingen werden getroffen.

Uit de simulatieresultaten bleek dat de empirisch verkregen effecten van zinscomplexiteit en ernstgraden alleen gesimuleerd konden worden wanneer de timingstoornis betrekking had op frasale categorieen, maar niet wanneer ze betrekking had op funktiewoord categorieen. In het laatste geval werden geheel onverwachte, contraintuitieve simulatieresultaten verkregen. Deze onverwachte resultaten onderstrepen het nut van computersimulatie om de vaak onvoorspelbare implicaties van de temporele assumpties van een linguistische procestheorie door te rekenen. Wanneer frasale categorieen de getroffen elementen waren, dan bleek het voor de fit niet veel uit te maken of er sprake was van een toename in de ophaaltijd, of van een afname in de geheugentijd. In zoverre het gaat om het Wat-aspect van de verwerkingsstoornis, suggereren de simulatieresultaten dat de timingstoornis minimaal aangrijpt of zinsrepresentationele elementen op een syntactisch-structureel (i.e., frasaal) nivo. Verder, in zoverre het gaat om het Hoe-aspect van de verwerkingsstoornis, suggereren de simulatieresultaten dat bij Broca's afatici zowel sprake zou kunnen zijn van een te trage activatiesnelheid (i.e., toename in ophaaltijd), als van een te snelle decaysnelheid (i.e., afname in geheugentijd). Tijdens de discussie van de computersimulatie wordt ingegaan op de enigszins verschillende manieren waarop de temporele veranderingen in activatie- en decaysnelheid de opbouw van een frase-structuur representatie van de zin kunnen verstoren. Bovendien wordt erop gewezen dat, alhoewel de simulatieresultaten goed het empirisch verkregen patroon bleken na te bootsen, de invoer van meer complexe zinnen dan in de simulatie gebruikt werden (i.e., simpele actieve NP - V - NP zinnen, hun passieve tegenhangers, en locatieve NP V NP PP zinnen) een verandering zou vereisen in de door het model gehanteerde definitie van co-activatie. Meer specifiek wordt gesuggereerd dat toekomstige versies van het model de definitie van co-activatie zouden moeten veranderen, zodanig dat ze niet alleen de onmiddellijke dochtercategorieen van een frasale categorie omvat, maar tevens de categorieen op diepere nivo's, en bovendien zodanig dat de voortijdige afsluiting van een frasale categorie op basis van deel-voor-deel ontleding mogelijk wordt gemaakt. Verder werd gesuggereerd dat toekomstige versies van het model uit zouden moeten gaan van een meer complete beschrijving van frase-structuur representaties met co-activatie assumpties voor het soort van abstracte, gecoindexeerde frase-structuur elementen die door Government en Binding theorie zijn voorgesteld.

In hoofdstuk 3 wordt een syntactisch primingexperiment met Broca's afatici en normale proefpersonen gepresenteerd. Dit experiment was ontworpen om empirische evidentie te vinden voor de trage activate en/of snelle decay hypothese. De proefpersonen moesten een lexicale decisie (i.e., woord/nonwoord beslissing) geven op doelletterreeksen, die in de woordconditie oftewel een syntactische welgevormde oftewel een syntactische foutieve voortzetting vormden van een voorafgaand prime fragment dat uit twee woorden bestond. Zowel de reactietijden als de accuratesse werden gemeten. De kritieke manipulatie had betrekking op de "stimulus onset asynchrony" (SOA) tussen het visueel gepresenteerde prime fragment en de doelletterreeks. Het SOA was 300, 700 of 1100 ms lang. De voorspelling was dat het syntactische primingeffect (i.e., significant snellere reactietijden in de grammaticale dan in de niet-grammaticale conditie) in geval van trage syntactische activatie later (i.e., in termen van de grootte van het SOA) zou optreden in Broca's afatici dan in normale controle-proefpersonen, terwijl het syntactische primingeffect in geval van snelle syntactische decay eerder zou moeten verdwijnen in Broca's afatici dan in normale controle-proefpersonen. Een combinatie van beide priming patronen, namelijk, later optreden en eerder verdwijnen, werd verwacht in geval bij Broca's afatici sprake zou zijn van beide pathologische temporele veranderingen. De resultaten boden ondersteuning voor de trage activatiehypothese, terwijl ze de mogelijkheid van snelle decay open lieten. In tegenstelling tot normale controle-proefpersonen, die syntactische priming lieten zien voor alle drie de SOAs, lieten Broca's afatici alleen syntactische priming zien voor het grootste SOA van 1100 ms.

