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FEATURE ARTICLE

Syntactic processing in high- and low-skill comprehenders
working under normal and stressful conditions

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Syntactic processing in high- and low-skill comprehenders working under normal and stressful conditions

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Abstract

The degree to which syntactic and discourse comprehension rely on common or disparate processing systems is a matter of continuing debate in psycholinguistics, particularly in aphasia research. The present study examines possible relationships between discourse comprehension and auditory syntactic comprehension assessed under normal listening, single, and dual "stress" conditions. Results showed that stress can dramatically exaggerate differences in syntactic difficulty and that general discourse comprehension skill can significantly predict syntactic comprehension profiles. We discuss the results with reference to competing models of language development, comprehension, and breakdown.

Introduction

Since the early 1980's, there has been great interest in aphasic patients' (particularly Broca's) productive and receptive syntactic deficits, in that (in the eyes of many psycholinguists) they provide a "testing ground for theoretical models of the normal mental grammar" (Mauner, Fromkin, & Cornell, 1993). In other words, different components of the 'mental grammar' could be revealed by showing selective deficits in patients' comprehension of different syntactic constructions. The examination of aphasic patients' syntactic competence has become a virtual cottage industry, and has engendered much debate on both linguistic and methodological grounds (Caplan, 2000; Caplan, 2001; Caramazza, Capitani, Rey, & Berndt, 2001; Grodzinsky, Pinango, Zurif, & Drai, 1999).

One difficulty with many studies of aphasic patients' syntactic processing is that the vast majority are either case studies of single patients or very small group studies of patients selected specifically for the deficit in question, thus making interpretation of results somewhat complicated. Caplan has pointed this and other difficulties out in several commentaries (Caplan, 1987; Caplan, 2000; Caplan, 2001; Caplan & Hildebrandt, 1986 – see also Bates, Appelbaum, & Allard, 1991a; Bates, McDonald, Macwhinney, & Appelbaum, 1991b), and over the years has also provided a number of studies reporting results on large groups of aphasic patients, often along with analyses of lesion-deficit mappings (see Caplan & Hildebrandt, 1988; Caplan, Hildebrandt, & Makris, 1996; Caplan & Waters, 1999.

For instance, Caplan and Hildebrandt (1988) report the results of 3 experiments which tested almost 150 aphasic patients on a battery of 9 sentence types varying in terms of syntactic and propositional complexity. Perhaps not surprisingly, patients[1] profiles of sparing and deficits showed wide individual variability, with no transparent mapping of aphasia syndrome or lesion site to distinct profiles of syntactic deficits (see also Caplan, Hildebrandt, & Makris, 1996). In order to better characterize different profiles of syntactic comprehension, Caplan and Hildebrandt performed a cluster analysis on subjects' accuracy scores. They found striking differences in aphasic patients' patterns of comprehension deficits and sparing, although an overall severity metric predicted much of the variance in patients' performance.

Caplan and Waters (1999) suggest that such deficits come about not through loss of linguistic knowledge, but through differential loss of a "separate language interpretation resource", a computational space dedicated exclusively to grammar in which language rules are processed separately from other information. In a somewhat related vein, Just & Carpenter (Just & Carpenter, 1992; Just, Carpenter, & Keller, 1996) suggest that syntactic deficits may arise from a lack, taxing, or frank loss of a more 'general-purpose' verbal working memory, again operating upon separately stored rules and 'procedures'.

In contrast, connectionist simulations emphasize the indivisibility of processing and representation, and suggest that the introduction of noise or diffuse 'lesions' of connection weights in a single processing network can result in such 'selective deficits' in comprehension and production (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Hinton & Shallice, 1991; Marchman, 1993; Plaut, 1995; Plaut, 1996; Plaut & Shallice, 1994; St. John & Gernsbacker, 1998). On such accounts, the relative vulnerability of different syntactic constructions is determined in part by the frequency of the particular construction in question, as well as the 'regularity' of that construction – e.g., how closely its structure patterns with other syntactic constructions. For example, simple active transitive constructions such as "The boy is petting the dog" are frequent in themselves, and also share a word order (Subject-Verb-Object) that predominates in English (Dick and Elman, 2001). Thus comprehension of these constructions should be relatively spared under stress or damage to the processing system. On the other hand, constructions such as object clefts ("It's the dog that the boy is petting") are themselves very low in relative frequency, and utilize a low-frequency word order pattern (Object-Subject-Verb). These frequency and regularity factors can interact with considerations such as overall sentence length and number of logical propositions (Christiansen & Chater, 1999).

Importantly, a logical extension of either the 'general-purpose' working memory theory or the connectionist approach to language breakdown is the following: by adding additional strains on processing resources (e.g., 'filling up' a computational buffer or incrementally decreasing the perceptual quality or informational content of linguistic information), it should be possible to simulate aphasic patients' language difficulties in neurologically intact subjects.

The possibility of simulating such syntactic comprehension deficits was first explored by Miyake, Carpenter, and Just (1994), who administered complex sentence stimuli (derived from those of Caplan & Hildebrandt, 1988) to college students in a serial visual presentation format, where each word was briefly shown on a video screen in sequential order. Half of their subjects received the stimuli at a comfortable presentation rate, while the other half read the sentences under speeded visual presentation (RSVP). Students in the RSVP condition produced significantly more errors, and displayed a hierarchy of difficulty that was strikingly similar to that of Caplan and Hildebrandt's aphasic patients (hierarchies that were predicted in large part by whether the sentence structure used the canonical English word order (SVO) and by how many propositions it contained). Posthoc cluster analyses of the RSVP subjects also revealed performance profiles congruent with those demonstrated by the aphasic patients; moreover, college students with small "working memory spans" appeared to be less accurate in comprehending more complex constructions, particularly in the RSVP condition. (This last point is heatedly debated - see Caplan & Walters, 1996; Caplan & Waters, 1995; Caplan & Waters, 1999; Just et al., 1996; Miyake et al., 1994; Miyake, Carpenter, & Just, 1995; Miyake, Emerson, & Friedman, 1999; Waters & Caplan, 1996a; Waters & Caplan, 1996b).

