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Brain and Language 86 (2003) 23–39
Brain and Language
www.elsevier.com/locate/b&l

Sentence comprehension and working memory limitation in aphasia: A dissociation between semantic-syntactic and phonological reactivation

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Accepted 23 July 2002

Abstract

The relation between working memory (WM) limitation and sentence comprehension was assessed in Hebrew-speaking aphasics, three conduction aphasics and three agrammatics. The study compared sentences that required different types of reactivation—syntactic-semantic reactivation, in relative clauses, and word form/phonological reactivation, in sentences with reanalysis of lexical ambiguity. The effect of phonological memory load, manipulated by number of words intervening between the activation and the reactivation, on comprehension of the two sentence types was examined. The findings were that agrammatic aphasics failed in the comprehension of object relatives but not on subject relatives irrespective of their antecedent–gap distance. Conduction aphasics, on the other hand, who showed severe WM limitation, comprehended well all types of relative clauses and were unaffected by antecedent–gap distance. The conduction aphasics failed to understand the sentences that required phonological reactivation when the phonological distance was long. These results suggest that the type of reactivation required by the sentence, as well as the type of memory overload are crucial in determining the effect of WM limitation on sentence comprehension.

Keywords: Language; Memory; Syntax; Working memory; Hebrew; Sentence comprehension; Aphasia; Agrammatism; Conduction aphasia

In the course of sentence comprehension, the listener is required to remember previous words and to relate previous words to other words in the sentence. Thus, on the intuitive level, it seems clear that some form of memory is needed for sentence comprehension. However, the nature of the relation between memory and sentence comprehension, though under extensive study in recent years, is still controversial and needs to be fully specified. The current study explored the nature of this relation

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doi:10.1016/S0093-934X(02)00530-8

between verbal Working Memory (WM) and sentence comprehension in individuals with aphasia, comparing two very specific structures that each requires a different type of language processing.

The main controversies in the field apply to whether a deficit in WM necessarily leads to a deficit in language understanding, and whether WM for language is a single resource that serves different language processes (as claimed by, for example, Just & Carpenter, 1992; King & Just, 1991; MacDonald, Just, & Carpenter, 1992; Miyake, Carpenter, & Just, 1994; Pearlmutter & MacDonald, 1995), or rather a resource that comprises multiple resources, each used for a different type of linguistic information (see Caplan & Waters, 1999 for a review; Martin, Shelton, & Yaffee, 1994; Waters, Caplan, & Hildebrandt, 1991; Withaar & Stowe, 1999).

Most studies on normal processing (King & Just, 1991; Miyake et al., 1994), normal aging (Zurif, Swinney, Prather, Wingfield, & Brownell, 1995), and aphasic patients (Martin & Feher, 1990; Martin et al., 1994; Smith & Geva, 2000 for a review; Waters et al., 1991; Wilson & Baddeley, 1993[1]) generally show that a deficit or limitation in WM leads to a deficit in language comprehension only when the sentences are complex in some respect. These studies crucially differ, however, with regard to their definition and manipulation of complexity—in terms of syntax, semantics or sentence length. Studies that focus on syntactic complexity tested mainly the comprehension of passives, object relatives, and garden-path sentences. Many of these studies found no impairment in comprehension in the presence of limited WM capacity (see Caplan & Waters, 1999 for a review; Butterworth, Campbell, & Howard, 1986; Butterworth, Shallice, & Watson, 1990; Martin & Feher, 1990; Waters & Caplan, 1996; Waters et al., 1991). Other studies used tasks such as the token test that mainly burden WM capacity with many lexical items (processing of this type was termed "post-interpretive" by Caplan & Waters (1999)). Some of these studies report a strong relationship between memory span and extracting of semantic information (Martin & Feher, 1990; Martin et al., 1994; Vallar & Baddeley, 1984; Waters et al., 1991; see also Smith & Geva, 2000, and Caplan & Waters, 1999 for reviews). Furthermore, a double dissociation has been reported between syntactic-semantic memory deficit and a deficit in phonological memory (Martin et al., 1994). It thus seems that different types of processing can be differentially affected by WM, and that the type of processing plays a crucial role in determining the effect WM has on comprehension.

In this study we compare two types of processing required during sentence comprehension: syntactic-semantic reactivation and word-form (phonological) reactivation. We use the same manipulation in both sentence types—loading phonological WM by increasing the number of words (and syllables) between a word and the position of its reactivation. We evaluate the contribution of working memory limitation to the deficit in sentence comprehension in two aphasic populations: Broca's agrammatic aphasics and conduction aphasics.

These types of aphasia were chosen because both are frequently coupled with working memory deficits (Belleville, Peretz, & Arguin, 1992; Martin & Feher, 1990; Saffran & Marin, 1975; Shallice, 1988; Shallice & Vallar, 1990; Smith & Geva, 2000), and specifically because conduction aphasia is frequently identified with a deficit in the phonological component of WM, and because the agrammatic deficit in relative clause comprehension was attributed by some researchers to working memory limitations (King & Just, 1991; Miyake et al., 1994), notably to the distance between the

[1] Wilson and Baddeley's conclusion is based on association of two deficits and association in recovery, which might have other plausible explanations in addition to their common mechanism explanation.

antecedent and the gap which is longer, for example, in object relatives (Frazier & Friederici, 1991).

Thus, we study the interaction between type of aphasia (and type of WM limitation) and type of reactivation required during sentence comprehension, using phonological and syntactic manipulations.