In hoofdstuk 4 wordt de theorie, volgens welke de syntactische problemen van Broca's afasie het gevolg zijn van een timingstoornis, verder getoetst door middel van een ander taakparadigma, namelijk identieke woordmonitoring. De proefpersonen, Broca's afatici en normale controle-proefpersonen, zagen op een beeldscherm een zelfstandig naamwoord en werden geinstrueerd om zo snel mogelijk op een knop te drukken wanneer ze dit doelwoord hoorden in de onmiddellijk erop volgende gesproken zin. In de kritieke zinnen werd het doelwoord voorafgegaan door een syntactisch fragment waarin al dan niet het grammaticaal subject en de persoonsvorm in getal met elkaar overeenkwamen (i.e., "subject-verb agreement" [congruentie] was wel of niet aanwezig). De on-line gevoeligheid voor deze congruentie schendingen werd bepaald door na te gaan of de monitoringtijden voor doelwoorden significant langer waren in de incongruente dan congruente conditie. De incongruentie tussen subject en persoonsvorm kon ingebed zijn in een simpel syntactisch fragment met een conjunctie van twee werkwoordsfrasen of in een complex syntactisch fragment waarin een van beide werkwoordsfrasen was ingebed in een subject-relatieve deelzin. De resultaten van een eerste experiment lieten zien dat Broca's afatici, in tegenstelling tot normale controles, alleen gevoelig waren voor subject-werkwoordsschendingen wanneer deze schendingen voorkwamen in het simpele syntactische fragment, maar niet wanneer deze schendingen voorkwamen in het complexe syntactische fragment. Deze resultaten werden geinterpreteerd ten gunste van de hypothese dat Broca's afatici bij het opbouwen van frase-structuur representaties gehinderd worden door een pathologische rekenbeperking (cf. Frazier en Friederici, 1991; Friederici en Frazier, 1992). Verder werd erop gewezen dat het optreden van een congruentie-effect voor Broca's afatici in syntactisch simpele zinnen strijdig leek te zijn met de resultaten van het syntactisch primingexperiment (dat trage activatie suggereerde, hoofdstuk 3), omdat dit congruentie-effect optrad onder condities die een relatief snelle syntactische activatie impliceerden. Snelle syntactische activatie werd met name geimpliceerd door het gegeven dat het congruentie-effect voor simpele zinnen optrad ondanks het feit dat het doelwoord vrijwel onmiddellijk (i.e., na gemiddeld 229 ms) volgde op het syntactisch fragment waarin de schending voorkwam en ondanks het feit dat voor de detectie van deze schending een syntactische analyse vereist was van een tamelijk lang zinsfragment dat uit 7 woorden bestond. De resultaten van een tweede woordmonitoringstudie suggereerden dat Broca's afatici leiden aan een pathologische toename in de snelheid van syntactische decay. Dit tweede experiment was geheel indentiek aan het eerste experiment met uitzondering van de timing van de presentatie van het targetwoord, die met 750 ms was uitgesteld. In tegenstelling tot normale controle-proefpersonen, vertoonden Broca's afatici onder deze omstandigheden geen congruentie-effect voor simpele zinnen meer. Snelle syntactische decay werd tevens gesuggereerd door de bevinding dat Broca's afatici in tegenstelling tot normale controle-proefpersonen onder deze condities niet langer gevoelig bleken voor de grammaticaliteitsschendingen in niet-kritische zinnen, die bedoeld waren als afleiders. Het hoofddoel van de algemene discussie van de monitoringresultaten was om een verklaring te vinden voor het schijnbaar tegenstrijdige karakter van de resultaten van het syntactische primingexperiment (hoofdstuk 3), dat trage syntactische activatie leek te suggereren, en de resultaten van de woordmonitoringstudie, die op een relatief snelle syntactische activatie leken te duiden, en bovendien, alhoewel niet noodzakelijkerwijs tegenstrijdig, op een pathologisch versnelde syntactische decay. De suggestie werd geopperd dat deze schijnbaar tegenstrijdige resultaten met elkaar verzoend konden worden binnen het theoretische kader van het CC READER model, een activatie-gedreven model van zinsontleding dat zeer recentelijk door Just en Carpenter (1992) is voorgesteld. Meer in het bijzonder, werd de suggestie gedaan dat de primaire syntactische verwerkingsstoornis van Broca's afatici beschreven zou kunnen worden in termen van een capaciteitsreductie of, equivalent, in termen van het CC READER model, als een reductie in de totale hoeveelheid activatie, die beschikbaar is voor "propagation" (bepaalt verwerkingssnelheid) en voor "maintenance" (bepaalt decay rate). Omdat beide activatiefunkties (i.e., propagation en maintenance) uit een-en-dezelfde activatiebron gevoed worden, bestaat er volgens Just en Carpenter de mogelijkheid van een trade-off tussen beide funkties, waarbij een nadruk op de ene funktie ten koste zal gaan van de effectiviteit van andere funktie. De trage activatie, die geobserveerd werd door Broca's afatici in het syntactisch primingexperiment werd toegeschreven aan de allocatie van relatief veel activatie aan maintenance en daardoor minder aan propagatie (i.e., de determinant van verwerkingssnelheid). De nadruk op maintenance in het syntactische primingexperiment zou het gevolg kunnen zijn van een strategie waarbij de proefpersonen proberen om contextuele informatie omtrent syntactische welgevormdheid (van de prime - target combinatie) te gebruiken ter facilitatie van hun lexicale decisierespons. Op een complementaire wijze werd gesuggereerd dat de taakomstandigheden in woordmonitoring geen nadruk op maintenance veroorzaken, omdat contextuele informatie (i.e. , over syntactische welgevormdheid) niet helpt om het verschijnen van een targetwoord te voorspellen. Er is in woordmonitoring waarschijnlijk eerder een nadruk op verwerkingssnelheid, omdat elk volgend woord een potentieele targetwoord is. Bij een dergelijke nadruk zal een proefpersoon relatief veel activatie alloceren aan de propagatiefunktie, hetgeen tenkoste gaat van de maintenancefunktie. Snellere verwerking, maar ook snellere decay van opgebouwde syntactische representaties zal dan het gevolg zijn.

