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Production of relative clauses: differences between normal and aphasic performance

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The commonly used Aachener Aphasie Test for the diagnosis of aphasia in German speaking subjects has deficits in distinguishing non-aphasic subjects from slightly impaired ones. Many of such patients classified as "Restaphasiker" or even as non-aphasics by the AAT may still have problems with more complex language material. Our paper will present a theoretical and empirical possibility to uncover impairments in grammatical encoding in the case of these complex tasks. To test the hypotheses derived from the language production model of Schade (Schade & Eikmeyer, 1998), we designed an experiment in which the subjects had to complete the beginning of a sentence containing a centre-embedded relative clause. In contrast to the sentences used by Bock and Miller (1991), our subjects had to replenish both the relative clause and the main clause. The results indicate that the group of aphasic subjects does indeed have considerably more difficulties in performing the task than the healthy controls. That means that the aphasic subjects gave significantly fewer correct answers than the healthy controls and made significantly more lexical and syntactical reproduction errors. Besides the effect of aphasia, the role of the relative pronoun led to significant differences in the syntactical reproduction condition.

Introduction

In Germany, the so-called Aachener Aphasie Test (AAT; Huber et al, 1983) is the standard and best evaluated diagnostic procedure to differentiate aphasic from non-aphasic subjects and to categorize different types of aphasia. Its results guide speech therapy in almost all hospitals and rehabilitation centres. However, subjects judged as so called "Restaphasiker" or even as non-aphasics by the AAT may still have severe problems in producing grammatically correct utterances if the task in question exceeds a certain level of complexity. The production of relative clauses is such a task.

In this paper, we will first discuss different accounts of modelling aphasic language production. We present approaches both on modelling impairments in lexical access and on modelling syntactic impairments (namely paragrammatism and agrammatism). A special focus will be laid on models of the local-connectionist paradigm in

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the tradition of Dell (1986) and in particular on our own implemented version of such a model (Schade & Eikmeyer, 1998). We will continue by describing how our model operates producing sentences with embedded relative clauses. This description as well as the discussion on modelling aphasic production allows for drawing hypotheses for the experiments we will introduce next. Finally, we will investigate the results of the experiments in order to derive some conclusions that might be interesting in the light of the aphasics' problems in the complex production tasks.

Modelling aphasic language production

It is still an open debate what exactly causes trouble in language production in aphasic subjects. Of course, this question can be tackled by examining language production models. These models can be impaired, and the results of the impairments on the production process can be compared with aphasic speech data. There are quite a lot of proposals trying to explain the (erroneous) process of phonological encoding in normal and impaired language production. The debate about the nature of lexical access between representatives of modular models on the one hand (e.g. Levelt, 1989) and those of interactive models on the other hand had produced a significant amount of new knowledge with respect to this process. It is necessary to initiate a similar competition with respect to the process of grammatical encoding. Interactive models have to be broadened in such a way that they can cover the process of grammatical encoding in order to become a serious competitor to modular models, e.g. those in the tradition of Kempen and Hoenkamp (1987; see also de Smedt, 1996). In our work, we will concentrate on a local-connectionist model in the tradition of Dell (1986), which is a subclass of interactive models. These kinds of models have prominently been put to good account if the mechanisms resulting in deficient speech, from slips of the tongue to aphasic utterances, had to be explained. In contrast, modular models have been studied prominently in order to explain the time courses of the subprocesses of language production.

Local-connectionist models are spreading activation models (McClelland & Rumelhart, 1981) in which every node represents one and only one item (Berg, 1988; Dell, 1986; Harley, 1984; MacKay, 1987; Schade, 1992; Stemberger, 1985). In language production models, these items are linguistic items like concepts, lemmata, word forms, and phonemes. Beside these content items, syntactical and structural information has to be represented, too. Thus, there are nodes for rules of different types (from sentence frames and phrasal structures to CV-patterns) and for syntactical features like singular and plural. There is almost no difference in the representation of the content items in the different versions of the local-connectionist models of language production (Berg, 1988; Dell, 1986; Harley, 1984; MacKay, 1987; Schade, 1992; Stemberger, 1985). However, there are considerable differences in the representation of the syntactical information that is guiding the sequentialisation of the content items during production (cf. Dell et al., 1997, for an overview).

