MIT Libraries | DSpace@MIT

MIT Open Access Articles

A rational inference approach to aphasic language comprehension

Massachusetts Institute of Technology

A rational inference approach to aphasic language comprehension

Edward Gibson[1], Chaleece Sandberg[2], Evelina Fedorenko[3], Leon Bergen[1] &

Swathi Kiran[4]

[1]Brain and Cognitive Sciences Department, Massachusetts Institute of Technology

[2]Department of Communication Sciences and Disorders, Pennsylvania State University

[3]Psychiatry Department, Massachusetts General Hospital

[4]Sargent College of Health and Rehabilitation Sciences, Boston University

Send correspondence to:

Edward Gibson, 46-3035, MIT, Cambridge, MA 02139; Email: egibson@mit.edu

Chaleece Sandberg, 308 Ford Building, Pennsylvania State University, University Park

PA 16802; Email: cws18@psu.com

Manuscript dated September 15, 2015

Please do not cite or quote without permission

Abstract

It has long been observed that, when confronted with an implausible sentence like *The ball kicked the girl*, individuals with aphasia rely more on plausibility information from world knowledge (such that a girl is likely to kick a ball, but not vice versa) than control non-impaired populations do. We here offer a novel hypothesis to explain this greater reliance on plausibility information for individuals with aphasia. The hypothesis is couched with the rational inference approach to language processing (e.g., Shannon, 1949; Levy et al., 2009; Gibson, Bergen & Piantadosi, 2013; cf. Bates, McDonald, MacWhinney & Appelbaum, 1991). A key idea in this approach is that to derive an interpretation for an input string, individuals combine their priors (about messages that are likely to be communicated) with their knowledge about how messages can get corrupted by noise (due to production or perception errors). We hypothesize that language comprehension in aphasia works in the same way, except with a greater amount of noise, which leads to stronger reliance on syntactic and semantic priors. We evaluated this hypothesis in an act-out task in three groups of participants (individuals with aphasia, older controls, younger controls) on two sets of materials: (a) implausible double-object (DO) / prepositional-phrase object (PO) materials, where a single added or deleted word could lead to a plausible meaning; and (b) implausible active-passive materials, where at least two added or deleted words are needed to arrive at a plausible meaning (Gibson, Bergen & Piantadosi, 2013). We observed that, similar to controls (e.g., Gibson et al., 2013), individuals with aphasia rely on plausibility to a greater extent in the DO/PO than in the active/passive alternation. Critically, however, as predicted, individuals with

aphasia rely less on the literal syntax overall than either of the control groups, and use their world knowledge prior (plausibility) in both the active/passive and DO/PO alternations, whereas controls rely on plausibility only in the DO/PO alternation. In addition, older persons and persons with aphasia made more errors on the DO structures (which are less frequent than PO structures) independent of plausibility, thus providing evidence for reliance on a syntactic prior, the more frequent structure.

Introduction

It is currently well-established that adults typically use a variety of sources of information – including the lexicon, syntax, world-knowledge, discourse, and prosody, constrained by working memory – to arrive at an interpretation for a sentence (for reviews see Gibson & Pearlmutter, 1998; Tanenhaus & Trueswell, 1995). An important open question in the literature involves understanding how the process of language interpretation is disrupted in patients with agrammatism.

Patients with agrammatism have difficulty using grammatical information, in both comprehension and production. In production, these patients can often haltingly produce content words, but will often have additional difficulty using function words (e.g., Biassou, Obler, Nespoulous, Dordain, & Harris, 1997; Friederici & Schonle, 1980; Gardner & Zurif, 1975). In comprehension, such patients have long been known to have difficulty in understanding low frequency words in sentences (Gahl, 2003; Gahl et al. 2003) and low frequency syntactic constructions when world knowledge does not constrain interpretation (Caramazza & Zurif, 1976; Heilman & Scholes, 1976; Caramazza, Berndt, Basili, & Koller, 1981; Bates, Friederici, & Wulfeck, 1987), such as the passive construction (1b) or an object-extracted relative clause (2b):

(1)

a. Active: The tiger chased the lion.

b. Passive: The lion was chased by the tiger.

(2)

a. Subject-extracted relative clause: The tiger that chased the lion caught the zebra.

b. Object-extracted relative clause: The lion that the tiger chased caught the zebra.

For example, in act-out tasks – where participants are asked to demonstrate the meaning of a sentence using dolls or animal figurines – patients with agrammatism typically show relatively intact performance when conveying the meaning of an active sentence like (1a), but are typically much worse at indicating who did what to whom in a passive sentence like (1b), and will often act out the reverse meaning: the lion chasing the tiger (Schwartz, Saffran, & Marin, 1980; Caplan, DeDe, & Michaud, 2006; Caplan, Michaud, & Hufford, 2013; Salis & Edwards, 2009). Similarly, an agrammatic patient can usually understand the meaning of a subject-extracted relative clause as in (2a), but may make many errors in understanding the meaning of an object-extracted relative clause as in (2b), and will often act out the reverse meaning: the lion chasing the tiger (Caramazza & Zurif, 1976; Caplan, DeDe, & Michaud, 2006; Caplan, Michaud, & Hufford, 2013).

Agrammatism is most often linked with nonfluent aphasia, such as Broca's and Transcortical Motor aphasia, and has historically been the focus of the study of sentence comprehension deficits in aphasia. However, persons with anomic aphasia (Berndt, Mitchum, & Wayland, 1997), mild fluent aphasia (Salis & Edwards, 2009), and mild expressive aphasia (Love & Oster, 2002) have been shown to perform worse during comprehension of noncanonical sentences, as in (1b) and (2b), than canonical sentences, as in (1a) and (2a). Thus, it is becoming evident that sentence comprehension deficits affect a wide range of aphasia types, and this paper will therefore discuss sentence comprehension deficits within persons with aphasia in general.