Syntactic-semantic reactivation was studied using relative clauses. Relative clauses such as "*I met the girl that grandma drew_*" include a constituent ("the girl") that is reactivated at the position of the gap (after "drew") (Nicol & Swinney, 1989; Swinney, Ford, Frauenfelder, & Bresnan, 1988; Swinney, Shapiro, & Love, in press). Love and Swinney (1996) have shown that this reactivation at the gap is semantic rather than phonological in nature. Namely, it is the meaning of the word rather than its word form that is reactivated. The position of this semantic reactivation is guided by syntactic processing, and we therefore call this reactivation "syntactic-semantic." For Broca's agrammatic aphasics it has long been known that relative clauses are selectively impaired in comprehension: Subject relatives (see example 1) are understood at a level above guessing rate, but object relatives (example 2) are understood at chance level (Caramazza & Zurif, 1976; Friedmann & Shapiro, in press; Grodzinsky, 1989; see Grodzinsky, Piñango, Zurif, & Drai, 1999 for a review).

1. Subject relative: This is the $woman_i$ **that** t_i hugs the girl
2. Object relative: This is the $woman_i$ **that the girl hugs** t_i

Accounts for this difference concentrate on the syntactic difference between these two structures, on the position of the NP arguments and the positions at which they receive their thematic roles. These accounts generally put the blame for the impaired comprehension of object relatives on the movement of the object to a non-canonical position before the subject (see for example Grodzinsky, 1990, 2000a).

However, beside this structural difference, subject and object relatives also differ in the number of words between the antecedent (the moved constituent) and the gap (Gap–Antecedent Distance, GAD). In the subject relative construction (1) the GAD is only one-word long ("that"); in the object relative (2), the GAD is larger, 4-word ("that the girl hugs"), as it contains, in addition to the complementizer "that," also the subject and the verb of the embedded clause.

In Experiment 1, our aim is twofold: first, we seek to isolate the effect of the distance between the antecedent and the gap on the one hand, from the effect of the structural difference between subject and object relatives on the other, by comparing subject and object relatives that have the same GAD, i.e., the same distance between the antecedent and the gap. Secondly, we examine the effect of increasing the GAD on relative clause comprehension in both object and subject relatives.

Phonological reactivation was examined in structures that contain a temporary lexical ambiguity. The lexical ambiguity was positioned in a strong biasing context towards one of the meanings, but got disambiguated at a later point in the sentence toward a different meaning in a way that required reanalysis.

We assume, based on Swinney (1979), Love and Swinney (1996), and Onifer and Swinney's (1981) findings, that immediately after the lexically ambiguous word, all meanings of the ambiguous word are activated. As the sentence unfolds, only the meaning that seems relevant to the biasing context remains activated, and the other apparently irrelevant meanings decay.

Our sentences required reactivation of a meaning at the disambiguation position that is different from the one that was initially chosen. The relevant question in the current work concerns the nature of this reactivation. Semantic reactivation of the meaning that was initially (incorrectly) chosen cannot suffice, and therefore we suggest that the reactivation that is required for the reanalysis is the reactivation of the *form* of the original, ambiguous word—in order to re-access all possible meanings—and cannot, therefore, be semantic only.

In experiment 2 we manipulated the distance between the ambiguous word and the reanalysis position. Reanalysis occurred either shortly after the ambiguous word (2–3 words distance) or after a longer (7–9 word) distance. Similarly to the relative clause condition, the increase of activation–reactivation distance was introduced in order to overload the phonological component of the WM.

Below, information about the participants in all the experiments is presented, followed by the method and results of the experimental examination of working memory, and the two experiments that tested syntactic and phonological reactivation in sentence comprehension tasks.

Participants

Six Hebrew-speaking aphasics—three agrammatic aphasics and three conduction aphasics, and six controls without language impairment participated in the study. All participants were right handed and native speakers of Hebrew. The agrammatic group included two women (HY, GR) and one man (AL). Their mean age was 27 years (range 19–31); mean educational level was 12.2 years (range 11–15); and mean time post onset was 2.5 years (range 1.5–4). The conduction aphasics were three men (GM, AF, IC), with mean age of 35 years (range 25–50); all had 12 years of education, and mean time post onset was 3.8 years (range 3.5–4). Two agrammatic patients (HY, GR) suffered from aphasia secondary to cerebrovascular accident; four patients suffered from aphasia following traumatic brain injury. All had a single lesion in the left cerebral hemisphere. The patients were classified using the Hebrew version of the Western Aphasia Battery (WAB, Kertesz, 1982; Hebrew version by Soroker, 1997). All participants in the control group had no history of neurological disease or developmental language disorders. Mean age of control subjects was 39 years (range 25–49); mean educational level was 15 years (range 12–17).

Working memory evaluation

In order to assess working memory limitation and in order to see which memory task, if any, correlated with sentence comprehension, we devised an extensive battery of working memory tests. Both recall and recognition tasks were tested.

Method

Digit span. Sequences of digits were presented orally. The participants were asked to point in the correct order to digits on a written 1–9 digit list. The test comprised 8 levels (2–9 digit sequences), 7 sequences each. Span was defined as the maximum level at which at least 3 sequences out of 7 were fully recognized. Success in 2 out of 7 sequences was scored as an additional half point. Digits were spoken at a 1 per second rate.

Word span. Sequences of unrelated words were presented orally. In order to assess phonological similarity and length effects, word lists that contained phonologically similar and dissimilar words were compared, as well as 2- and 4-syllable word lists.

Non-word span. A list of 2-syllable non-words was constructed by changing a single letter in real words.

Word- and non-word lists were presented orally at 1 per second rate and verbal recall was requested. All tests included 6 levels (2–7 word/non-word sequences), 5 sequences each. Span was defined as the maximum level at which at least 3 sequences per level were fully recalled; an additional half point was given for success in 2 out of 5 sequences.