Despite the suggestive results of Miyake et al., it is unclear if the "stress" effects of RSVP are unique to this paradigm, or if they can be extended to other, more ecologically valid stressors. It is also unclear whether verbal working memory span is an especially "privileged" measure of language processing ability, or alternatively whether other measures (such as discourse comprehension skill) are equally as good predictors (MacDonald & Christiansen, in press). Finally, it is equally unclear how often these 'selective deficits' in grammatical processing can arise purely by chance in a large sample of neurologically intact adults (Appelbaum, Bates, Pizzamiglio, & Salcedo, 2000; Bates et al., 1991a; Juola & Plunkett, 1998; Plaut, 1995). Thus, it would be informative to test the sentence comprehension of a substantial sample of normal subjects under different conditions in order to ascertain a) the robustness of the 'stress' technique to changes in modality; b) the predictive value of other language skill measures for vulnerability to syntactic deficits; and c) the base rate of 'selective syntactic deficits' that occur by chance in a neurologically normal sample.

In Experiments 1a and 1b, we test two large samples of college students on a battery of auditory syntactic comprehension under normal and 'stressed' conditions, using the same sentence stimuli as Miyake, Carpenter, and Just (1994). These particular stress conditions were chosen for their ecological validity, simulating environmental (exogenous) conditions that are known to be detrimental to language processing (Gordon-Salant & Fitzgibbons, 1993; Gordon-Salant & Fitzgibbons, 1995a; Gordon-Salant & Fitzgibbons, 1995b; Gordon-Salant & Fitzgibbons, 1997) as well as endogenous reductions in speed of processing and perceptual clarity that often accompany neurological deficits and/or cognitive aging (Utman & Bates, 1998; Utman, 1997; Utman, 1998). In Experiment. 1a, the stressed condition is an auditory replication of the RSVP technique discussed above; in Experiment 1b, we increase the intensity of the stressor by combining speeded auditory presentation with a reduction in spectral information -- see Dick, Bates, Wulfeck, Utman, Dronkers, & Gernsbacher (2001) for a more complete set of stress manipulations. In both experiments, we assess subjects' general discourse comprehension skill with the Multi-Media Comprehension Battery (Gernsbacher & Varner, 1988) in order to evaluate the relationship between syntactic comprehension and general higher-level language abilities. We also inspect a subset of individual subjects' sentence data for the presence of a selective deficit referred to by Hickok and Avrutin (1995) as the "core data" of agrammatism; Grodzinsky (1999, reviewed and amplified in Grodzinsky, 2000) has proposed specific behavioral criteria for these "core data", criteria we use in this subject sample to establish a baseline rate in healthy samples for the presence of a given syntactic dissociation. In addition, we use the group accuracy averages to assess the relative difficulty of each sentence type[1].

[1] Note: These data have been previously presented in abstract and poster form (Dick, Gernsbacher, & Robertson, 2000). The poster presentation also included data from a literacy test that is not reported here.

Method – Experiment 1a

Participants

158 University of Wisconsin - Madison students participated in the study. All were enrolled in Introductory Psychology courses and received extra credit points for their time. All were native English speakers. Participants were treated in accordance with the "Ethical Principles of Psychologists and Code of Conduct" (American Psychological Association, 1992).

Design

A three-factor design was used in both experiments, incorporating two within-subjects factors and one subject-grouping factor. The within-subjects factors were: (1) Speed of Sentence Presentation (Normal and 66% Compressed Speech), and (2) Syntactic Structure (12 levels - see Table 1 for examples). The subject-grouping factor was Level of Sentence Comprehension (High, Medium, and Low) as measured by the Multi-Media Comprehension Battery (Gernsbacher & Varner, 1988). For the syntax task we measured response accuracy and reaction time to the test question; because of the offline nature of both the task and the nature of previous studies (e.g., Caplan & Hildebrandt, 1988) , we report only response accuracy. For the discourse task, we measured only response accuracy.

Materials

Syntax task: Syntactic comprehension materials were derived from those used in Miyake, Carpenter, & Just (1994) and consisted of two stimulus blocks (A and B). Each block was assigned a separate pool of eight nouns that could act as semantically plausible sentential subjects or objects (e.g., director, producer, actor), as well as eight transitive verbs (e.g., kicked, liked). Blocks were composed of 96 sentences a piece. In order to generate each sentence stimulus, a randomly drawn set of nouns and verbs was assigned to the syntactic slots belonging to one of twelve syntactic structures (see Table 1 for examples). For each block, 8 exemplars of every sentence type were generated. Each verb and noun in the pool was used an equal number of times; in addition, each noun played an equal number of semantic roles. Order of sentence presentation was fully randomized within each block.

Every sentence was paired with a yes/no comprehension question in the active voice (e.g., "Did the director kick the producer?"). The sentences were created in such a way so that "yes" and "no" answers to questions would be balanced for each sentence type. Both blocks were paired with a set of twelve practice sentences. Each practice block contained one exemplar of each of the twelve different syntactic constructions found in the two stimulus sets; the verbs and nouns used were drawn from the pools corresponding to the appropriate experimental block.