Ging het in de hoofdstukken 2, 3, en 4 over de syntactische problemen van Broca's afatici in taalbegrip, in hoofdstuk 5 komt de taalproduktiecomponent aan bod. De agrammatische output in de spontane spraak van Broca's afatici wordt vaak gecontrasteerd met de paragrammatsiche output in de spontane spraak van Wernicke's afatici. Terwijl Broca's afatici de neiging hebben om grammaticale morfemen weg te laten in de context van een niet-vloeiende, syntactisch simpele taalproduktie, hebben Wernicke's afatici de neiging om grammaticale morfemen te substitueren in de context van een vloeiende, syntactisch vaak complexe taalproduktie. Vanwege deze kwalitatieve verschillen ligt het voor de hand om aan te nemen dat Broca's en Wernicke's afatici een verschillende onderliggende syntactische stoornis hebben. Kolk en collega's (Heeschen, 1985; Kolk en van Grunsven, 1985; Kolk en Heeschen, 1992; Kolk et al., 1985) hebben echter de mogelijkheid gesuggereerd dat agrammatisme en paragrammatisme het gevolg zouden kunnen zijn van een verschillende reactie op dezelfde onderliggende syntactische stoornis. Meer in het bijzonder, hebben deze onderzoekers gesuggereerd dat agrammatisme in Broca's afatici het gevolg is van een strategisch gebruik van ellipitische uitingen, dat de syntactische complexiteit helpt te reduceren, en, daardoor, de overeenkomstige syntactische representaties minder gevoelig maakt voor een timingstoornis. Wernicke's afatici daarentegen zouden dezelfde complexe zinnen proberen te produceren als pre-morbide het geval was. Daardoor zal een timingstoornis in veel gevallen een voortijdige disintegratie van de zinsrepresentatie tot gevolg hebben, waardoor deze incompleet is, zodat paragrammatische substitutiefouten en verkeerde constructies resulteren. De hypothese dat er van een en dezelfde syntactische stoornis sprake is wordt ondersteund door de bevinding dat men de spraakuitvoer van Broca's afatici van agrammatisch naar meer paragrammatisch kan doen veranderen onder condities, zoals plaatjesbeschrijving (Heeschen, 1985; Hofstede, 1992), die de patient dwingen om meer complexe syntactische frames te selecteren. In hoofdstuk 5 wordt een experiment gerapporteerd dat ontworpen was als een directe test voor de hypothese dat er van een en dezelfde syntactische stoornis sprake is. Om de mogelijkheid van vermijdingsgedrag tegen te gaan, dat wil zeggen, om er zoveel mogelijk voor te zorgen dat alle proefpersonen dezelfde syntactische representatie voor elke zin moeten construeren, werd een CLOZE taak gekozen. In deze taak moesten Broca's en Wernicke's afatici verschillende typen van vrije en gebonden grammaticale morfemen, die in een zin ontbraken, hardop uitspreken. De resultaten boden ondersteuning voor de hypothese dat er van een en dezelfde syntactische stoornis sprake is. Broca's en Wernicke's bleken vrijwel identieke responseprofielen te vertonen, zowel wat het aantal fouten als de responstijd betreft. In de discussie van de CLOZE data, wordt de verkregen moeilijkheidsvolgorde voor gebonden morfemen verklaard vanuit Bison's (1990) recente model van paragrammatisme. Er zijn twee eigenschappen van Bison's taalproduktiemodel, die het analoog maken aan de in deze dissertatie voorgestelde theorie voor de receptieve, syntactische verwerkingsproblemen van Broca's afatici. Ten eerste, fouten zijn het gevolg van een pathologische verandering in de temporele beschikbaarheid van syntactische informatie. Ten tweede, de moeilijkheid van een bepaald grammaticaal morfeem is afhankelijk van de complexiteit van de syntactische context, dat dit morfeem nodig heeft voor de berekening van congruentie tussen subject en persoonsvorm.