One well-known class of explanations of sentence comprehension deficits is that syntactic knowledge is somehow damaged in persons with aphasia. According to this view, more complex syntactic operations in constructions like passives and object-extracted relative clauses are difficult for persons with aphasia (Caramazza & Zurif, 1976; Caplan, 1981; Grodzinsky, 1986; 1995a; 1995b; 2000). A challenge for this view is that some patients often have preserved ability to judge which sentences are grammatical and which are not, even for complex structures (Linebarger, Schwartz, & Saffran, 1983; Wulfeck, 1988; Shankweiler, Crain, Gorrell, & Tuller, 1989; Wulfeck & Bates, 1991). Furthermore, a number of case studies have reported patients who display expressive agrammatism but no apparent comprehension deficit (Kolk & van Grunsven, 1985; MacWhinney, Osmán-Sági, & Slobin, 1991). These patients appear to lack the ability to generate many linguistic structures, but they can understand them. Moreover, when under increased memory demands, people without aphasia have difficulty on the same structures that persons with aphasia have (Miyake, Carpenter & Just, 1994; Dick et al., 2001). The overall pattern of evidence is thus most consistent with a model of sentence comprehension deficits where syntactic knowledge is preserved, but access to and processing of this knowledge is impaired in some way, such that accessing lower frequency syntactic constructions is more difficult for persons with aphasia than for neurologically healthy adults (Bates, Wulfeck, & MacWhinney, 1991; Wulfeck & Bates, 1991; Dick et al., 2001; cf., Friederici, 1988; Prather, Shapiro, Zurif, & Swinney, 1991).

An open question for all approaches is why persons with aphasia seem to rely more on meaning than control participants when confronted with implausible sentences (Caramazza & Zurif, 1976). For example, consider the implausible examples in (3):

6

(3)

a. Active: The ball kicked the girl.

b. Passive: The girl was kicked by the ball.

With no memory component to the language comprehension task (e.g., written sentence-to-picture matching), a non-impaired participant will typically interpret these sentences according to the literal meaning assigned by the syntax, which results in the implausible meaning: a ball kicking a girl (MacWhinney & Bates, 1989; Gibson, Bergen & Piantadosi, 2013). When a memory component is added to the task, participants have more difficulty interpreting implausible sentences according to the literal meaning assigned by the syntax for the lower frequency passive structure, but still arrive at the implausible meaning for the active structure most of the time (Ferreira, 2003). In contrast, persons with aphasia often interpret such materials according to the more plausible interpretation (a girl kicking a ball) (Caramazza & Zurif, 1976; Kudo, 1984; Saffran & Schwartz, 1994; Saffran, Schwartz & Linebarger, 1998). The view whereby syntactic knowledge is damaged in persons with aphasia could explain this observation: damage to syntactic knowledge may force persons with aphasia to rely more on non-syntactic knowledge. But this proposal faces the problem raised above, that individuals with aphasia are typically good at judging the grammaticality of sentences, certainly for high-frequency syntactic structures like active sentences. So why then do they rely less on syntactic information in these situations?

One possible explanation for the observed effects is a generalization of earlier proposals (Caramazza & Zurif, 1976; Caplan, 1981; Grodzinsky, 2000): that more complex syntactic structures (like object-extracted relative clauses as compared to subject-extracted relative clauses) require more working memory to retain and process (cf. discussion of complexity in Caplan, Waters & Hildebrandt, 1997; Caplan & Waters, 1999; Miyake, Carpenter & Just, 1994; Caplan, Michaud & Hufford, 2013). This could be because there are operations in complex structures that are difficult to perform, such as long-distance dependency formation (e.g., Gibson, 1998, 2000), or it could be that structures are complex because they are less frequent (e.g., Hale, 2001; Levy, 2008a). Here, we will discuss this idea in terms of construction frequency (e.g., Goldberg, 2006), because it may apply most generally, to the passive / active comparison in addition to the relative clause comparison. Under some syntactic frameworks, passive structures are derived from active structures via syntactic movement, which might lead to longer or more complex dependencies in passives compared to actives (e.g., Chomsky, 1981; MacDonald, 1989). But in other frameworks, such as Lexical Functional Grammar (Bresnan, 1982) or Construction Grammar (Goldberg, 2006), passives are related to actives only via a lexical rule, so that there is no difference in dependency distance between the two. One – the passive – is simply less frequent than the other – the active. We currently see no compelling reason to favor the syntactic-movement based hypothesis. Consequently, we discuss the observed syntactic complexity differences in terms of syntactic structure frequency, and we refer to this hypothesis as the *structural frequency* hypothesis.

If working memory for language is damaged in persons with aphasia, then, depending on the task, they might show more or less of a deficit. They might succeed with both simple (frequent) and complex (infrequent) structures in a task with low working memory demands, such as an acceptability judgment, where accurate performance does not require semantic interpretation, but fail with infrequent structures in tasks with higher working memory demands, such as an act-out task, where the interpretation of meaning is needed for accurate performance. This could explain at least part of the behavior given implausible sentences: this hypothesis predicts that persons with aphasia should have difficulty with interpreting the implausible low-frequency syntactic structures, like passives, so that (3b) *The girl was kicked by the ball* should be interpreted sometimes as the active *The girl kicked the ball* (possibly due to an "agent-first" strategy when a structure is too complex). But the converse is not expected: persons with aphasia should not misinterpret an implausible active sentence like *The ball kicked the girl*, since its syntactic structure is so frequent.

In this paper, we propose an alternative explanation for why persons with aphasia rely more on their priors – consisting of their syntactic priors (construction frequency information) and their semantic priors (plausibility information) – during the process of language interpretation. We propose that this property of impaired comprehension follows from a Bayesian approach to sentence comprehension, under which there is a possibility of noise corrupting the intended meaning (Shannon, 1948; Jelinek, 1976; Aylett & Turk, 2004; Clayards et al., 2008; Levy, 2008b; Levy et al., 2009; cf. Bates et al., 1991; MacWhinney et al., 1991), which we will refer to as the *noisy-channel* or *rational inference* approach. In a linguistic exchange, it is not uncommon that the

speaker might make an error and intend something different than what they actually said. The comprehender's guess of what the speaker intended can be formalized as the probability of the speaker's intended meaning (s_i) given the perceptual input (s_p): $P(s_i \mid s_p)$. By Bayes' rule, this is achieved by multiplying the prior (i.e., what is likely to be said), $P(s_i)$, with the likelihood that a noise process would generate s_p from s_i, $P(s_i \rightarrow s_p)$. The noise likelihood term $P(s_i \rightarrow s_p)$ encodes the comprehender's knowledge of how sentences are likely to be corrupted during speech transmission—for instance, the fact that smaller changes to a sentence are likelier than larger ones. Gibson et al. (2013) showed that the noisy-channel approach is supported by four kinds of results in their sentence comprehension experiments, two of which are most relevant to the current experiment:

   a) The rate of literal interpretation was affected by how close an implausible sentence string was to a plausible alternative, with fewer insertions and deletions leading to a higher rate of participants using plausibility information instead of the literal syntax to derive their interpretation. For example, Gibson et al. found that people generally rely on the literal string to interpret active vs. passive materials as in (3a) and (3b). In (3a), two deletions (of *was* and *by*) are required in order to get from the plausible passive sentence *The ball was kicked by the girl* to the implausible active sentence in (3a). And in (3b), two insertions (of *was* and *by*) are required in order to get from the plausible active sentence *The girl kicked the ball* to the implausible passive sentence in (3b).