All questions and sentences were analog-recorded by a native English speaker and were digitized using SoundEditPro at 22.025 kHz, with 8-bit quantization. Compressed speech stimuli were created by making copies of each sentence recording, then reducing them to 66% of their original length, again using SoundEditPro. The proprietary compression algorithm reduces overall duration of a complex waveform by excising redundant periods in the speech signal, thereby retaining the original spectral and frequency characteristics.

Table 1: Example Sentence Types with Complexity Factors, Experiment 1

Sentence Type *Example*	***Three + actors***	***Two verbs***	***Non-canonical order***
Active (ACT) The producer kicked the actor			
Cleft Subject (CES) It was the producer that kicked the actor			
Dative Subject (DAS) The producer recommended the actor to the comedian	X		
Passive (PAO) The actor was kicked by the producer			X
Conjoined (CJS) The producer kicked the actor and praised the comedian	X	X	
Right Branching Subject (RBS) The producer kicked the actor that called the comedian	X	X	
Cleft Object (CLO) It was the actor that the producer kicked			X
Coordinated Cleft Subject (CDS) The producer kicked the actor and the comedian praised the dancer	X	X	
Center-Embedded Subject (CES) The producer that kicked the actor praised the comedian	X	X	
Dative Object (DAO) The actor was recommended to the producer by the comedian	X		X
Right-Branching Object (RBO) The producer kicked the actor that the comedian recommended	X	X	X
Center-Embedded Object (CEO) The actor that the producer kicked liked the comedian	X	X	X

Four experimental conditions were then created. Every condition contained both stimulus blocks, with one normally presented, and the other presented as compressed speech. Block order and presentation speed were counterbalanced over experimental condition. All comprehension questions were presented at a normal rate of speech.

Discourse Comprehension Task: The Multi-Media Comprehension Battery (Gernsbacher & Varner, 1988) consists of four original short stories of approximately 1000 words each. Each story is paired with 12 multiple choice comprehension questions. Both text and questions can be viewed via Internet at http://psych.wisc.edu/lang/materials/Compbat.html. Story text is presented on a computer monitor paragraph by paragraph; the related comprehension questions follow each story . In order to correctly respond to the questions, subjects must remember exact details, understand relationships between characters, recall the order of a story's events, and so forth.

Procedure

Both tasks were conducted in an acoustically insulated, windowless room with a white noise generator to block out extraneous sounds. Participants sat at one of four carrels containing a Macintosh VGA monitor, two button boxes (one for each task), and a pair of monaural headphones with adjustable volume. The syntax task and Multi-Media

Comprehension Battery were presented using SuperLab software on four independent LCII Macintosh computers.

Syntax Task: After random assignment to one of the four experimental conditions, participants read a series of instructions on the monitor at their own pace. They were informed that they would hear a series of sentences, each sentence preceded by a single tone. After each sentence, they would hear two tones, and then hear a "yes/no" question about the sentence. Immediately following the end of the question, subjects would be prompted to answer by seeing "Yes/No" appear on the monitor (which otherwise remained blank); they would then push the appropriate button on the button box. The instructions stressed that subjects should always try to correctly answer the test questions no matter how long it took them to respond.

Subjects heard an example sentence and question, and then began a 12-sentence practice block; for practice trials only, accuracy feedback ("correct", "wrong") was displayed on the monitor. After completing the practice trials, subjects were asked if they had further questions; they then began the first block of 96 experimental trials. After the first block, subjects took a short break, then read additional instructions which explained the change in presentation (normal or compressed) in the subsequent block. They then completed a second 12-trial practice block (with accuracy feedback) and the corresponding experimental block (without feedback).

Discourse Comprehension Task: After completing the syntax task, subjects took a short break, then began the multi-media comprehension battery. After reading a series of instructions, subjects read each story at their own pace by pushing a button for the next paragraph. They answered each comprehension question by pushing the button corresponding to one of the four answers presented on the screen. Only one answer of the four was correct.

Results - Experiment 1a

We will report results as follows: (1) analyses of syntactic comprehension under the normal or 66% compressed speech (fast) presentation conditions, and (2) analyses of the relationship of syntactic comprehension under normal/fast conditions to general discourse comprehension (as measured by the Multi-Media Comprehension Battery). Because of the "offline" nature of the experiment (and the thrust of the larger theoretical issues), we report correct response (CR) data only. Due to computer malfunction or missing values, 10 of the 157 subjects we ran were dropped from all analyses, leaving 147 subjects total.

We carried out all ANOVAs with SuperAnova for Macintosh; correlations were performed with SuperAnova or JMP for Macintosh, and cluster analyses were performed with SPSS 9.0 for Windows. P-values reported for all within-subjects factors are Geisser-Greenhouse corrected (Geisser & Greenhouse, 1958), and all pairwise comparison values are Geisser-Greenhouse- and Bonferroni-adjusted unless specifically noted. Because of the homogeneity of the sentence exemplars, we carry out only analyses using subjects as the random factor (see Clark, 1973 for a discussion of relevant factors). Error bars on all graphs are +/– 1 standard error of the mean.

1. Syntactic comprehension under Normal vs. Fast conditions

We first ran an omnibus analysis of variance to investigate effects of sentence type and stress condition. The 2-within subject (sentence type x stress condition) ANOVA showed a main effect of presentation speed, where students processing under normal conditions were slightly more accurate overall than students under fast conditions ($F(1, 146) = 11.806$, $p = .0008$). There was also a main effect of sentence type ($F(11, 146) = 107.465$, $p = .0001$) but, contrary to expectations, there was no significant interaction of sentence type with presentation condition ($F(11, 1606) = 1.205$, $p = .288$ - see Figure 1a).