In het 6de en laatste hoofdstuk worden de voornaamste conclusies van het onderzoek, dat gerapporteerd werd in de hoofdstukken 2 tot en met 5, nog eens samengevat. Tevens worden nog niet eerder genoemde methodologische en theoretische implicaties voor onderzoek met Broca's afatici besproken, alsmede enkele beperkingen van het gerapporteerde onderzoek in een poging om richting te geven aan toekomstige studies. Voor wat het computersimulatiemodel betreft wordt benadrukt dat het met name de hierarchische aard van een frase-structuur representatie is, waardoor syntactische verwerking kwetsbaar is voor een toename in de ophaaltijd of een afname in de geheugentijd, vooral wanneer de meest centrale elementen van deze representatie (i.e., frasale categorieen) hierdoor getroffen worden. Verder wordt ingegaan op de methodologische en theoretische implicaties van het stochastische karakter van het model. En, tenslotte, wordt ervoor gepleit dat toekomstige versies van het model (1) co-activatie eisen moeten omvatten niet alleen op een puur syntactisch nivo, maar ook daar waar het syntactisch en semantisch nivo met elkaar communiceren en (2) een continue vorm van activatie moeten gebruiken om syntactische complexiteitseffecten beter te kunnen modelleren en om niet alleen voorspellingen te kunnen maken omtrent het eindprodukt van zinsontleding maar ook omtrent de on-line eigenschappen ervan. Het laatste hoofdstuk biedt tevens een hernieuwde discussie van de discrepante resultaten, die werden verkregen in de syntactische priming (hoofdstuk 3) en monitoring studie (hoofdstuk 4). Er wordt beargumenteerd dat binnen het theoretische kader van Just en Carpenter's (1992) model voor zinsontleding de syntactische verwerkingsstoornis van Broca's afatici niet alleen gespecificeerd kan worden in termen van een capaciteitsreductie, maar ook in termen van een efficiency reductie. In een poging om Kolk en van Grunsven's notie van correctieve adaptatie nader uit te werken, wordt bovendien beargumenteerd dat patienten zich op twee verschillende manieren aan hun receptieve syntactische stoornis kunnen aanpassen, namelijk, door hun selectieve aandacht voor woordinvoer oftewel op oude, reeds eerder geactiveerde invoer te richten, oftewel op nieuwe, niet eerder geactiveerde invoer. Wat syntactische priming betreft maakt de eerste strategie, namelijk, selectieve attentie voor oude input, het strategisch gebruik van contextuele informatie mogelijk en wel ten koste van de verwerkingssnelheid. Wat woordmonitoring betreft zorgt de tweede strategie, namelijk, selectieve attentie voor nieuwe input voor een snellere verwerking, maar daardoor wel snellere decay van contextuele informatie. Tenslotte, wordt geconcludeerd dat het effect van syntactische complexiteit op de produktie van een-en-hetzelfde grammaticale morfeem bestudeerd dient te worden in een toekomstige studie, zodat een verdere ondersteuning verkregen kan worden van de hypothese dat eenzelfde syntactische stoornis ten grondslag ligt aan de agrammatische en paragrammatische spraak van, respectievelijk, Broca's en Wernicke's afatici.