   In contrast, Gibson et al. found that people are much less likely to rely on the literal string to interpret double-object (DO) vs. prepositional phrase

10

object (PO) materials as in (4a) and (4b), arguably because fewer edits from a plausible alternative are needed in these examples. In (4a), only one deletion is needed from the plausible sentence *The brother gave the bike to the sister* in order to generate (4a), and only one insertion is needed to generate (4b) from *The brother gave the sister the bike.*

(4)

a. Implausible DO: The brother gave the bike the sister.

b. Implausible PO: The brother gave the sister to the bike.

b) The rate of literal interpretation was lower for a single-word deletion from a plausible alternative relative to a single-word insertion to plausible alternative. For example, participants were less likely to follow the literal syntactic interpretation of an example like (4a) – which can be formed by deleting one word (*to*) from the plausible string *The brother gave the bike to the sister* – than they were to follow the literal syntactic interpretation of an example like (4b) – which can formed by inserting the word *to* in the plausible string *The brother gave the sister the bike.*

   The prediction that deletions are more likely to result in non-literal interpretations than insertions is argued to follow from the Bayesian size principle (MacKay, 2003; Xu & Tenenbaum, 2007), because a deletion of a word is much more likely than an insertion of a particular word.

Thinking about language comprehension in this way provides us with a natural class of explanations for why individuals with aphasia may rely more on plausibility than non-impaired individuals in interpreting utterances. The basic idea is that individuals with aphasia assign higher probability to noise corrupting the messages they receive (cf. McDonald & MacWhinney, 1989, who proposed that individuals with aphasia process language using a maximum likelihood estimator model assuming overall processing through noise).[1] Several hypotheses can be constructed about the origins of this higher noise probability. One possibility is that persons with aphasia actually have higher levels of noise in their perceptual system (Dick et al., 2001), and so their language processing system is more likely to receive corrupted messages. This possibility seems unlikely given that a) most persons with aphasia have intact lower-level auditory / visual processing, and b) deficits at the sentence interpretation level look similar regardless of whether the materials are presented auditorily or visually. A more plausible hypothesis is that the language *processing* system is noisier for persons with aphasia. For example, this system may have difficulty maintaining an accurate representation of the linguistic input, or in accurately retrieving this input from memory. This process may even be driven by high-level meta-cognitive reasoning in patients with a production deficit but without a comprehension deficit. In particular, an individual with a production deficit may believe that their deficit is general in their language system, leading them to postulate noisier representations during comprehension.

---

[1] Caplan, DeDe, & Michaud (2006) and Caplan, Michaud, & Hufford (2013) appeal to a different notion of noise in explaining some of their experimental results. In particular, they appeal to measurement error to explain why sometimes a participant with aphasia appears to do better than the baseline in a particular condition (e.g., Caplan, Michaud, & Hufford (2013, p. 22). Note that this is a different notion of noise than we are discussing here. In our case, the relevant notion is that noise can hinder communication. In contrast, the cases that Caplan et al. discuss do not involve noisy communication.

Regardless of why persons with aphasia may assign higher probability to noise corrupting the messages, their calibration to a higher noise rate will lead to discounting the precise (literal) form of the linguistic input. During communication, the goal of a person with aphasia – as any other individual – is to understand speaker intent. Thus, if they infer that the utterance they received may have been corrupted by noise, they will rely more on their prior beliefs about what meaning the speaker wanted to communicate, and which linguistic expressions the speaker would have used to communicate this intended meaning. The degree to which the interpretation is based on the prior is thus a function of how noisy the input is assumed to be.

In the current paper, we test the rational inference account in a act-out paradigm, using two of the syntactic alternations that Gibson et al. (2013) used in their sentence comprehension experiments: actives / passives as in (3) and DO/PO structures, as in (4).

Rational inference predictions.

1. The rational inference approach predicts that persons with aphasia should sometimes rely on plausibility information rather than the literal syntax because, by hypothesis, their representations are sometimes corrupted by noise. Thus this account predicts a main effect of plausibility for persons with aphasia in each construction. This effect should be smaller in the control populations, whose linguistic representations are less corrupted by noise. Thus participants with aphasia are predicted to have a lower rate of literal interpretation, across all item types.

2. The rational inference approach predicts a larger effect of plausibility in the DO/PO structures – which only require one edit to shift from one alternative to the other – than in the active-passive structures – which require two edits. Thus, the rational inference approach predicts an interaction between sentence plausibility (plausible / implausible: the reliance on the prior) and the number of edits (active/passive vs. DO/PO), for each population. In Gibson et al. (2013), this analysis was presented as a main effect between active/passive and DO/PO of the number of edits in the implausible conditions because the plausible versions were interpreted literally close to 100% of the time. We include the plausible baseline conditions here, because participants are unlikely to be close to 100% in following the literal interpretation for these materials, for several reasons. First, individuals with aphasia make many more errors on language tasks than control participants, and are thus likely to make errors even on some plausible materials. Second, the materials are presented auditorily and only once (cf. visual presentation with no time constraints in Gibson et al., 2013). This method places greater demands on memory. Third, participants can't use plausibility as a strong cue to interpretation in the current set of materials, because of the higher percentage of implausible items in these materials compared to Gibson et al.'s.

3. The rational inference approach predicts an effect of deletions vs. insertions for the DO/PO structures for each population, replicating Gibson et al. (2013). That is, participants in each population should interpret a DO item as a deletion from a PO more often than they should interpret a PO item as an insertion to a DO. This

asymmetry is additionally predicted because there is a structural frequency asymmetry between the DO and PO structures: The DO structure occurs frequently with a pronoun as its indirect object (e.g., *Mary gave me a book*), but it is rare for the DO structure to occur with two full noun phrases, as in the current examples (Bresnan, 2007). In contrast, the PO structure occurs more often with two full noun phrases. Thus the rational inference approach predicts an effect of structural frequency for the DO/PO items, such that people are more likely to interpret a DO as a PO (the higher syntactic prior) than vice versa. Thus, the rational inference account predicts more errors with the DO than PO structures, and that this effect may be exacerbated in the implausible versions (cf. O'Grady & Lee, 2005, for other possible reasons why PO structures might be easier to process than DO structures). The prediction does not extend to the active/passive construction pair, even though the passive structure occurs less frequently than the active one. This is because both the active and passive constructions require two edits in order to be corrected, and thus neither is predicted to be corrected by a rational comprehender (Gibson et al. 2013), under the noise model considered here (insertions and deletions).