In order to better understand the sentence type effects, we performed Bonferroni-corrected pairwise comparisons on correct responses over all sentence types for both normal and fast conditions. As can be seen in Figure 1a, comprehension of sentence types under normal conditions tended to roughly break down into three classes, where classes are formed by sentence types whose accuracy does not signicantly differ from other members of the class, but does significantly differ from each other sentence type (with one exception - see below). We term these classes *Easy*, *Mid*, and *Hard* sentences (refer to Table 1 for examples of each sentence type). The 3 sentence types we class as *Easy* are actives (ACS), subject clefts (CLS), and dative subjects or ditransitives (DAS). Performance on actives and subject clefts was generally high, and did not differ; performance on simple ditransitives (DAS) was significantly lower than actives and marginally lower than subject clefts, but was closer in overall accuracy to these types than to any others. Comprehension accuracy for all three sentence types averaged 94.5% (range: 91.7-98.9%). The sentence types we classed as *Mid* were coordinated subjects (CDS), object clefts (CLO), conjoined subjects (CJS), center-embedded subjects (CES), passives (PAO), and right-branching subjects (RBS). Performance on these sentence types clustered around 81% correct response (range: 80-84%). Correct response did not differ over these 6 constructions, but did differ significantly from all other sentence types. The sentence types we classed as *Hard* were right-branching objects (RBO), dative objects (DAO), and center-embedded objects (CEO). Performance on these sentence types clustered around 73% (range: 72.3-73.6%) and no Hard sentence type differed significantly from any other.

Figure 1a: Average percent correct response for each sentence type in normal and 66% speech rate compression conditions, Experiment 1a. Shaded ellipsoids indicate that means within each ellipsoid do not differ significantly.

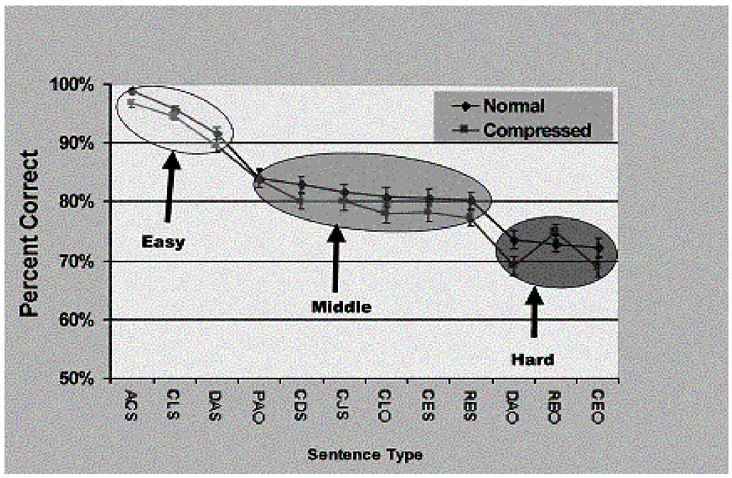

Figure 1a

As was indicated by the lack of interaction of sentence type with presentation condition, relative accuracy over sentences changed little in the fast condition, with the three difficulty groupings staying essentially intact. In both stress conditions, grouping sentences by accuracy seems to correspond to syntactic structure in the following way: *Easy* sentences (actives, subject clefts, and ditransitives) all obey the canonical SVO word order, and actives and subject clefts contain only two actors (agent and patient). Ditransitives contain a third actor, which may account for the slightly lower level of overall comprehension compared to actives and subject clefts. *Mid*-difficulty sentences (passives, object clefts, right-branching subject clefts, conjoined subjects, coordinated subjects, and center-embedded subjects) are a more heterogeneous assortment: Passives and object clefts use non-canonical, low-frequency word orders (OVS and OSV, respectively) but have only two actors and one verb, while right-branching-, conjoined-, coordinated-, and center-embedded-subject sentence types use a canonical SVO word order, but contain 2 verbs and 3-4 actors. *Hard* sentence types (dative-, right-branching-, and center-embedded-objects) combine both of the difficulty factors that occur separately in *Mid*-difficulty sentences: all three contain 2 verbs, 3 actors, *and* employ a low-frequency, noncanonical OVS or OSV word order.

After grouping the sentence types according to the results of the pairwise comparisons, we asked whether these apparent difficulty levels were statistically reliable, and whether they interacted with presentation condition. There was indeed a main effect of difficulty (Easy, Mid, Hard) (F(2, 292) = 598.294), p = .0001) but as before there was no significant interaction of difficulty and stress (F(2, 292) = .063, p = .9164). We also examined possible effects on the subset of sentence types comprising the "core data" of agrammatism, namely actives, subject clefts, object clefts, and passives. There was a main effect of presentation condition (F(1, 146) = 4.414, p = .0374), where accuracy was slightly lower in the fast condition, as well as of sentence type (F(3, 146) = 118.405, p = .0001), where passives and object clefts were comprehended less accurately than actives and subject clefts. Again, there was no interaction of presentation condition with sentence type (F(3,438) = .847, p = .4468).

Finally, we determined whether any of our normal subjects (in either normal or fast conditions) would be classified as "agrammatic" using any of Grodzinsky's (2000) criteria. First we found that 6 subjects in the normal, and 11 in the fast condition performed perfectly on active sentences, and at chance (50% correct) on passives (see Figure 2c). In addition, 0 normal and 2 fast presentation condition subjects were "true agrammatics", with perfect performance on actives and subject clefts, and 50% performance on passives and object clefts. Finally, using the looser definition of Grodzinsky et al. (1999), we found that 1 normal and 3 fast presentation condition subjects were agrammatic by these criteria, where performance on actives and subject clefts was perfect, and performance on passives and object clefts was between 35% and 65% correct**.** In other words, performance equivalent to either definition of "core" agrammatism can be observed in normal listeners, especially when performance is assessed under speeded processing conditions.