In the following part, we will first address some general possibilities of modelling lexical and syntactic error patterns in aphasic speech in network structures. We will then present different approaches on modelling these error patterns (e.g. Butterworth & Howard, 1987; Harley, 1990; Kolk & Heeschen, 1992; Schade & Hielscher, 1998; Stemberger, 1984) and will proceed later to the local-connectionist model of Schade in order to discuss our proposals regarding the processes of grammatical encoding in complex structures.

In local-connectionist models, two general features could be identified which can account for most patterns of aphasic lexical access problems (Dell et al., 1997). These factors are a reduction of the activation flow and a too rapid decay of activation. The reduction of activation flow means that the access of items like lemmata, word forms or phonemes is delayed or even blocked. Thus, production becomes non-fluent and limited to the use of those items that are frequent enough to get activated at all. This is the typical production pattern of Broca's aphasia. Rapid decay means that activated items cannot stay activated long enough. If for example, a word form cannot stay activated during the production of its phonemes, the latter phonemes of the word will not receive activation from the word. This means that the ends of longer words are error-prone. Besides content items like lemmata, also syntactic and structural items can be activated insufficiently due to a low flow of activation. Additionally, rapid decay can also be used to model aphasic error patterns in syntax. Both impairments mentioned contribute to a simplification of the syntactic structures. First, due to a low flow of activation, syntactic items may not get enough activation to be produced. Accordingly, only highly frequent syntactic structures will be produced. Second, rapid decay lets longer sentences become more error-prone. A more detailed description of different accounts on modelling syntactic production patterns in aphasia will be given below. But before going into details, a short overview on syntactic impairments in aphasia will be given.

Syntactic impairments in aphasic subjects can generally be divided into two main groups, paragrammatism and agrammatism. Paragrammatism often can be noticed in Wernicke's aphasics. Its characteristic marks are substitution errors in inflections and function words as well as sentence blends (Butterworth & Howard, 1987). Agrammatism is part of Broca's aphasia. Its marks are deletions of inflections and function words as well as a reduction of production to simple utterances in a telegraphic style (Berndt, 1990).

Using the local-connectionist paradigm, Harley (1990) describes paragrammatism as impaired lateral inhibition within the levels representing syntactical items like sentence frames, inflections, and function words. Impaired lateral inhibition means less competition among items. The target item cannot inhibit its competitors sufficiently. Thus, competitors often find their way into production and incorrect inflections and function words cumulate within the utterance. Even worse, several sentence frames can become activated in parallel, which results in sentence blends that are typical for paragrammatism. Agrammatism can be modelled by falling back to the general impairments proposed and discussed by Dell et al. (1997). If activation flow is low, not only content items may be activated insufficiently but also syntactic items. Thus, they may get too little

activation to be produced. As a result they are deleted from production. Rapid decay can contribute to an agrammatic production style, too. If syntactic information cannot stay activated long enough, speakers have to produce simple sentences in order to avoid syntactical errors. For example, the production of a relative clause modifying a subject is risky since the information about the subject's number has to maintain until the verb is to be produced. Indeed, Stemberger (1984) had explained agrammatism already along this line. Besides, he argues that frequency is an important factor in explaining agrammatic production. The more frequent an item is the higher is its specific resting level (the amount of activation an item has if it is not part of the production at all). Thus, frequent items can be produced quite easily, but infrequent items suffer from the broad gap between resting level and selection threshold that cannot be closed by an insufficiently low activation flow.