Experiment

Methods

Participants   Three groups of participants were recruited to participate in the study:

Persons with aphasia. Eight persons with chronic aphasia secondary to stroke (at least 6 months post-onset) aged 29-67 years (mean = 55.8; 5 male, 3 female) were

recruited from the Aphasia Research laboratory at Boston University (BU). All

participants were native English speakers and had attained at least a high school

education. One participant had a right hemisphere stroke, but is left handed and was

diagnosed with aphasia by a certified Speech Language Pathologist prior to enrollment.

All participants, except P8, were simultaneously enrolled in a sentence comprehension

treatment study in the lab, from which we were able to obtain sentence comprehension

performance for a variety of sentence types during an object manipulation task. As shown

in Table 1, all participants tested showed sentence comprehension deficits for at least one

syntactic construction, but all had above chance performance for active sentences.

Although the Western Aphasia Battery - Revised (Kertesz, 2006) was not part of the

assessment for the current study or the parallel treatment study, all participants were

given the WAB-R within approximately 6 months of this study date, except for P5,

whose WAB-R score was obtained approximately 3 years after the study. Also note that

although P1 and P8 scored within the "normal" range on the WAB-R, they exhibited

marked language deficits in conversation and were judged to have aphasia according to a

certified Speech Language Pathologist. Although P8 was not given a sentence screener to

establish sentence comprehension deficits, she performed at 65% accuracy on the

experimental task, with accuracy ranging from 0-60% accuracy on the implausible

sentences, suggesting a deficit in syntactic interpretation. See Table 1 for demographic

information, lesion information, and language scores. All participants gave consent

according to BU IRB protocol.

Table 1.
Patient Demographics

	P1	P2	P3	P4	P5	P6	P7	P8
Sex	F	M	M	F	M	M	M	F

Age	67	54	29	62	63	59	56	57
MPO	72	112	7	53	93	17	75	38
Handedness	Right	Left	Right	Right	Left	Right	Right	Right
Education	College	High School	High School	High School	College	MBA	MBA	BA
Lesion site	Left temporal lobe	Right MCA	Left Hemisphere	Left BG	Left Hemisphere	Left MCA	Left temporal / frontal lobes	Left MCA
WAB AQ	98	81.8	53.4	74.4	48.7	78.6	77.7	99.2
Aphasia type	Anomic	Anomic	Broca's	TCM	Broca's	Anomic	Conduction	Anomic
Object Manipulation Sentence Screener Performance								
TOTAL	90.0%	54.5%	26.4%	41.8%	30.9%	62.7%	41.8%	NA
3 noun phrase	100.0%	80.0%	20.0%	20.0%	0.0%	80.0%	100.0%	NA
active	90.0%	100.0%	80.0%	60.0%	70.0%	100.0%	90.0%	NA
raising NP	90.0%	60.0%	20.0%	0.0%	20.0%	80.0%	0.0%	NA
object cleft	90.0%	40.0%	20.0%	40.0%	20.0%	90.0%	30.0%	NA
object control	100.0%	60.0%	20.0%	40.0%	10.0%	70.0%	50.0%	NA
object relative	60.0%	20.0%	0.0%	0.0%	10.0%	0.0%	0.0%	NA
OR complex NP	40.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	NA
passive	100.0%	70.0%	20.0%	60.0%	40.0%	100.0%	0.0%	NA
pronoun	100.0%	30.0%	80.0%	40.0%	30.0%	30.0%	40.0%	NA
reflexive	90.0%	0.0%	0.0%	100.0%	30.0%	0.0%	100.0%	NA
subject control	100.0%	80.0%	20.0%	10.0%	10.0%	80.0%	0.0%	NA
unaccusative	100.0%	100.0%	20.0%	100.0%	100.0%	100.0%	100.0%	NA

Note. NA = not available, WAB AQ = Western Aphasia Battery Aphasia Quotient, BG = basal ganglia, MCA = middle cerebral artery, TCM = Transcortical Motor, NP = noun phrase, OR = object relative

Younger neurologically healthy adults. Eleven neurologically healthy adults aged 19-40 (mean = 27.2; 6 male, 5 female) were recruited from the Massachusetts Institute of Technology (MIT) community. All participants were native English speakers and had

attained at least a high school education. All participants gave consent according to the
MIT IRB protocol.

Older neurologically healthy adults. Seven neurologically healthy adults aged 56-
80 (mean = 70.8; 2 male, 5 female) were recruited from the BU community. All
participants were native English speakers and had attained at least a high school
education. All participants gave consent according to the BU IRB protocol.

Materials

The study was originally designed to examine the nature of syntactic priming in persons
with aphasia in DO / PO structures. In addition to the comprehension trials (to be
described below), there were also production trials where participants were asked to
complete picture descriptions as English sentences. These are not the focus of the present
study and hence they are not included here. Because the experiment was designed to
investigate the nature of priming in DO/PO structures, there was only one list of
active/passive materials, whereas there were four counterbalanced lists of DO/PO
materials.

There were two sets of target materials: active / passive structures as in (5)
(similar to (3), but the comparison is between items here, with plausible controls) and
DO/PO structures as in (6) (repeated from (4), with plausible controls) (cf. Caplan, Baker
& Dehaut, 1985; Caplan & Futter, 1986; O'Grady & Lee, 2005; who also used DO/PO
materials with persons with aphasia):

(5)

a. Plausible active: The man drove the truck.

b. Plausible passive: The cake was eaten by the son.

c. Implausible active: The ball kicked the nephew.

d. Implausible passive: The daughter was folded by the blanket.

Four static versions of the task were given, with versions counterbalanced across participants. Each version of the task contained the same set of active and passive sentences: three plausible nonreversible active sentences, two plausible reversible active sentences, five implausible nonreversible active sentences, four plausible nonreversible passive sentences, one plausible reversible passive sentence, and five implausible nonreversible passive sentences (see the Appendix for the complete list of sentences).

(6)

a. Plausible DO: The brother gave the sister the bike.

b. Plausible PO: The brother gave the bike to the sister.

c. Implausible DO: The brother gave the bike the sister.

d. Implausible PO: The brother gave the sister to the bike.