Curriculum Vitae

Hendrik Johan Haarmann werd geboren op 28 oktober 1961 te Kerkrade. Van 1974 tot 1980 volgde hij de gymnasium-B opleiding aan het Bernadinus College te Heerlen, waar hij cum laude zijn eindexamen behaalde. In september 1980 begon hij aan zijn Psychologie opleiding aan de K.U. Nijmegen. In augustus 1983 behaalde hij cum-laude zijn kandidaats-examen en in augustus 1987 behaalde hij met genoegen zijn doctoraal-examen met als hoofdrichting Cognitiewetenschap, en als bijvakken Informatica en Psychologische Funktieleer. Voor zijn afstudeerscriptie "A computer simulation of syntactic understanding in normals and aphasics: slow activity propagation" ontving hij van het NIP (Nederlands Instituut voor Psychologen) een eerste prijs in het kader van de scriptieprijsvraag 1988. Het in deze scriptie gerapporteerde onderzoek werd grotendeels verricht tijdens een buitenlandse stage van augustus 1985 tot september 1986 aan de Computer Science afdeling van de Universiteit van New Hampshire, in de V.S., onder begeleiding van Dr. H. Gigley. Tijdens zijn stage nam hij tevens deel aan de eerste Connectionist Models Summer School (1986) aan de Carnegie Mellon Universiteit, te Pittsburgh, Pennsylvania, V.S. onder begeleiding van de hoogleraren J. McCLelland, D. Rumelhart en G. Hinton. In verband met zijn buitenlandse stage ontving hij een Fulbright Graduate Grant van de NACEE (Netherlands American Commission for Educational Exchange) en een studiebeurs van I.B.M. Nederland N.V..