There is, however, another possibility for modelling agrammatism that might be more suitable for at least some subjects. Kolk and Heeschen (1992) presume only one underlying disorder causing both paragrammatism and agrammatism. While subjects with paragrammatically impaired language also suffer from an impaired monitor and thus fail in realizing their errors, agrammatical subjects are judged to have a functioning monitor. This implies that agrammatic subjects realize their errors. According to Kolk and Heeschen, their attempts to avoid errors lead to a compensatory strategy: They switch to elliptic utterances. Combining the theory of Kolk and Heeschen with Harley's explanation of paragrammatism and Stemberger's idea of representing frequency by resting levels, agrammatism can be modelled as originating from reduced lateral inhibition among syntactic items like paragrammatism. However, since frequency means the frequency of correct productions, the system adapts itself if the monitor still functions. On the one side, the resting levels for elliptic style utterances increases since these are relatively often produced correctly. On the other side, the resting levels for complex utterances decrease since these are highly error-prone (Schade & Hielscher, 1998).

The theoretical background

The proposed accounts for paragrammatism and agrammatism within the local-connectionist paradigm have been offered although local-connectionist models of lan-

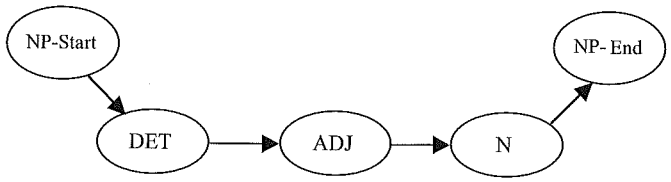

Figure 1. Example for a control chain: a noun phrase is built up by a determiner (DET), an adjective (ADJ), and a noun (N).

guage production have yet not tackled the issue of grammatical encoding. In order to overcome these deficits, we developed mechanisms for sequentialisation (Eikmeyer & Schade, 1991) to be integrated in our own version of a local-connectionist production model. This had been tested in the limited domain of noun phrase production providing some insights to the problems of word order, especially the order of adjectives (Schade & Eikmeyer, 1998). In order to offer a model that can produce even some complex sentences, we upgraded the model. It now can produce sentences with relative clauses embedded. The model consists of four functionally separable subnetworks: the phonological encoding space, the feature space, the object space and the control space. The activation flow is downwards and there is lateral inhibition on all levels. The centre of attention with respect to the problems discussed above is the control space. There, the sequentialisation of utterances is managed. Furthermore, the control space yields information about what exactly happens to agreement information causing errors like those we have found in our experiment (see the description of the experiment). The representation of a message in the object space activates a sentence structure. There are chains of nodes representing these structures. For instance, one chain representing a noun phrase structure is built up of three nodes: The first node represents the class of determiners, the second one the class of adjectives, and the last one the class of nouns. Of course, there are much more chains for constructing noun phrases which represent other appropriate structures. If the chain just mentioned gets activated, the determiner node sends activation to all word forms belonging to the class of determiners, while the node representing the adjective class activates all adjectives, and the node representing the noun class activates all nouns. There must be additional activation flowing downwards from the conceptual space to guarantee that it is the target determiner, the target adjective and the target noun that gets more activation in comparison to other members of the respective class such that the target words will be produced. When the first node of a chain is selected it sends its activation to the next one in the chain and inhibits itself. In this way the correct word order is ensured.

Relative clauses

Relative clauses can be considered as modifiers to nouns. Therefore, in some chains controlling noun phrase production, activation can spread to a control node responsible for initiating the production of a relative clause. However, by the time of the production of the relative clause, the production of the superordinated noun phrase is not completed. This might raise problems, as the relative clause may contain noun phrases by itself. The production of these noun phrases requires the usage of the noun phrase control chains. Unimpaired subjects manage sentences of this kind without difficulties as long as there is only one relative clause embedded. Aphasics might have problems, because the superordinated noun phrase has to be remembered in order to continue the main sentence after finishing the relative clause; rapid decay may have terminated the

information. If the noun to be modified by the relative clause is the subject of the main sentence, its number has to be preserved during the production of the noun phrase as well. The number information is needed to ensure agreement between subject and verb.