Listening span. A version of the listening span task (Caspari, Parkinson, LaPointe, & Katz, 1998; Daneman & Carpenter, 1980; Tompkins, Bloise, Timko, & Baumgaertner, 1994) was created for Hebrew-speaking aphasics. The test was composed of five levels (2–6 sentences per set) each containing five sets. Sentences were controlled for length in words and syllables, for word frequency and for number of correct and incorrect sentences in each level. The participants were requested to make true/false judgments to each sentence in increasingly larger sets of unrelated sentences, and to remember the final word in each sentence after the whole set was read. Span was defined as the highest level at which at least three out of five sets of sentences resulted in full recognition of the final words; success in two out of five sets was scored as an additional half a point. Recognition of the final words was assessed by pointing to the words in a set of $2n + 1$ presented words; all the foils were dissimilar to the target words both semantically and phonologically. Prior to the listening span task, each participant was trained in true/false decision, final word retention, and the combination of the two.

Recognition span. The exact same sets of words that were used in the listening span test were also used without a preceding sentence (and without intervening delays between words), in a simple word recognition task, with the same foils.

N-back. In the 2-back task (Awh et al., 1996; Smith & Jonides, 1997) the participants had to judge whether the item presented was the same as the item before the last. The lists were presented auditorily. Three types of lists were used: digits, short animal names, and long animal names. Each list included 99 items. Each list was tested twice: once with 1-s SOA, and once with SOA of 3 s.

Results

Normal control group

For the control group, the average digit span was 7.25 (range 6.5–9). The word spans were affected by phonological similarity: average span for phonologically dissimilar list was 5.8 words (range 5–6.5); the span for phonologically similar lists was 5 words for all participants (significant difference using Wilcoxon, $T = 0$, $p = .031$). Word length also affected the span: 2-syllable words yielded an average span of 5.8 words (range 5–6.5) and 4-syllable words yielded an average span of 4.75 words (range 4–6) (this difference was not significant using Wilcoxon, $T = 2$, $p = .094$). Lexical status had an effect as well: the average span for real words was 5.8 (range 5–6.5), compared to 3.3 average span for non-words of the same length (range 3–4). This difference was significant ($T = 0$, $p = .016$). All control subjects reached the maximal score of 6 in the listening span task. Performance in the 2-back task reached ceiling values in all subjects.

Conduction aphasics

The conduction aphasics showed very limited digit-, word-, and non-word-spans in both recall and recognition tasks. The average digit span was 3.2 (range 2.5–4.5). No phonological similarity and no length effect were evinced: the average span was 2.6 for phonologically dissimilar words (range 2–3) and 2.5 for phonologically similar words (range 2–3). The average span for both 2- and 4-syllable words was 2.6 (range 2–3). Lexicality effect did emerge: the average score for real words reached 2.6 (range 2–3), while the average span for non-words of the same length was 1 (range 0–1.5). Listening span was limited in one patient (span of 3), but reached ceiling values in the two other patients. The relatively good performance of the conduction aphasics in this task was probably due to semantic encoding and reliance on the sentence that preceded the word, because when the same word lists were used in a recognition task without the preceding sentences, they yielded a very limited span: 2.6 words (range 2.5–3) (see Butterworth et al., 1990 for a discussion of the difference between memory for word lists and for words within sentences). Surprisingly, performance in all three variations of the 2-back task was quite preserved: 93.7% average (range 83–98%) in all sub-tests of the 1-s SOA and 93.8% average score (87–98%) on the 3-s SOA.

Agrammatic aphasics

The agrammatic aphasics showed limited digit-, word-, and non-word-spans only in recall, but not in recognition tasks. This might be due to articulatory agility difficulties, as the recognition span tasks for words approached normal values (with the exception of the digit span test, which was a recognition task as well but yielded an average score of only 2.6, range 2–3 digits). No similarity or length effects were evinced: the average word span for phonologically dissimilar words was identical to the span of the similar words, 2.7 (range 2–3). The average span for 2-syllable words was 2.7, compared to 2.5 span for 4-syllable words. Their span was affected by lexical status: the average score for real words was 2.3 words (range 2–3), while the span for non-words of the same length was only 1.2 words (range 0–2). Listening span reached ceiling values in two patients. In contrast to the conduction aphasics, the performance of the two agrammatic patients with the normal score did not deteriorate when the same word lists were presented without the preceding sentences, keeping the same ceiling values. The other agrammatic patient had a limited listening span of 4, but almost reached ceiling with a span of 5.5 in the word recognition task without the preceding sentences. The agrammatic participants also had good performance in the 2-back tasks: 94% average (range 93–99%) in all sub-tests with 1-s SOA and average of 90% on the 3-s SOA test (range 91–100%. The 3-s data are based currently only on four lists).

Sentence comprehension experiments

Experiment 1: does gap–antecedent distance interact with WM limitation?

Stimuli and procedure

One hundred and sixty semantically reversible Hebrew relative clauses were included in a binary sentence–picture matching task. The number of words between the antecedent and the gap (2,5,7 or 9 words), and relative clause type (subject vs. object) were manipulated. Of the 160 sentences, 80 were subject relatives, and 80 were object relative sentences. Within each type of relative clause, there were 20 sentences each of the 2, 5, 7, and 9 word distances. The Gap–Antecedent distance (GAD) was manipulated by adding adjunct prepositional phrases and adjectives to the noun: for the object relative sentences, the GAD included, in addition to the complementizer, the embedded subject, and the verb, also prepositional phrases and adjectives (sentences 4b–d). In half of the sentences the padding was on the agent (4b, 4c), in half—on the theme (sentence 4d). In the subject relative sentences, prepositional phrases and adjectives had to follow the subject and precede the object in order to be located in the interval between the antecedent and the gap (see sentences 3a–d). In order to discourage the participants from adopting a strategy according to which the padded NP is the agent, eight subject relative sentences were added, two at the beginning of each of the four sessions, in which prepositional phrases and adjectives followed the object (GAD 0 see sentence 3e). The subject and the object relatives were matched also in terms of the number of noun phrases between the antecedent and the gap, and did not differ significantly in this respect ($t(3) = 0.43$, $p = .34$). Mean number of syllables between the antecedent and the gap in the 2, 5, 7, and 9-word GADs were 6, 16, 22, and 28 syllables, respectively.