2. Relationship of general discourse comprehension to syntactic comprehension

In order to better understand how subjects' general discourse comprehension abilities might relate to their ability to comprehend complex syntax, we first grouped all subjects by their performance on the Multi-Media Comprehension Battery (Gernsbacher & Varner, 1988). We classified subjects who scored above the top quartile cutoff (22.5% of subjects) as "High" comprehenders, and classified those who scored below the bottom quartile cutoff (22.5% of subjects) as "Low" comprehenders. Subjects who fell between these two extremes (Medium) were not included in any categorical analyses. We then investigated whether *High* and *Low* discourse comprehenders performed differently on our test of syntactic comprehension.

Figure 1b: Average percent correct response for levels of sentence difficulty, split by discourse comprehension level (normal sentence presentation only), Experiment 1a.

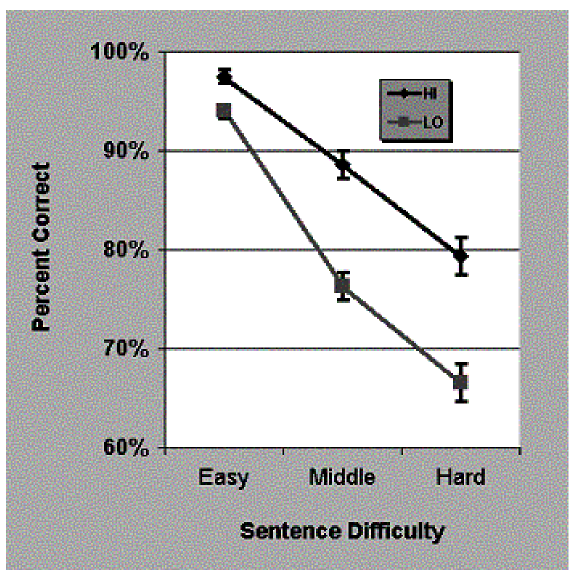

Figure 1b

A 2-within (Sentence Type x Presentation Condition), 1-between (Discourse Comprehension Level) ANOVA revealed a significant main effect of Discourse Comprehension Level ($F(1, 64) = 20.182$, $p = .0001$), where *High* comprehenders were 8.5% more accurate overall in their syntactic comprehension than were *Low* comprehenders. There was a marginally significant interaction of Presentation Condition with Discourse Comprehension Level ($F(1, 64) = 3.621$, $p = .0616$), where *High* comprehenders appear to be more negatively affected by the fast presentation than are *Low* comprehenders. This is, of course, *not* the direction that we predicted for this interaction.

However, comprehension level did interact in the predicted fashion with sentence type ($F(11, 704) = 2.596$, $p = .0092$) where both *High* and *Low* comprehenders interpreted active, subject cleft, and ditransitive sentence types almost equally accurately, but *Low* comprehenders were significantly less accurate in interpreting the more complex sentence types; this is borne out by a significant interaction of Comprehension Level with Difficulty ($F(2, 128) = 9.310$, $p = .0004$) – see Figure 1b. Again contrary to our predictions, the effect of sentence type and comprehension level did not significantly interact with speed of presentation ($F(11, 704) = 1.109$, $p = .3553$).

When we narrowed our focus to the sentences comprising the "core data" of agrammatism, we again found that discourse comprehension level significantly interacted with sentence type ($F(3, 192) = 7.374$, $p = .0006$), where both *High* and *Low* comprehenders interpreted actives and subject clefts at near-ceiling levels, but *Low* comprehenders were at a severe disadvantage in interpreting both passives and object clefts compared to their high-comprehender counterparts – see Figure 1c. Once again, however, this effect did not further interact with presentation speed ($F(3, 192) = .379$, $p = .7173$).

Summary of Results for Experiment 1a

Accuracy in auditory syntactic comprehension appeared to be affected by a few basic principles. The easiest sentences followed the most frequent word order in English (Subject-Verb-Object), and contained only 2 or 3 actors; the middle-difficulty sentences were either 2 actor/1 verb sentences with noncanonical word orders (OVS/OSV), or were 3-or-4-actor/2-verb sentences with canonical word order (Figure 1a). The most difficult sentences simply combined noncanonical word order with the greater number of actors and verbs. It is worth noting that perfectly healthy college students were affected by these factors, independent of processing conditions: when faced with the most difficult sentence types, the average student made an error one of every four times. In contrast to the results of Miyake et al., students' comprehension of the more challenging sentence types was not exacerbated by speeded presentation; indeed, this stressor had only a very slight impact overall. This skill-related difference in syntactic comprehension did not translate into greater susceptibility to the fast condition, in that there was no interaction of difficulty, skill level, and presentation processing. However, students' discourse comprehension skill *did* predict how accurately they processed more complex sentences, with low-skill comprehenders finding all but the easiest sentence types significantly more challenging than did high-skill comprehenders (Figure 1b). This finding also applied to the sentences comprising the "core data" of agrammatism (Figure 1c). As predicted by statistical or computational accounts, we did observe a fairly large number of naturally occurring "dissociations" in syntactic comprehension in both normal and compressed speech conditions (Figure 2c). However, the auditory compression manipulation had relatively little effect. This brings us to Experiment 1b, in which the same stimuli are used (including the discourse comprehension variable) with a stronger stress manipulation.

Method - Experiment 1b

Participants

131 University of Wisconsin - Madison undergraduate students participated in the study. All were enrolled in Introductory Psychology courses and received extra credit points for their time. All were native English speakers. Participants were treated in accordance with the "Ethical Principles of Psychologists and Code of Conduct" (American Psychological Association, 1992).

Design

As in Experiment 1a but for the substitution of the compression-plus-low-pass-filter condition for the compression-only condition.