The experimental background

The experimental background of our work is inspired by a paradigm introduced by Bock and Miller who examined processes underlying number agreement in language production (Bock & Miller, 1991). In their experiment, Bock and Miller presented sentence beginnings in which a nominal postmodifier was embedded. This modifier could either be a relative clause or a prepositional phrase. The subjects' task was to complete the main clause. The nouns of both the main clause (the head noun) and the postmodifier (the local noun) were varied with regard to their syntactic number. Thus, every sentence occurred in either a match (e.g. "The boy that liked the snake") or a mismatch condition (e.g. "The boy that liked the snakes"). Besides, the length of the nominal postmodifier was varied (e.g. "The boy that liked the snakes" vs. "The boy that liked the colourful garter snakes"). The results showed that the length of the postmodifiers did not affect the frequency of agreement errors. Errors were most likely to occur in the number mismatch condition in which the head noun was singular and the local noun plural. This led us to the assumption that in a similar sentence completion task, subjects would presumably make errors in number agreement.

Hypotheses

Our version of the local-connectionist production model offers perspicuous hypotheses regarding the performance of aphasic subjects in tasks that demand reliable functioning of grammatical encoding processes. The frequency of number agreement errors as examined by Bock and Miller should rise because the information ensuring agreement is endangered by rapid decay. Indeed, we assume a general statistical difference in the quantity of errors between the aphasics and the controls. We also predict their appearance under all experimental conditions. Next, since aphasic subjects are supposed to suffer from reduced activation flow and rapid decay, we expect them to prematurely abort the sentence production process statistically more often than the control subjects. This will lead to abortions and to omissions of parts of the sentence completion. Additionally, for reasons of frequency (Fox & Thompson, 1990), we assume the aphasics to change relative clauses in which the pronoun is the object of the relative clause into sentences in which the pronoun is the subject of the relative clause. Finally, we expect differences in the performance of paragrammatic and agrammatic subjects. Paragrammatic subjects will abort the production process more often and additionally produce more sentence blendings, because the supposed decrease of lateral inhibition and the malfunctioning of the monitor allow switching

among control chains, which represent the structures. Agrammatic subjects are assumed to show a larger effect of frequency (i.e. raised resting levels), as explained above. Therefore, agrammatic subjects should prefer relative clauses in which the relative pronoun is the subject of the clause (if they produce relative clauses at all).

The experiment - material and method

To test our hypotheses, we designed an experiment similar to the one described above. Our subjects' task was to complete the beginning of a sentence containing a centre-embedded relative clause. In contrast to the sentences used by Bock and Miller, our subjects had to replenish both the relative clause and the main clause. The sentence beginnings we presented were as the following:
"Der großzügige Sponsor, den der bekannte Rennfahrer..."
("The generous sponsor whom the famous race driver...")

The material was varied with regard to the syntactic number of both NPs (in the example above the sponsor and the race driver) and the grammatical role of the relative pronoun that was either the subject or the object of the relative clause. In German, the verb closes subclasses, so subject relative clauses and object relative clauses look quite similar. In the experiment, every sentence occurred in one of eight possible variations (see Table 1).

Eight sets of 24 sentence beginnings were generated in which each condition of the eight was realised three times. The sentence beginnings were presented auditorily and the subjects' task was to repeat and complete them. Before starting with the

Table 1. The material was varied concerning the syntactic number of the noun phrases and the grammatical role of the relative pronoun.

	Role of the relative pronoun	
Number condition	Subject relative clause	Object relative clause
Main clause singular – relative clause singular	Der großzügige Sponsor, der den bekannten Rennfahrer... *The generous sponsor who the famous race driver...*	Der großzügige Sponsor, den der bekannte Rennfahrer... *The generous sponsor whom the famous race driver...*
Main clause singular – relative clause plural	Der großzügige Sponsor, der die bekannten Rennfahrer... *The generous sponsor who the famous race drivers...*	Der großzügige Sponsor, den die bekannten Rennfahrer... *The generous sponsor whom the famous race drivers...*
Main clause plural – relative clause singular	Die großzügigen Sponsoren, die den bekannten Rennfahrer... *The generous sponsors who the famous race driver...*	Die großzügigen Sponsoren, die der bekannte Rennfahrer... *The generous sponsors whom the famous race driver...*
Main clause plural – relative clause plural	Die großzügigen Sponsoren, die die bekannten Rennfahrer... *The generous sponsors who the famous race drivers...*	Die großzügigen Sponsoren, die die bekannten Rennfahrer... *The generous sponsors whom the famous race drivers...*