Comprehension was assessed using binary sentence–picture matching task. Before task administration, identification of the figures that appear in the pictures was trained. During the task, the participant heard a sentence and chose between two pictures that appeared on the same page. The pictures included two figures, one of them performing the action; the other is the theme/recipient of the action. In the foil picture the roles were reversed. In half of the trials the top picture was the matching one, in the other half, the bottom one. The location of the matching and non-matching pictures was randomized. Sentence types were randomized and no more than two sentences of the same type appeared consecutively. Each sentence was read only once. The participants were instructed to pay attention to the sentence and were asked to answer questions regarding the post-subject or the post-object adjuncts. The 168 sentences were divided into four sets with the same number of sentences of each type, which were administered in four different sessions. Each set of sentences was assessed in a quiet room, with only the experimenter and the participant present.

(3) Subject relatives

(a) GAD 2:

Ze **baxur**$_{\mathbf{i}}$ <u>im zakan</u> she-**t**$_{\mathbf{i}}$ -malbish et ha-xayal

This guy with beard that dresses acc the-soldier

'*This is a guy with a beard that dresses the soldier.*'

(b) GAD 5:

Zo ha-**baxura**$_{\mathbf{i}}$ <u>im ha-mixnasaim ha-xumim ve-ha-xulca ha-levana</u> she-**t**$_{\mathbf{i}}$ -mexabeket et ha-yalda

This the-woman with the-pants the-brown and-the-shirt the-white that hugs acc the-girl

'*This is the woman with the brown pants and the white shirt that hugs the girl.*'

(c) GAD 7:

Zo ha-**yalda**$_{\mathbf{i}}$ <u>ha-blondinit ha-nemuxa im ha-mixnasaim ha-kehim ve-ha-xulca ha-levana</u> she-**t**$_{\mathbf{i}}$ -mexabeket et ha-isha

This the-girl the-blond the-short with the-pants the-dark and-the-shirt the-white that hugs acc the-woman

'*This is the short*[2] *blond girl with the dark pants and the white shirt that hugs the woman.*'

(d) GAD 9:

Ze ha-**xayal**$_{\mathbf{i}}$ <u>ha-nexmad im ha-se'ar ha-kacar im madei ha-cava ha-yeshanim ha-yerukim</u> she-**t**$_{\mathbf{i}}$ -ma'axil et ha-'ish

This the-soldier the-nice with the-hair the-short with uniform the-army the-old the-green that-feeds acc the-man

'*This is the nice soldier with the short haircut with the green worn-out army uniform that feeds the man.*'

(e) GAD 0, object padding (filler):

Zo ha-**yalda**$_{\mathbf{i}}$ she-**t**$_{\mathbf{i}}$ -menagevet et ha-'isha im ha-se'ar ha-'arox ve-ha-mishkafaim ha-kehim

This the-girl that-dries acc the-woman with the-hair the-long and-the-glasses the-dark

[2] Note that in Hebrew adjectives follow the noun rather than precede it.

'*This is the girl that dries the woman with the long hair and the dark glasses.*'

(4) Object relatives
(a) GAD 2:
Ze ha-**baxur**$_i$ she-ha-yeled tofes **t**$_i$
This the-guy that-the-boy catches
'*This is the man that the boy catches.*'
(b) GAD 5:
Ze ha-**xayal**$_i$ she-ha-rofe im ha-xaluk ha-lavan mecayer **t**$_i$
This the-soldier that-the-doctor with the-robe the white draws
'*This is the soldier that the doctor with the white robe draws.*'
(c) GAD 7:
Ze ha-**rofe**$_i$ she-ha-xayal im ha-madim ha-yeshanim be-ceva yarok mecayer **t**$_i$
This the-doctor that-the-soldier with the-uniform the-old in-color green draws
'*This is the doctor that the soldier with the worn-out green colored army uniform draws.*'
(d) GAD 9:
Ze ha-**saba**$_i$ ha-nexmad im ha-eynaim ha-xumot ha-neimot ve-ha-zakan ha-lavan *she-ha-yeled mexabek* **t**$_i$
This the-grandfather the-nice with the-eyes the-brown the-pleasant and-the-beard the-white that-the-boy hugs
'*This is the nice grandpa with the pleasant brown eyes and the white beard that the boy hugs.*'

Results

Normal controls performed well in all types of sentences. They scored 99–100% correct in all sub-tests, and showed no difference between subject and object relatives, or between sentences of different GADs.

Agrammatic aphasics showed the "classical" dissociation, with better comprehension of subject relatives than of object relatives as may be seen in Fig. 1 (subject relatives significantly better than object relatives for each individual participant