Each version of the task contained a different set of DO and PO sentences: 5 plausible DO, 5 plausible PO, 5 implausible DO, and 5 implausible PO. This was achieved by creating 20 plausible DO sentences and rearranging the nouns and verbs to create a plausible PO version, an implausible DO version, and an implausible PO version of each

sentence for a total of 80 sentences. These were split into four test versions using a Latin Square method such that each version of a sentence was assigned to a different test version and so that each type of sentence was represented an equal number of times resulting in each test version (see Appendix for a full list of the materials). There were no materials other than the two sets of target items.

A "doll" picturing each noun was used for enactment of each sentence. These dolls consisted of a black-and-white drawing of a person or object that was attached to a Popsicle stick for easy handling.

Testing procedure. An act-out task was used to assess sentence comprehension because it allows for a number of possible interpretation errors, rather than restricting errors to the foils provided by the experimenter, as in a sentence-to-picture matching task (as discussed in Caplan et al., 1985). For each trial, the experimenter (either CS or BR[2]) would introduce a set of referents by laying out a set of dolls, where each doll represented one of the noun phrase referents in the trial. Only dolls of the nouns that occurred in the sentence were provided and dolls were not laid out in any particular order. For example for the sentences "the girl kicked the ball" or "the ball kicked the girl", the experimenter would put out a popsicle stick with a picture of a little girl on it, and one with a picture of a ball on it, and would say "this is a girl; this is a ball". The participant was then instructed to listen carefully to a sentence provided by the experimenter and show comprehension by acting out the events in the sentence using the dolls, even if the sentence did not seem to make sense. Prior to beginning the task, the experimenter gave

---

[2] BR is Balaji Rangarathnam, who helped with data collection.

examples (using sentences not included in the actual task) of how to act out the events of each type of sentence.

Two experimenters coded the participants' responses. Each trial was scored as either 'follows the syntax', or 'doesn't follow syntax'. For active sentences, a trial was coded as following the syntax if the initial subject noun phrase was acted out as the agent of the action, and the noun phrase following the verb was acted out as the patient of the action. The reverse was true for sentences that were coded as following the syntax for the passive sentences. For DO sentences that were coded as following the syntax, the first noun phrase following the verb was acted out as the goal of the action, and the second noun phrase following the verb was acted out as the patient of the action. The reverse was true for PO sentences coded as following the syntax.

Results

Although 3 of the 10 plausible active/passive items were reversible, we analyzed participants' errors with these items with the irreversible ones. This may have slightly increased the error rates for the active/passive materials (because there is one less cue to the meaning of these materials), but it does so across all population groups. Furthermore, it lowers the possibility of seeing a difference with the DO/PO materials, which is therefore conservative with respect to our hypotheses.

We first analyzed the effect of population type on the interpretation of each construction. For analysis purposes, we coded each trial as 1 if it was interpreted according to the literal syntactic meaning, and 0 otherwise. If a trial was not interpreted according to the literal syntactic meaning (an entry of zero), it was usually interpreted

21

with the agent and patient reversed for the active / passive materials or with the DO and

PO reversed for the DO/PO materials, but not always. In particular, this was true for all

of the older adult's trials, and all but 3 of the younger adults' trials, where there were two

"other" errors for the DO implausible condition, and one "other" error for the PO

implausible condition. Table 2 provides a table containing the number of agent/patient

swaps for the active / passive materials, and direct object / prepositional phrase object for

the DO/PO materials. As can be seen in the table, most of the errors are swaps, but there

are other kinds of errors, especially in the DO/PO materials, where there is a greater

possibility of making an error, due to the greater number of elements involved in the

relation.

Table 2.

Numbers of trials across participants in each group, organized by response type.

	Active	Passive	DO	PO
Young adults				
Plausible	55 / 0 / 0	51 / 4 / 0	53 / 2 / 0	53 / 2 / 0
Implausible	55 / 0 / 0	54 / 1 / 0	30 / 23 / 2	52 / 2 / 1
Older adults				
Plausible	35 / 0 / 0	28 / 7 / 0	24 / 11 / 0	35 / 0 / 0
Implausible	34 / 1 / 0	28 / 7 / 0	13 / 22 / 0	33 / 2 / 0
Persons with aphasia				
Plausible	33 / 7 / 0	30 / 10 / 0	24 / 10 / 6	38 / 1 / 1
Implausible	29 / 10 / 1	25 / 15 / 0	1 / 34 / 5	25 / 9 / 6

Note. Response types a / b / c = (a) following the literal syntax, (b) swapping the agent / patient

for active / passive items, or swapping the direct object and prepositional phrase object for DO / PO items, or (c) with some other interpretation of the materials.