main task, a speaking span test was administered. Furthermore, subjects performed some practice trials in order to get used to the task. We examined two groups of German speaking subjects. The test group were 16 aphasics that performed well on the AAT, such as e.g. "Restaphasiker". The control group consisted of 24 healthy older persons. The data of five of the 16 aphasics could not be analysed, because the task turned out to be much too difficult for them. The test group therefore was reduced to one Wernicke Aphasic, six Anomic Aphasics, and four 'Residual Aphasics'. The utterances of the subjects were tape-recorded and classified with respect to the following categories: (0) correct answers; (1) lexical reproduction errors, such as semantic paraphrases; (2) syntactic reproduction errors, such as use of a wrong pronoun; (3) omissions, such as a missing completion of either the main or the relative clause; (4) errors in number agreement; (5) errors in case agreement; (6) abortions, (7) repairs, and (8) nearly correct answers, i.e. sentences in which the subject made an error in reproduction but completed this structure correctly.

Results

The data were examined by means of analyses of variance.

In a first run, we compared the data of the aphasics as one group with the healthy controls and in a second analysis compared every aphasic group (according to the respective syndrome) with each other and the healthy controls. The results of this second analysis will not be reported here, because it would extend the scope of this paper. For similar reasons, we restricted ourselves to report only the most important data. The re-

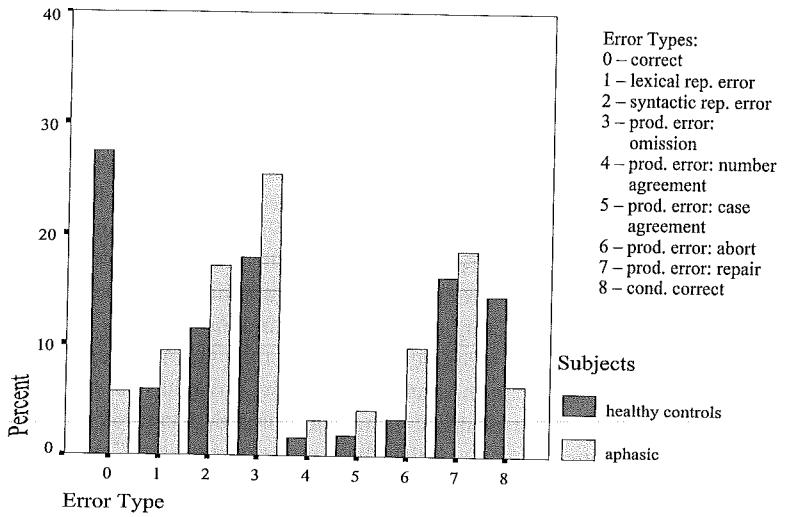

Figure 2. The proportion of error types comparing the data of the aphasic and the healthy control subjects.

sults of our first analysis indicate that the group of aphasic subjects does indeed have considerably more difficulties in performing the task than the healthy controls.

With two exceptions - both groups showed hardly any variations in the amount of repairs they made and in their performance regarding number agreement - these differences reached significance. That means in detail that the aphasic subjects gave significantly fewer correct answers than the healthy controls [$F(3,89) = 48{,}219$; $p = .000$] and made significantly more lexical [$F(3,89) = 6{,}323$; $p = .013$] and syntactical reproduction errors [$F(3,89) = 16{,}467$; $p = .000$]. Besides the effect of aphasia, the role of the relative pronoun led to significant differences in the syntactical reproduction condition. Both groups made more syntactical reproduction errors when the relative pronoun was the object of the relative clause [$F(3,89) = 40{,}500$; $p = .000$]. Furthermore, the aphasic subjects omitted significantly more sentence fragments (in any of the mentioned possibilities) [$F(3,89) = 11{,}308$; $p = .001$]. Also significant were the differences concerning abortions [$F(3,89) = 21{,}665$; $p = .000$]. In addition to that, the aphasics gave significantly less conditionally correct answers [$F(3,89) = 16{,}192$; $p=.000$]. With regard to number agreement, the aphasic subjects surprisingly did not perform statistically different from the healthy controls. Nonetheless, the analyses yielded a significant effect of number mismatch, with more number agreement errors in the number-mismatching than in the -matching condition [$F(3,89) = 12{,}324$; $p = .001$].