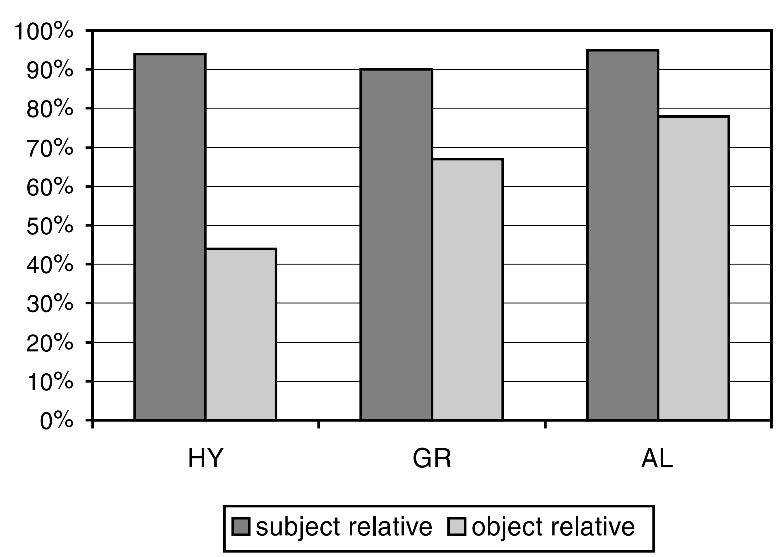

Fig. 1. Agrammatic aphasics—significant difference between object and subject relatives.

using Fisher's exact test, $p < .03$). Subject relatives were above chance for each individual patient and object relatives were not significantly different from chance (except for AL who was marginally above chance on object relatives) using binom.

Conduction aphasics showed good comprehension of relative clauses, and each individual patient performed significantly above chance on all sentence types (using binom) as may be seen in Fig. 2. No difference was found between subject and object relatives (using Fisher's exact test for each individual patient, $p > .05$).

Both agrammatic and conduction aphasics were *unaffected* by the distance between the antecedent and the gap, as may be seen in Figs. 3 and 4. No linear decrease in comprehension was witnessed as distance increased in either of the groups. When analyzing subject relatives and object relatives separately, also no distance effect was found for either of these sentence types.

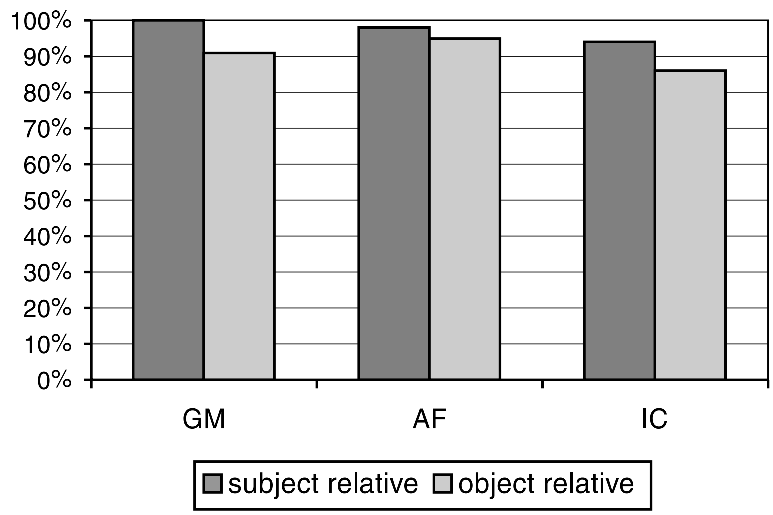

Fig. 2. Conduction aphasics—no significant difference between object and subject relatives.

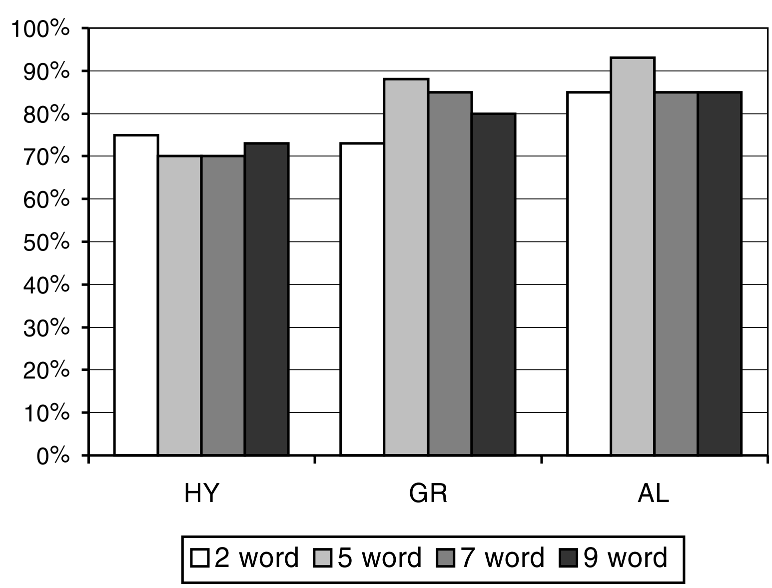

Fig. 3. Agrammatic aphasics, subject and object relatives combined—no distance effect.

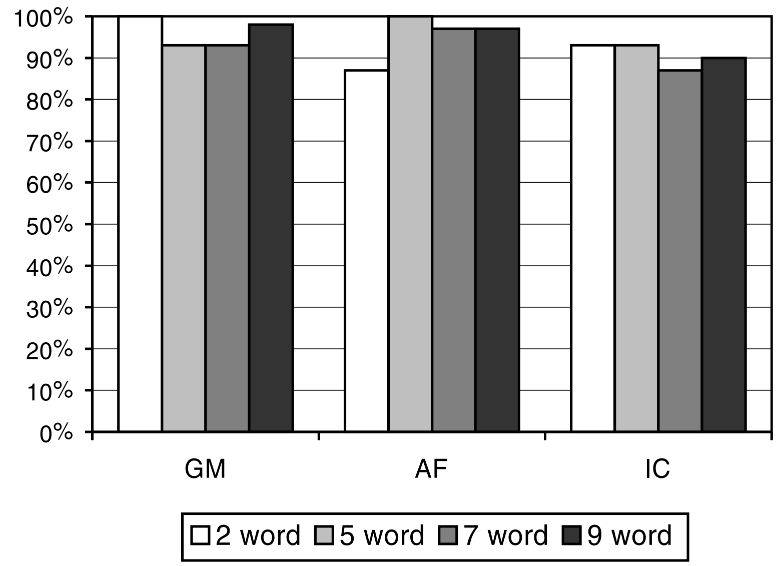

Fig. 4. Conduction aphasics, subject and object relatives combined—no distance effect.