For all analyses, we used logistic mixed-effects models with random slopes for participants and items; in cases where these models failed to converge, we report results for the maximal converging models. For visualization purposes, we present the means and 95% confidence intervals for each of the populations and the two pairs of constructions in Figures 1-3.
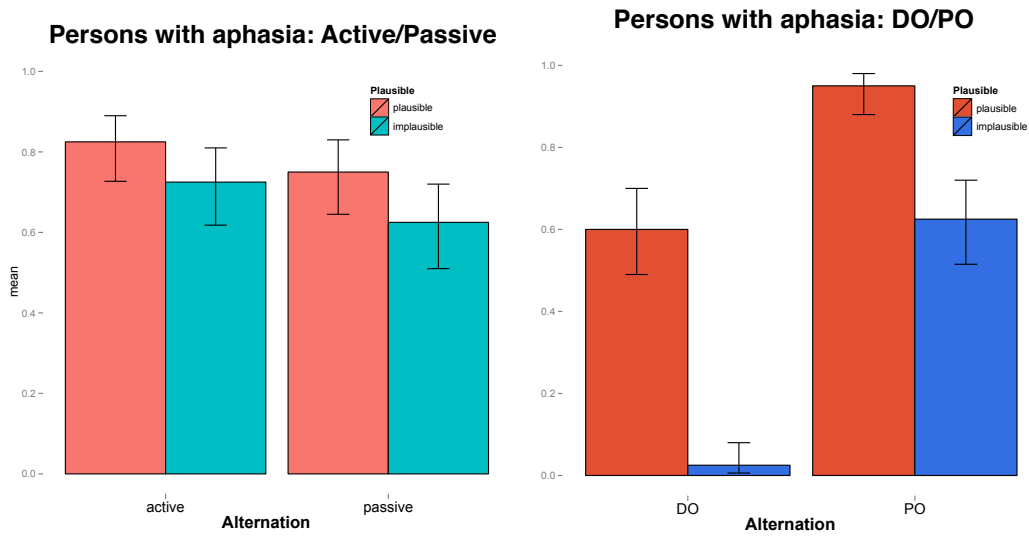
Figure 1: Proportion of items which were acted out according to the literal syntax of the target item, for persons with aphasia, in the active/passive materials (left) and the double-object (DO) / prepositional-phrase object (PO) materials. Error bars represent 95% confidence intervals.
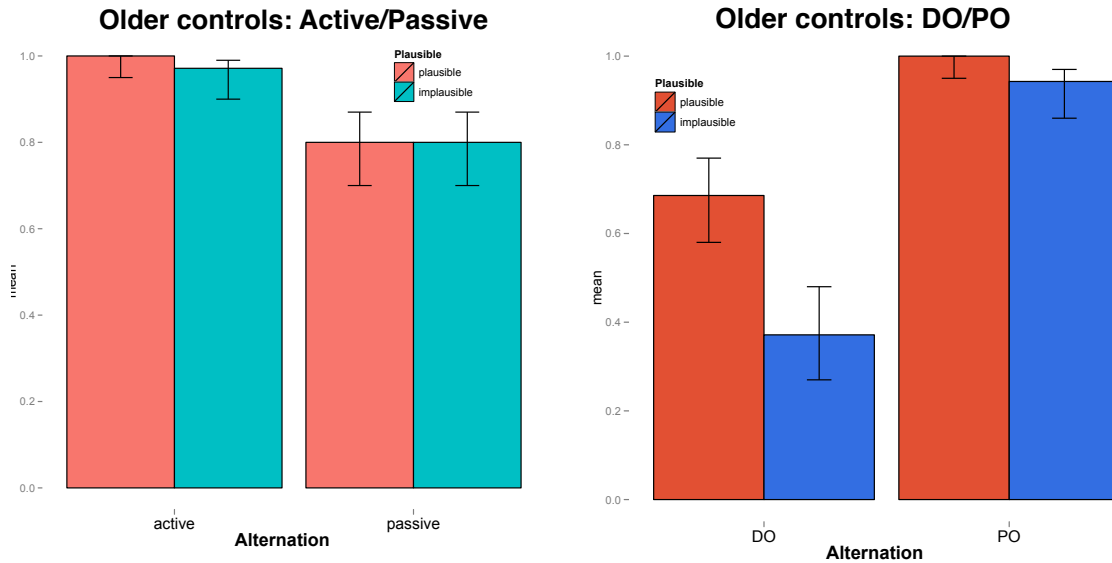
Figure 2: Proportion of items which were acted out according to the literal syntax of the target item, for the older control population, in the active/passive materials (left) and the double-object (DO) / prepositional-phrase object (PO) materials. Error bars represent 95% confidence intervals.
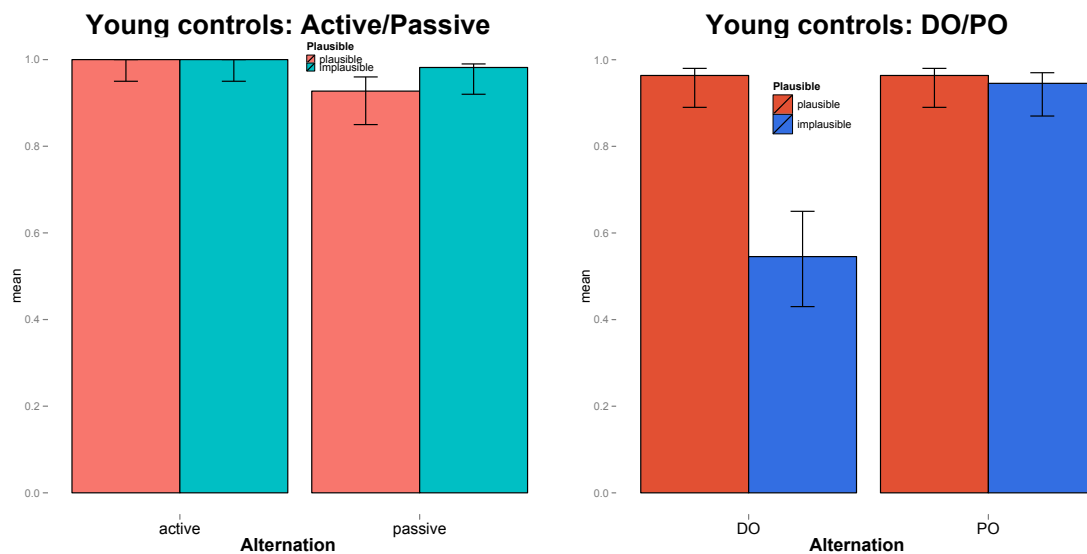

Figure 3: Proportion of items which were acted out according to the literal syntax of the target item, for the younger control populations, in the active/passive materials (left) and

the double-object (DO) / prepositional-phrase object (PO) materials. Error bars represent 95% confidence intervals.

We first evaluated plausibility effects within each construction pair. For persons with aphasia, there was a marginal effect of plausibility (plausible: 0.79, 95% CI [0.69, 0.86]; implausible: 0.68, 95% CI [0.57, 0.77]; β=-1.51, t=1.75, p=0.08) on the active/passive construction, providing evidence that persons with aphasia were less likely to interpret the implausible items according to their literal meanings. In the younger (plausible: 0.96, 95% CI [0.91, 0.99]; implausible: 0.99, 95% CI [0.95, 0.99]; β=0.36, t=0.00, p=1) and older (plausible: 0.90, 95% CI [0.81, 0.95]; implausible: 0.89, 95% CI [0.79, 0.94]; β=-15.91, t=0.00, p=1) control conditions, there was no effect of plausibility on interpretation in this construction pair.[3] For the DO/PO alternation, there was a main effect of plausibility for persons with aphasia (plausible: 0.78, 95% CI [0.67, 0.85]; implausible: 0.32, 95% CI [0.23, 0.43]; β=-7.05, t=2.98, p<0.005), younger controls (plausible: 0.96, 95% CI [0.91, 0.99]; implausible: 0.75, 95% CI [0.66, 0.82]; β=-8.35, t=2.00, p<0.05), and older controls (plausible: 0.84, 95% CI [0.74, 0.91]; implausible: 0.66, 95% CI [0.54, 0.76]; β=-3.05, t=2.77, p<0.01), indicating that participants were more likely to assign non-literal interpretations to the implausible items. In addition to analyzing the effect of plausibility on the rate of literal interpretation, we also evaluated whether participants with aphasia had an overall lower rate of literal interpretation, across all item types. Indeed, we found that rate of literal interpretation for participants with

---

[3] Of course, a stronger statistical test of a difference in plausibility reliance between populations would be to look for an interaction between reliance on literal syntax and the population group. This interaction was not reliable in the current data set, but that is plausibly related to the small participant pools in each group. Further work is clearly needed to evaluate these issues more rigorously.

aphasia (mean: 0.64, 95% CI [0.59, 0.69]) was lower than for older controls (mean: 0.82,

95% CI [0.77, 0.86]; β=-1.41, t=2.96, p<0.005) and younger controls (mean: 0.92, 95%

CI [0.89, 0.94]; β=2.60, t=5.73, p<0.001).