Materials and Procedure

As in Experiment 1a, but for the above substitution. The compression-plus-low-pass-filter stimuli were created by imposing a 1000Hz low-pass filter over a copy of the original compressed sentences (using SoundEdit16). This process reduced by >20 dB all spectral information above 1000Hz without any further spectral or temporal distortions.

Figure 1c: Average percent correct response for sentences comprising the 'core data' of agrammatism, split by discourse comprehension level (normal sentence presentation only), Experiment 1a.

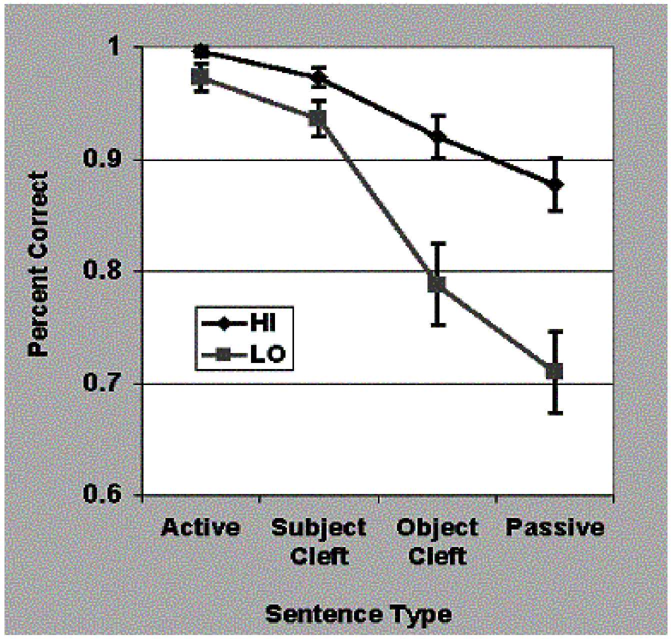

Figure 1c

Results - Experiment 1b

We report the results of Experiment 1b following the same structure and guidelines used in the previous results section. Three subjects of 131 total were eliminated from these analyses due to computer failure or missing values, leaving 128 subjects for analysis.

1. Syntactic comprehension under Normal vs. Low-Pass Filter plus Speech Compression (LPC) conditions

A 2-within subject (sentence type x presentation condition) omnibus ANOVA showed a main effect of presentation, where students under the normal condition were much more accurate overall than students under the LPC condition ($F(1, 127) = 395.228$, $p = .0001$). Accuracy also differed significantly over sentence type ($F(11, 127) = 65.568$ $p = .0001$), and sentence type also interacted strongly with presentation condition ($F(11, 1397) = 7.327$, $p = .0001$ - see Figure 2a), where comprehension of many "difficult" sentence types (such as passives, object clefts, ditransitives) was greatly impaired in the LPC condition relative to easier sentence types (such as actives and subject clefts - see below for analyses of sentence difficulty.)

We again performed Bonferroni-adjusted pairwise comparisons over all sentence types, separately for each presentation condition. As shown in Figure 2a, comprehension of sentence types under *normal* conditions again broke down into "Easy", "Mid", and "Hard" sentence types (shaded ellipsoids in Figure 2a), with accuracy scores closely paralleling those in Experiment 1a. Indeed, scores on sentence types in the two experiments differed at the most -5.34% (on passives), and on average only differed -.76%, with subjects in Experiment 1a being more accurate.

As before, the 3 sentence types we class as *Easy* are actives (ACS), subject clefts (CLS), and dative subjects or ditransitives (DAS). Again, performance on actives and subject clefts was generally high, and did not differ, whereas accuracy on simple ditransitives (DAS) was significantly lower than actives and marginally lower than subject clefts, but was closer in overall accuracy to these types than to any others. Comprehension accuracy for all three sentence types averaged 94% (range: 89.5-96.5%). *Mid*-difficulty sentence types were again: coordinated subjects (CDS), object clefts (CLO), conjoined subjects (CJS), center-embedded subjects (CES), passives (PAO), and right-branching subjects (RBS); performance on these sentence types clustered around 80.5 % correct response (range: 78.4-82.8%). Correct response did not differ over these 6 constructions, but did differ significantly from all other sentence types. *Hard* sentences were, as before, right-branching objects (RBO), dative objects (DAO), and center-embedded objects (CEO); performance on these sentence types clustered around 73.9% (range: 73.5-74%) and no *Hard* sentence type differed significantly from any other.

In the *LPC* condition, this "tripartite" grouping began to unravel somewhat. The easiest sentence types, actives and subject clefts, were still comprehended best, and did not significantly differ from each other in response accuracy. However, the other "easy" sentence type, the ditransitive, became much more difficult to comprehend under the LPC condition, where it did not differ in accuracy from most *Mid* and *Hard* sentences. This vulnerability under stress (compared to the other easy sentences) may stem from the third actor present.

Figure 2a: Average percent correct response for each sentence type in normal and 66% speech rate compression plus 1000Hz low-pass-filter conditions, Experiment 1b. Shaded ellipsoids indicate that means within each ellipsoid do not differ significantly.