Experiment 2: does disambiguation distance interact with working memory limitation?

The results of Experiment 1 indicated that increasing antecedent–gap distance does not affect sentence comprehension for agrammatic or conduction aphasics. We conjectured that increasing antecedent–gap distance had no effect on comprehension even in patients with limited WM, because the distance was measured in *phonological* units (words or syllables), while the processing at the gap involves *semantic* reactivation of the antecedent (Love & Swinney, 1996). This led us to search for a structure in which semantic reactivation is not enough for comprehension, and phonological reactivation is obligatory. In this type of structure, we surmised, phonological reactivation would be hampered by phonological overload, and comprehension should be compromised when phonological WM is limited. The structure we used included temporary lexical ambiguity that at some point of the sentence gets disambiguated to the less dominant meaning, and thus requires the reactivation of the original word in order to re-access all meanings and allow for reanalysis.

Stimuli

One hundred and eighty Hebrew sentences were presented to each participant. Eighty of the sentences included an ambiguous word. In half of the sentences the word gets disambiguated after 2–3 words (see example 5 in Hebrew, and example 7 for a relevant example in English); in half only after 7–9 words (sentences 6 in Hebrew, 8 in English).

(5) ha-**SAL** shel saxkan ha-po'el **male** micraxim
The-basket of player Hapoel full groceries
'*The basket of the "Hapoel" player is packed with groceries.*'

(6) ha-**SAL** shel saxkan ha-kadursal ha-mefursam mi-kvucat ha-po'el tel 'aviv haya **male** micraxim
The-basket of player the-basketball the-famous from-team Hapoel Tel Aviv was full grocery-products
'*The basket of the famous basketball player from "Hapoel Tel Aviv" was packed with grocery products.*'

(7) The **PEN** is always **packed** with woolly sheep.
(8) The **PEN** that the man received from his wife when he retired was **packed** with woolly sheep.

Each ambiguous word was tested in both disambiguation distances. One hundred semantically implausible and plausible sentences matched for length to each other and to the test sentences served as filler items. The order of the sentences was randomized and no more than two sentences of the same type appeared consecutively.

Procedure

Each sentence was presented auditorily and the participants were requested to judge the plausibility of the sentence and paraphrase it as accurately as possible. When the patients had difficulties in oral paraphrasing, hand gestures were accepted as well.

The sentences were divided into two sets, administered with at least two weeks interval. The long disambiguation distance and the filler sentences matched in length were presented in one session, the short sentences and their fillers in another session. The order of the sessions was randomized among participants.

Results

All the participants in the control group performed above 93% correct in both short and long disambiguation distance sentences as well as in the filler sentences.

Conduction aphasics showed a severe deficit in comprehension of long distance disambiguation sentences, rejecting half of them as implausible (performance not significantly different from chance for the group and for each individual patient, using binom). As can be seen in Fig. 5, the same ambiguous words did not cause comprehension problems when they were incorporated in sentences in which the ambiguity was resolved after 2–3 words (significantly better than chance for the group and for each individual patient, using binom). The difference between short and long disambiguation sentences was statistically significant (for each individual patient and for the group using Fisher exact test, $p < .03$). Performance on the control items was above 85% correct and significantly above chance for each individual subject.

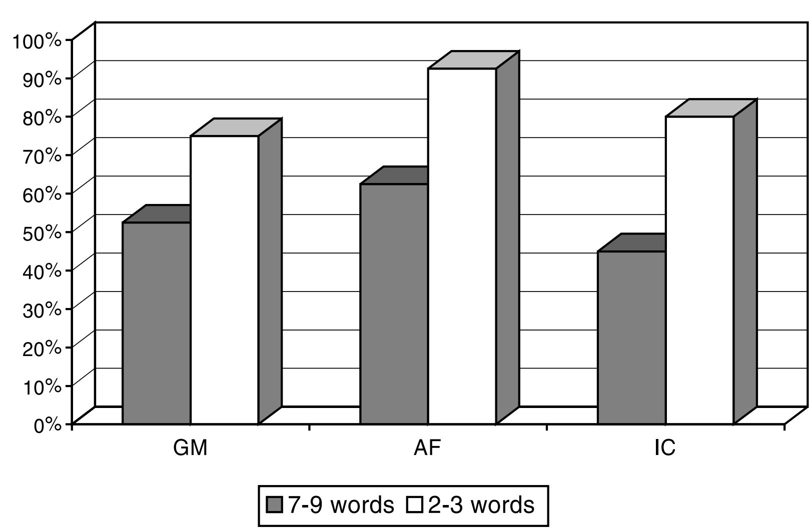

Fig. 5. Conduction aphasics—distance effect in ambiguous word reactivation.

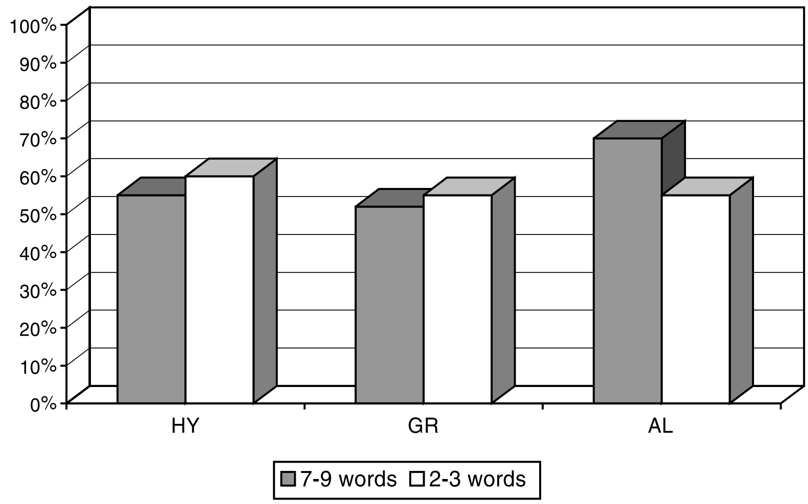

Fig. 6. Agrammatic aphasics—no distance effect in ambiguous word reactivation.