We next evaluated the second prediction of the rational inference approach, that

there will be a larger effect of plausibility in the DO/PO alternation than in the

active/passive alternation across the three populations. In particular, we evaluated

whether the reduction in the rate of literal interpretation was greater for the implausible

items in the DO/PO alternation than in the active/passive alternation. If the rate of

reduction is greater in the DO/PO alternation, then a significant interaction should obtain

between plausibility and alternation type. Collapsing across the three participant groups,

who are not predicted to differ in this respect, we found a significant interaction between

plausibility and alternation type (DO/PO plausible: 0.87, 95% CI [0.83, 0.91]; DO/PO

implausible: 0.59, 95% CI [0.53, 0.65]; active/passive plausible: 0.89, 95% CI [0.85,

0.92]; active/passive implausible: 0.87, 95% CI [0.82, 0.90]; β=-3.07, t=4.29, p<0.001).

When the participant groups were analyzed separately, the interaction was significant for

the persons with aphasia and the younger control population, though not for the older

control population (means and CIs are reported above; persons with aphasia: β=-2.04,

t=2.56, p<0.05; older controls: β=-1.53, t=0.75, p=0.45; younger controls: β=-5.62,

t=3.05, p<0.005).

Finally we evaluated potential differences between each of the pairs of

constructions. As predicted by the rational inference approach, there was a significant

effect of construction type (DO: 0.56, 95% CI [0.50, 0.61]; PO: 0.91, 95% CI [0.87,

0.94]; β=-3.68, t=7.88, p<0.001), with the DO items interpreted non-literally more often

than the PO items. There was no interaction with plausibility (β=-0.95, t=1.25, p=0.21):

people also made more mistakes in the plausible DO materials than in the plausible PO

materials. We also found a significant effect of construction type in the active/passive

sentences (active: 0.92, 95% CI [0.89, 0.95]; passive: 0.83, 95% CI [0.78, 0.87]; β=-0.99,

t=2.02, p<0.05) such that passives were more likely to be corrected than actives. As for

the DO/PO structures, this effect did not interact with plausibility (β=-0.54, t=0.72,

p=0.46). This was not predicted by the rational inference account. We discuss this effect

further in the discussion below.

Discussion

We have proposed a novel approach to aphasic language comprehension, whereby

persons with aphasia postulate higher levels of noise in their language processing systems.

This account predicts that, when faced with implausible materials, persons with aphasia

should rely on the prior (world knowledge and structure frequency) more than persons

with no damage to the language system, as has standardly been observed in the aphasic

processing literature (e.g., Caramazza & Zurif, 1976). We have replicated this effect here

for active/passive sentences (albeit with a marginal effect) and extended it to DO/PO

sentence structures. Second, we have shown that our participants with aphasia relied less

on the literal syntax overall than either of the control groups. Third, we have shown that

they relied more on plausibility in the DO/PO constructions than in the active/passive

constructions, similar to results from Gibson, Bergen & Piantadosi (2013) for measures

from the normal population, and to results here from both older and younger control

participants.

Finally, participants made more errors on the less frequent DO structure than the PO structure, independent of plausibility (cf. O'Grady & Lee, 2005, who propose that word order alignment may also make PO structures easier to process). This effect is explained by the rational inference account: participants are predicted to infer that the speaker intended the more frequent structure in noisy environments. An important outcome of our results is that it appears that older participants and persons with aphasia, in addition to being sensitive to noise, are sensitive to structural frequency.

A similar frequency effect was observed in the active/passive alternation as well: participants were less likely to use syntax to interpret the passive structures than the active structures. However, the rational inference account proposed here (with its edit model consisting of insertions and deletions) does not predict an effect of frequency on the error rate for these structures. Similar results have been found in studies which have investigated active/passives and subject- vs. object-extracted relative clauses in persons with aphasia (Caramazza & Zurif, 1976; Heilman & Scholes, 1976; Caramazza, Berndt, Basili, & Koller, 1981; Caplan et al., 1985; Bates, Friederici, & Wulfeck, 1987). Therefore, it is possible that the rational inference account may need to be altered or supplemented by additional factors in order to fully explain how individuals with aphasia interpret complex sentences. An alternative error-correction model might help account for the observed effects, perhaps one that includes a probability of swaps, in addition to deletions, as possible edits, which might make e.g., subject-extractions more likely edits from object-extractions. Moreover, there are two general ways that the account could be extended. First, both object-extracted relative clauses and passive structures (under certain syntactic analyses) have large dependency lengths. Dependency length may play

28

an independent role in increasing processing complexity for individuals with aphasia, therefore increasing the error rate. Second, though structural frequency already is factored into the rational inference account, it is possible that it plays an additional role in determining sentence complexity, which is not currently captured by the account. Future experiments will be required to distinguish these possibilities.

Recently, Warren, Liburd, and Dickey (2014) have replicated some of these results in preliminary work. They showed that persons with aphasia showed a preference for plausibility in interpreting both DO/PO alternations and active/passive alternations in a forced-choice sentence-to-picture matching task. In addition, Warren et al. found that both older controls and persons with aphasia showed a larger effect of plausibility with the DO/PO alternation than the active/passive alternation and that this effect was more pronounced in the persons with aphasia.

In summary, our data suggest a novel interpretation of the observation that persons with aphasia rely on priors, such as semantic world knowledge, more than non-brain-damaged controls, in terms of greater noise in the language comprehension mechanisms of persons with aphasia. Noise repair in persons with aphasia does not appear to be damaged, leaving open the possibility that some of their behavior in comprehension is a rational adaptation to the noisiness of their representations. Under this hypothesis, it is the greater presence of noise in the language comprehension mechanisms of persons with aphasia which leads to the observed bias toward the priors.

References

Aylett M, & Turk A (2004) The smooth signal redundancy hypothesis: A functional explanation for relationships between redundancy, prosodic prominence, and duration in spontaneous speech. *Language and Speech,* 47, 31–56.

Bates E., McDonald, J.L., MacWhinney, B.M. & Appelbaum, M. (1991) A maximum likelihood procedure for the analysis of group and individual data in aphasia research. *Brain and Language*, 40(2): 231–265.