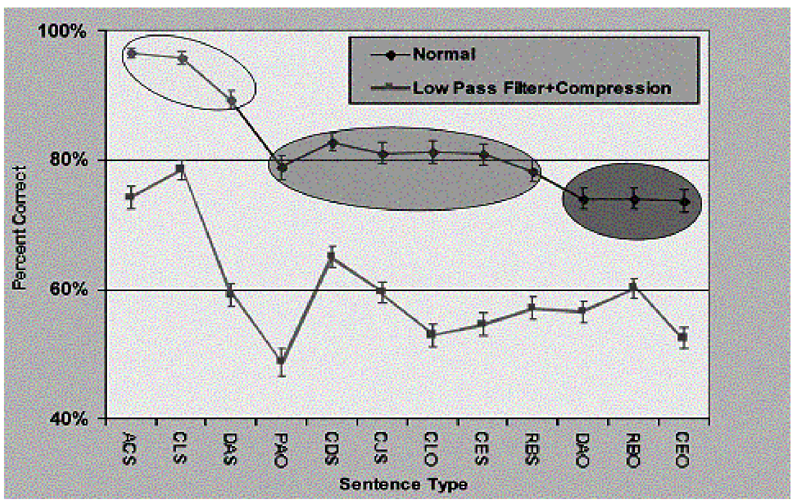

Figure 2a

The *Mid* sentence types were also hard-hit by the combined stressor, and tended to be comprehended at the same levels as the *Hard* sentences. Passives and object clefts were especially difficult to understand (perhaps due to the non-canonical word order), as were center-embedded subjects. Coordinated-subject sentences seemed to show some sparing, compared to passives and object clefts, perhaps because of the use of canonical word order. *Hard* sentence types all tended to be comprehended near chance levels, although right-branching objects did appear to be somewhat more spared than center-embedded objects. We note, however, that all differences in the *Mid* and *Hard* sentences are small -- the more important trend is that *Mid* difficulty sentence types seem to sink to *Hard* levels under the dual stressor, and that both are comprehended at or slightly above chance.

These general observations were confirmed by a 2-within-subject (Difficulty x Presentation) ANOVA. There was a main effect of difficulty (Easy, Mid, Hard) ($F(2, 254) = 308.174$), $p = .0001$), where accuracy was in general much lower under the LPC condition; there was also a significant interaction of difficulty and presentation ($F(2, 254) = 10.507$, $p = .0001$), with both *Mid* and *Hard* sentence types pushed to floor levels in the LPC condition, with *Easy* sentence comprehension around 72%.

We then examined the subset of *Easy* and *Mid/Hard* sentences representing the "core data" of agrammatism: Not only were there main effects of sentence type ($F(3, 381) = 147.858$, $p = .0001$), (with actives and subject clefts more accurately comprehended than passives and object clefts), and presentation ($F(1, 127) = 310.763$, $p = .0001$) (with accuracy in Normal presentation higher than LPC) but there was a significant interaction of sentence type with presentation ($F(3, 381) = 8.544$, $p = .0001$), where comprehension of passives and object clefts fared much worse in LPC than in normal conditions, relative to actives and subject clefts (see Figure 2b). Hence the predicted interaction between sentence type and presentation condition does appear when a more difficult stress condition is employed.

Figure 2b: Average percent correct response for sentences comprising the 'core data' of agrammatism, split by presentation condition, Experiment 1b.

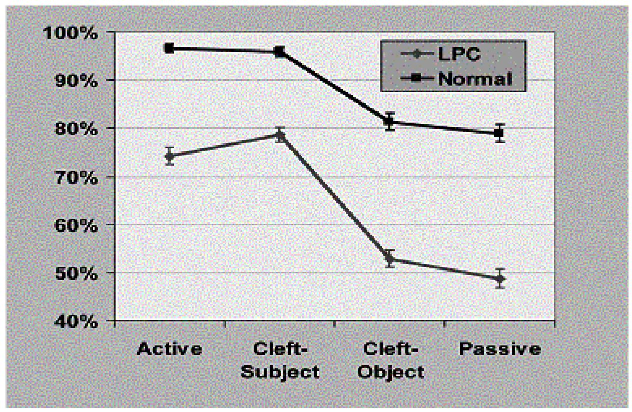

Figure 2b

As with Experiment 1a, we looked to see whether our normal subjects (in either normal or LPC conditions) would be classified as "agrammatic" using any of Grodzinsky's (1999) criteria. Three subjects in the normal, and 6 in the LPC condition performed perfectly on active sentences, and at chance (50% correct) on passives. In addition, 0 normal and 1 LPC condition subjects were "true agrammatics", with perfect performance on actives and subject clefts, and 50% performance on passives and object clefts (see Figure 2c). Finally, using the "probabilistic" definition of Grodzinsky et al. (1999), we found that 5 normal and 4 LPC condition subjects were agrammatic, where performance on actives and subject clefts was perfect, and performance on passives and object clefts was between 35% and 65% correct[2].

2. Relationship of general discourse comprehension to syntactic comprehension

Following the procedure outlined in Experiment 1a, we grouped our subjects into *High*-, *Medium*-, and *Low*-skill comprehenders, again dropping *Medium*-skilled subjects for group analyses. Before examining any effects of presentation condition, we examined the data from the *Normal* condition only as a way to verify the relationship between discourse comprehension level and syntactic processing we uncovered in Experiment 1a (where *Low* comprehenders were less accurate in interpreting *Mid*- and *Hard*- difficulty sentences than were *High* comprehenders). A 1-within (sentence type) by 1-between (discourse comprehension level) ANOVA did show that *Low* comprehenders were generally less accurate than were their *High* counterparts ($F(1, 58) = 5.137$, $p = .0272$); in contrast to Experiment 1a, the interaction of sentence type and discourse comprehension level failed to reach significance ($F(11, 638) = 1.428$, $p = .1829$). However, when sentence types were grouped by difficulty as in Experiment 1a, we saw both the effect of discourse comprehension level ($F(1, 58) = 4.877$, $p = .0312$) and the interaction of difficulty with comprehension level ($F(2, 116) = 4.193$, $p = .0175$) where *Low*-skill comprehenders were again less accurate in interpreting *Mid*- and *Hard*-difficulty sentences than were *High*-skill comprehenders, while both groups were equally accurate with *Easy* sentence types.