Conduction aphasics' difficulty in interpreting long distance disambiguation sentences is exemplified by IC's response to sentence (9) in which the ambiguous word "tsir": (= diplomat/pivot, axis/birth pain/sauce) initially appeared in a biasing context toward the 'diplomat' meaning, and then was reanalyzed to the 'pivot' meaning:

(9) hatsir shehigia me'arcot habrit behazmanat misrad haxuc haisre'eli hutkan bedelet halishka shel rosh hamemshala. (= the-diplomat/pivot that-arrived from the-United States by-invitation of the-Israeli ministry of foreign affairs was-installed in-the-door of the-prime-minister bureau.)

> The sentence is wrong...what can you understand here...the airplane arrived from the United States, the minister arrived back and then blah, blah, blah..., the first half of the sentence is OK, the second part is OK, but they cannot be combined...

Agrammatic aphasics' performance on both sentence types was at chance level (for the group and for each individual subject, not significantly different from chance, using binom). They showed no significant difference between short and long distance disambiguation (for each individual patient and for the group using Fisher exact test, $p > .1$; see Fig. 6). Their scores in the filler sentences were above 83% correct, and significantly above chance for each individual, using binom.

Discussion

The study explored the effect of verbal WM limitation on sentence comprehension in conduction and agrammatic aphasia. In Experiment 1 we independently manipulated syntactic complexity and phonological memory load by manipulating the type of the relative clause (subject vs. object relative), and the number of words and syllables between the antecedent and the gap. The main findings were that agrammatic aphasics were sensitive to the syntactic structure of the relative clause and failed in object relatives but not in subject relatives, but they were not influenced by the amount of words or syllables interpolated between the antecedent and the gap. The conduction aphasics had normal comprehension of both subject and object relatives, in the presence of very limited WM. They, too, were uninfluenced by the amount of interpolated words and syllables, and did well in comprehending even sentences with as many as 28 syllables between the antecedent and the gap.

The results are consistent with the studies of Schwartz, Linebarger, Saffran, and Pate (1987) and Kolk and Weijts (1996), who tested the effect of lexical padding on the comprehension of simple active sentences, and found no padding effect or a relatively small lexical padding effect on plausibility judgments in agrammatic and conduction aphasics, in the presence of syntactic movement effect in the agrammatic patients (Schwartz et al. found that movement decreased performance also for two conduction aphasics, but their performance in the movement condition was still above chance). The results are also consistent with earlier findings from patients with small phonological STM capacity who nevertheless exhibited good grammaticality judgment and comprehension of grammatically complex sentences such as object relatives (Butterworth et al., 1986; Butterworth et al., 1990).

These results are inconsistent with theories that assume a single WM capacity, which is responsible for all types and facets of language processing (Just & Carpenter, 1992; King & Just, 1991), and they are inconsistent with theories that ascribe the deficit in all types of aphasia to "resource reduction" (Haarmann, Just, & Carpenter, 1997; Miyake et al., 1994). A general capacity reduction theory cannot account for the finding that the conduction aphasics, who clearly demonstrated limited verbal WM capacity in this study, did not show a deficit in comprehension of relative clauses or a discrepancy between subject and object relatives, because according to the criteria of Miyake et al. (1994), for example, object relatives are more difficult and therefore should have been harder than subject relatives for the limited WM patients. Furthermore, although longer distances between the antecedent and the gap should put more demands on WM, increasing the distance did not induce decreased performance, neither for the agrammatics nor for the conduction aphasics.

This experiment also indicates that the deficit in agrammatic aphasia is not due to a general WM deficit and that the discrepancy between object and subject relative comprehension cannot be ascribed to the fact that they differ with respect to the antecedent–gap distance. Rather, these results indicate that if one wants to depict the agrammatic deficit in comprehension in working memory terms, the description has to use syntactic-specific terms such as movement of phrases and the relative position of arguments.

The results of Experiment 1 are consistent with McElree (2000), who suggested, based on his findings in speed-accuracy tradeoff paradigm in normals, that reactivation or binding of fillers and gaps are content-addressable and therefore unaffected by the amount of interpolated material. (The susceptibility of lexical ambiguity resolution to distance effects in Experiment 2 suggests that in lexical ambiguity reanalysis the processing is search-based rather than content-addressable.)

The second experiment looked at the comprehension of sentences that include reanalysis of an ambiguous word, which occurred either shortly after or long after the word. The results of this experiment indicated that when the appropriate sentences are examined, the WM limitation of the conduction aphasics can cause comprehension failure. In this experiment, distance did play a crucial role in the comprehension of conduction aphasics, who understood the sentences well only when the disambiguation distance was short, but failed completely in the long disambiguation sentences, frequently declaring them to be "nonsense." The agrammatic aphasics were not affected by distance in these sentences and performed poorly on both short- and long-distance disambiguation sentences.