Discussion

We attribute the increased rate of lexical reproduction errors shown by the aphasics to accumulated semantic paraphasias. This would suggest that in a second analysis among the different aphasic syndromes, Wernicke's (and possibly Anomic) aphasics should statistically differ from the others with regard to lexical reproduction errors. The syntactic reproduction errors can be explained twofold. First, they may reflect frequency effects. Sentence structures in which the relative pronoun is the subject of the relative clause are more frequent than those in which they are object of the relative clause. Our model postulates that it is easier to produce a more frequent structure. Thus, the infrequent structures, e.g. the one having the pronoun as an object, might be substituted by the more frequent ones, e.g. the one in which the pronoun is subject. As a result, a syntactic reproduction error occurs. Indeed, the syntactic errors show the shift from pronouns acting as objects to pronouns acting as subjects, as is proposed by this explanation. A second explanation for the syntactic reproduction errors can be seen in a simplification strategy applied by the aphasics. In these cases, the sentence beginnings were changed from subordinate structures to coordinate structures (e.g. "The generous sponsor that the famous race driver..." was changed to "The generous sponsor and the famous race driver...").

With regard to the effects of frequency, it would be interesting to compare the data of the agrammatic and the paragrammatic aphasics. Unfortunately, the task requirements were beyond the agrammatics' abilities so that we had to discard their data from

the analysis. The observed omissions can be explained by the decreased flow of activation and the rapid decay. Thus, information (e.g. syntactic information in the respective levels) cannot be held up long enough, and is therefore not available any more when it is needed for the completion of the sentence. There were, however, no statistical differences in the amount of number agreement errors between the aphasics and the controls. This might be attributed to the small amount of agreement errors we observed, which did not allow significant results to show up. A second explanation lies in an assumed tendency of the aphasics to change mismatching sentences into matching sentences. This kind of error is classified as a syntactical reproduction error which indeed were produced significantly more often by aphasics than by controls.

Conclusion

Our intention was to investigate a theoretically founded possibility to uncover impairments in grammatical encoding in aphasic subjects with slightest impairments. Our version of the local-connectionist production model predicted that the production of relative clauses is especially well suited to highlight the impairments that still restrict the language use of the patients. Indeed, the sentence completion task we presented confronted the aphasics with problems that one would not expect from their very good performance in the AAT.

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Nederlandse samenvatting

De Akense Afasie Test schiet tekort in het onderscheiden tussen niet-afatische personen en personen met een lichte afasie. Veel van dergelijke patiënten, geclassificeerd als 'Restafasie' of zelfs als niet-afatisch, kunnen met meer complexe taal nog altijd problemen hebben. In dit artikel wordt een theoretische en empirische mogelijkheid gepresenteerd om bij dergelijke taken stoornissen te ontdekken in de grammaticale encodering. Om hypotheses afgeleid van het taalproductiemodel van Schade (Schade & Eikmeyer, 1998) te kunnen toetsen, ontwierpen wij een experiment waarin de proefpersonen het begin moesten aanvullen van een zin waarbij in het midden van de

zin een relatieve bijzin voorkwam. In tegenstelling tot de zinnen gebruikt door Bock en Miller (1991) moesten onze proefpersonen zowel de hoofdzin als de bijzin aanvullen. De resultaten geven aan dat de groep afasiepatiënten inderdaad aanzienlijk meer problemen hebben in het uitvoeren van de taak dan gezonde proefpersonen. Dat betekent dat de afatische proefpersonen minder correcte antwoorden gaven dan de gezonde personen uit de controlegroep en meer lexicale en syntactische fouten maakten. Niet alleen het effect van de afasie, ook de rol van het betrekkelijke voornaamwoord leidde tot verschillen bij de syntactische weergave van de zin.

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