We then expanded our window of analysis to include both *Normal* and *LPC* conditions: a 2-within

[2] The relatively small number of 'probabilistic' aphasic profiles in the LPC condition is due to the hard constraint of perfect performance on actives and subject clefts, as many LPC conditions subjects made a single mistake on one of these sentence types.

(sentence type x presentation condition), 1-between (discourse comprehension level) ANOVA revealed a main effect of discourse comprehension level ($F(1, 58) = 5.348$, $p = .0243$), where *High* discourse comprehenders were more accurate overall in their syntactic comprehension than were *Low* comprehenders. Contrary to our expectations, there was no interaction of presentation with discourse comprehension level ($F(1, 58) = 1.484$, $p = .228$), nor was there a three-way interaction of presentation, discourse comprehension level, and sentence type ($F(11, 638) = 1.396$, $p = .1903$). When we again regrouped sentence types by difficulty level, we failed again to find a three-way interaction of discourse level, presentation, and difficulty ($F(2, 116) = 2.251$, $p = .1139$). We speculate that the lack of effects may be in part due to floor effects for *Mid*- and *Hard*-difficulty sentences in the LPC condition (as depicted in Figure 2a).

Figure 2c: Number of subjects falling into agrammatic categories in Experiments 1a and 1b.

Experiment	"True" Agrammatic	Active 100% Passive 50%
Experiment One, *Normal*	0	6
Experiment One, *Compression*	2	11
Experiment Two, *Normal*	0	3
Experiment Two, *Low Pass/Compression*	1	6

Figure 2c

Summary of Results - Experiment 1b

Results from the Normal presentation condition replicated those of Experiment 1a, where sentences fell into Easy, Middle, and Hard comprehension accuracy groupings (as described above); low discourse skill again predicted increased difficulty with Middle and Hard sentences. Unlike the single stressor of Experiment 1a, the LPC manipulation had a striking effect on comprehension, particularly on Middle and Hard sentences, which tended to be comprehended at chance levels. The "selective" effect of the LPC stressor was particularly dramatic in the prototypic active/subject cleft vs. passive/object cleft contrast, where both actives and subject clefts were relatively spared, while passives and object clefts were at chance levels. Contrary to expectations, there was no three-way interaction of stressor, discourse comprehension skill, and sentence difficulty. We speculate that this may be due to floor effects for the harder sentence types under the LPC condition.

Overall Discussion

There are several noteworthy results here. First, sentence processing difficulty appears to predicted by two simple factors: word order frequency, and number of propositions. If sentences use the most common word order (SVO) and contain one verb and 2-3 nouns (1 proposition), they are easy to understand. If they contain 3-4 actors and 2 verbs (2 propositions), OR use an infrequent word order (OVS or OSV), then they are moderately difficult; when the two factors are combined, sentences are the most difficult (of the set tested). These levels of difficulty appear to be quite stable, in that the stratification did not differ over Experiments 1a and 1b.

However, the *mean* performance masks considerable individual differences in performance. Within two separate samples of healthy college students, we found "textbook examples" of agrammatic performance, both in the active-passive contrast, and the active/subject cleft vs. passive/object cleft contrast. The fact that such dissociations occur in two samples of neurologically intact normals indicates that the use of such "exclusionary criteria" as a diagnostic for locus of brain damage is a questionable pursuit (for further discussion see Juola & Plunkett, 1998; Munakata, 2001; Van Orden, Pennington, & Stone, 2001).

Second, the *extent* to which syntactic difficulty manifests itself is predicted by an individual's ability to draw inferences from higher-level discourse. Subjects who have relatively low discourse skill levels keep up with their high-skill counterparts when interpreting simple syntactic forms, but are much less successful than high-skilled comprehenders in interpreting sentences with more complex syntactic and propositional relationships. This result could be taken as suggesting that the same cognitive resources comprehenders use for making higher-order inferences are the ones they use for syntactic and/or propositional processing. Of course, one could argue that there is a "chicken and egg" problem here, in that having less syntactic processing resources could make comprehenders less efficient discourse processors. At the very least, the fact that low-skill comprehenders also exhibit a statistically significant (if qualitative) agrammatism again indicates that such "deficits" are not exclusive to brain injury. This point is brought home by the results of the "dual-stress" condition, where the *average* performance of college students is very similar to that reported for agrammatic patients. Not only is the gulf in accuracy between the easier and more difficult sentences greatly increased, but comprehension of the harder sentences falls around chance levels. In fact, when average performance on the "core data" of agrammatism is assessed, accuracy on both passives and object clefts hovers at almost exactly 50%, while active and subject cleft levels are at about 80%.

Third, manipulations of sentence processing are neither modality neutral nor stimulus neutral. With exactly the same sentences used by Miyake et al., we found only a minuscule effect of speeded presentation alone (our auditory analogue of RSVP), and no differential effect of speeded presentation on sentence type. Hence we fail to replicate this aspect of Miyake et al.'s results in the auditory modality. At the very least, such a finding should heighten our attention to the effect of modality on language processing (see also Federmeier, 1999). Syntactic processing may be more tightly linked to perceptual systems than an abstract symbolic account might predict.

Finally, in both experiments we failed to find the predicted three-way interaction of stress condition, sentence type/difficulty, and comprehension level. Whereas we predicted that low-skill comprehenders would be more affected by the stressors, especially when interpreting complex sentences, we did not find any evidence to support this hypothesis. The lack of effects in Experiment 1b may be due in part to floor effects for all subjects in the LPC condition; however, it should be noted that neither Miyake et al. nor Caplan and Waters have found significant interactions of this type. We are currently beginning experiments on a more sensitive set of materials (those used in Dick et al., 2001) in order to better evaluate the relationship between general comprehension level, stress, and sentence complexity.

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