Na zijn afstuderen was hij van september 1987 tot januari 1992 verbonden aan het Max-Planck-Instituut voor de Psycholinguistiek te Nijmegen als mede-uitvoerder van het NWO-zwaartepuntproject "Aphasia in adults II." Meer specifiek was hij belast met de uitvoering van het deelproject "Adaptation to delay," dat door Dr. H. Kolk van het NICI (Nijmegen Institute for Cognition and Information, K.U. Nijmegen) was aangevraagd. Zijn dagelijkse werkzaamheden voerde hij onder diens leiding aan het NICI uit. Sinds mei 1992 is hij aan het NICI verbonden als ervaren onderzoeker en uitvoerder van het NWO-project "Automaticiteit van episodisch en semantisch geheugen." Dit project maakt deel uit van het PSYCHON aandachtsgebied "Activatie en Geheugen."

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PAPERS PRESENTED

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HAARMANN, H.J., & Kolk, H.H.J. Syntactic priming in Broca's aphasia: evidence for a timing disorder. *Academy of Aphasia*, Baltimore, Maryland (U.S.A.), October, 1990.

HAARMANN, H.J., & Kolk, H.H.J. The production of grammatical morphology in Broca's and Wernicke's aphasics: same underlying impairment? *Academy of Aphasia*, Rome, Italy, October, 1991.

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STELLINGEN
behorend bij het proefschrift
Agrammatic aphasia as a timing deficit
Henk J. Haarmann

1 Vertraging van syntactische activatie heeft niet alleen een verlangzamend, maar ook een verstorend effect op de zinsontleding. *Dit proefschrift.*

2 Een vertraging in postlexicale integratie, zoals Hagoort (1990) voor Broca's afatici veronderstelt, zal met name de opbouw van syntactische boomrepresentaties verstoren: dit vanwege de sterk hiërarchische opbouw van dergelijke representaties. *Dit proefschrift.*

Hagoort, P. (1990). *Tracking the time course of language understanding in aphasia.* Unpublished doctoral dissertation, University of Nijmegen, Nijmegen, The Netherlands.

3 Een linguïstische theorie voor tussen-zinsvariatie in agrammatisch begrip dient te worden aangevuld door een procesmodel dat de graduele aard van dergelijke variatie verklaart. *Dit proefschrift.*

4 Om tussen-proefpersoonvariatie in de effecten van zinstype op agrammatisch begrip toe te kunnen schrijven aan een kwalitatief verschil in de onderliggende stoornis, moet men uitsluiten dat dergelijke variatie niet het gevolg is van toevalsfluctuatie in de ernst van één en dezelfde stoornis. *Dit proefschrift.*

5 De afwijzing van groepsstudies met neuropsychologische patiënten, omdat deze aan funktioneel verschillende lesies kunnen lijden (Caramazza en Badecker, 1991), is voorbarig. Men kan immers niet a priori uitsluiten dat dergelijke patiënten op een bepaalde criteriumvariabele theoretisch interessant en overeenkomstig gedrag zullen vertonen.

Caramazza, A., & Badecker, W. (1991). Clinical syndromes are not god's gift to cognitive neuropsychology: A reply to a rebuttal to an answer to a response to the case against syndrome-based research. *Brain and Cognition, 16*, 211-227.

6 Computersimulatie vervult een belangrijke brugfunktie tussen theorie en experiment. De complexiteit van moderne cognitieve theorieën maakt het veelal onmogelijk de empirische consequenties ervan te doorzien zonder computersimulatie.

7 Het gevoel van verwondering dat gepaard gaat met een "Aha Erlebnis" is voor een belangrijk deel het gevolg van het onbewust doorlopen van de vele tussenliggende redeneerstappen waarvan zo'n beleving het gevolg is.

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