We assume, on the basis of Swinney (1979), Onifer and Swinney (1981), and Love and Swinney (1996), that in the course of the unfolding of the sentence only the meaning that seems relevant to the context remains activated, and the other apparently irrelevant meanings decay within approximately three syllables or 1.5 s. In order to comprehend a sentence that requires reanalysis and adoption of an alternative meaning that has already decayed it is necessary to reactivate the word form itself because reactivation of the chosen semantic meaning will be inappropriate. This is exactly why the conduction aphasics failed in the long distance condition when the memory load was phonological. When the distance was 7–9 words, the meaning had already decayed and a word-form reactivation was required, but because these individuals' phonological WM was limited, the phonological memory load prevented successful reactivation. In the short distance condition, which included only 2–3 words between the first activation of the word and the reanalysis, either the relevant meaning had not yet decayed, and a phonological reactivation was not required, or even if it has decayed, the small number of words did not interfere with phonological reactivation.

The poor performance of the agrammatic aphasics on both short and long ambiguity sentences in this experiment might be explained by referring to Swinney, Zurif, and Nicol (1989). Using Cross Modal Lexical Priming experiments they demonstrated that Broca's aphasics have a slower-than-normal time course of lexical activation and that at the offset of an ambiguous word they activate only the most frequent meaning of the ambiguous word (in contrast to non-impaired population who access all the meanings of the ambiguous item). Such inability to immediately access the subordinate meaning should impair the comprehension of sentences that include ambiguous lexical items (see also Prather, Zurif, Love, & Brownell, 1997; Swaab, Brown, & Hagoort, 1997; Swinney, Prather, & Love, 2000).

Taking the results of the two experiments together, it seems that the crucial factor in determining the effect of WM limitation on sentence comprehension is the type of processing required in the sentence. A possible way to account for the findings of the current study is that WM limitation affects sentence comprehension only when the reactivation required, the memory load, and the WM limitation are all of the same type. This explanatory triad determines for example that phonological WM limitation will only impair comprehension when the reactivation required is phonological and the memory load is phonological. On the other hand, when the reactivation needed is syntactic-semantic, as is the case in relative clauses for example, phonological memory load and phonological WM limitation will not hamper comprehension.

It seems, then, that at least two types of WM interact with sentence comprehension. One is a syntactic WM,[3] which is responsible for example for the comprehension of sentences that include transformations. A deficit in this subcomponent impairs the comprehension of such structures but does not necessarily interact with manipulations that overload the phonological capacity. It is, however, affected by syntactic manipulations such as using sentences that include movement of phrases, and using object rather than subject relatives. This subcomponent possibly uses a content-addressable reactivation.[4]

[3] At this point we feel that calling this component "syntactic processing ability" or "syntactic WM" is mainly a matter of taste, and we remain agnostic to the choice between the two.

[4] This explanation carries a prediction regarding syntactic memory load, which we are currently studying empirically. In the current experiments we manipulated phonological memory load by adding words (and syllables), and patients with phonological WM limitation (conduction aphasics) were affected when the reactivation was phonological. A similar manipulation can be devised in the syntactic domain as well: if indeed the addition of CP has a syntactic memory cost (see Gibson & Thomas, 1999) then the addition of embedding between the antecedent and the gap can be used to manipulate syntactic memory load. In this case we expect that in sentences in which the required reactivation is syntactic, the introduction of double embedding would impair the comprehension of aphasics with syntactic limitation (agrammatics) but not of conduction aphasics. An initial support for the effect of embedding on agrammatic comprehension can be found in Kolk and Weijts (1996). They did not examine the effect of adding an embedded clause between the antecedent and the gap as we did here, but they did find that the addition of an embedded clause between a subject and its predicate impaired plausibility judgment.

The other WM subcomponent is a phonological WM, which is measured in a series of WM tasks and is needed in the reactivation of word form. This type of WM is affected by phonological overload such as increasing the amount of words and syllables, when a reactivation of word-form is required.

The syntactic-movement WM component is impaired in agrammatic aphasia, and a phonological WM component is impaired in conduction aphasia, hence their different performance on the two experiments in this study.

These results fit nicely into accounts that think of the verbal WM not as one single capacity for all types of language tasks but rather as a multiple resource entity including, among others, also a capacity specialized in automatic syntactic processing, lexical access and thematic role assignment, which is different from the capacity measured by WM span measures (Caplan & Waters, 1990, 1999).

As a last point, note that the dissociation between the good performance of the agrammatic group on the 2-back task and their poor comprehension of object relatives suggests an additional insight regarding the relation between the two (or lack thereof). Although several studies have found that 2-back tasks activate Broca's area (Left Inferior Frontal area, LIFG), the same area that is active in the processing of movement of phrasal constituents (Awh et al., 1996; Ben-Shachar, Hendler, Kahn, Ben-Bashat, & Grodzinsky, 2001; Braver, Cohen, Jonides, Smith, & Noll, 1997; Cohen et al., 1994; Grodzinsky, 2000a; Jonides et al., 1997; Smith and Jonides, 1998; Stowe, Withaar, Wijers, Broere, & Paans, 2002), and although some structural similarities have been detected between the processing of 2-back tasks and of long distance dependencies with an intervening NP (Grodzinsky, 2000b), the dissociation indicates that 2-back and syntactic processing of movement dependencies can be separately impaired, and therefore they are probably not subserved by the same functional module.

To conclude, the study indicated that the interaction between WM and sentence comprehension is highly intricate but can be accurately characterized by reference to the specific types of overload, reactivation, and limitation. Our results suggest that only when the overload and the required reactivation are of the same type would a WM limitation of the relevant type hinder sentence comprehension. When the overload and the required reactivation are of different types (such as phonological overload with semantic reactivation) no comprehension deficit is caused.

Acknowledgments

We thank David Swinney and Ed Smith for interesting and stimulating discussions on the relation between working memory and sentence comprehension. The research reported in this article was supported by the Joint German–Israeli Research Program Grant GR01791.

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