Bates, E., Wulfeck, B., & MacWhinney, B. (1991). Cross-linguistic research in aphasia: An overview. *Brain and language*, 41(2), 123-148.

Bates, E., Friederici, A., & Wulfeck, B. (1987). Comprehension in aphasia: A cross-linguistic study. *Brain and Language*, 32(1), 19-67.

Berndt, R. S., Mitchum, C. C., Wayland, S. (1997). Patterns of sentence comprehension in aphasia: A consideration of three hypotheses. *Brain and Language*, 60, 197-221.

Biassou, Obler, Nespoulous, Dordain, & Harris, 1997. Dual processing of open- and closed-class words. *Brain and Language*, 57, 360-373

Bresnan, J. (1982). The Passive in Lexical Theory. In J. Bresnan (ed.) *The Mental Representation of Grammatical Relations*, MIT Press, Cambridge, MA.

Bresnan, J. (2007). Is syntactic knowledge probabilistic? Experiments with the English dative alternation. In S. Featherston, W. Sternefeld (eds.), *Roots: Linguistics in*

search of its evidential base, Mouton de Gruyter, Berlin, Germany, pp. 75-96.

Caplan, D., Matthei, E., & Gigley, H. (1981). Comprehension of gerundive constructions by Broca's aphasics. *Brain and Language*, 13(1), 145-160.

Caplan, D., Baker, C., & Dehaut, F. (1985). Syntactic determinants of sentence comprehension in aphasia. *Cognition*, 21(2), 117-175.

Caplan, D., & Futter, C. (1986). Assignment of thematic roles to nouns in sentence comprehension by an agrammatic patient. *Brain and Language*, 27(1), 117-134.

Caplan, D., DeDe, G., & Michaud, J. (2006). Task-independent and task-specific syntactic deficits in aphasic comprehension. *Aphasiology*, 20, 893–920.

Caplan, Michaud, & Hufford, 2013. Dissociations and associations of performance in syntactic comprehension in aphasia and their implications for the nature of aphasic deficits. *Brain and Language*, 127 (2013) 21–33

Caplan, D., Waters, G., & Hildebrandt, N. (1997). Determinants of sentence comprehension in aphasic patients in sentence-picture matching tasks. *Journal of Speech and Hearing Research*, 40, 542–555.

Caplan, D., Waters, G. S. (1999). Verbal working memory and sentence comprehension. *Behavioral and Brain Sciences*, 22, 77-126.

Caramazza, A., Basili, A. G., Koller, J. J., & Berndt, R. S. (1981). An investigation of repetition and language processing in a case of conduction aphasia. *Brain and Language*, 14(2), 235-271.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes

in language comprehension: Evidence from aphasia. *Brain and Language*, 3(4), 572-582.

Chomsky, N. (1981). *Lectures on government and binding: The Pisa lectures (No. 9)*. Walter de Gruyter.

Christianson, K., Hollingworth, A., Halliwell, J. F., & Ferreira, F. (2001). Thematic roles assigned along the garden path linger. *Cognitive Psychology*, 42(4), 368-407.

Clayards, M., Tanenhaus, M. K., Aslin, R. N., & Jacobs, R. A. (2008). Perception of speech reflects optimal use of probabilistic speech cues. *Cognition*, 108(3), 804-809.

Dick, F., Bates, E., Wulfeck, B., Utman, J., Dronkers, N., & Gernsbacher, M. (2001). Language deficits, localization, and grammar: Evidence for a distributive model of language breakdown in aphasic patients and neurologically intact individuals. *Psychological Review*, 108(4), 759-788.

Ferreira, F. (2003) The misinterpretation of noncanonical sentences. *Cognitive Psychology*, 47(2):164–203.

Friederici, A. D., & Schoenle, P. W. (1980). Computational dissociation of two vocabulary types: Evidence from aphasia. *Neuropsychologia*, 18(1), 11-20.

Friederici, A. D. (1988). Agrammatic comprehension: Picture of a computational mismatch. *Aphasiology*, 2(3-4), 279-282.

Gahl, S. (2002). Lexical biases in aphasic sentence comprehension: An experimental and corpus linguistic study. *Aphasiology*, 16(12), 1173-1198.

Gahl, S., Menn, L., Ramsberger, G., Jurafsky, D. S., Elder, E., Rewega, M., & Audrey, L.
H. (2003). Syntactic frame and verb bias in aphasia: Plausibility judgments of
undergoer-subject sentences. *Brain and Cognition*, 53(2), 223-228.

Gardner, H., & Zurif, E. (1975). Bee but not be: Oral reading of single words in aphasia
and alexia. *Neuropsychologia*, 13(2), 181-190.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*,
68, 1-76.

Gibson, E. (2000). The dependency locality theory: A distance-based theory of linguistic
complexity. In Miyashita, Y., Marantz, A., & O'Neil, W. (Eds.), *Image, language,
brain* (pp. 95-126), Cambridge, MA: MIT Press.

Gibson, E., Bergen, L., & Piantadosi, S. T. (2013). Rational integration of noisy evidence
and prior semantic expectations in sentence interpretation. *Proceedings of the
National Academy of Sciences*, 110(20), 8051-8056.

Gibson, E. & Pearlmutter, N. (1998). Constraints on sentence comprehension. *Trends in
Cognitive Science*, 2, 262-268.

Goldberg, A.E. (2006). *Constructions at Work. The Nature of Generalization in
Language*. Oxford: Oxford University Press.

Grodzinsky, Y. (1986). Language deficits and the theory of syntax. *Brain and Language*,
27, 135–159.

Grodzinsky, Y. (1995a). Trace deletion, theta-roles, and cognitive strategies. *Brain and
Language*, 51, 467–497.

Grodzinsky, Y. (1995b). A restrictive theory of agrammatic comprehension. *Brain and Language*, 51, 26–51.

Grodzinsky, Y. (2000). The neurology of syntax: Language use without Broca's area. *Behavioral and Brain Sciences*, 23, 47–117.

Hale, J. (2001). A probabilistic Earley parser as a psycholinguistic model. In *Proceedings of NAACL* (Vol. 2, pp. 159–166).

Heilman, K. M., & Scholes, R. J. (1976). The nature of comprehension errors in Broca's, conduction and Wernicke's aphasics. *Cortex*, 12(3), 258-265.

Jelinek, F. (1976). Continuous speech recognition by statistical methods. *Proceedings of IEEE,* 64: 532–556.

Kertesz, A. (2006). Western Aphasia Battery - Revised (WAB-R): Harcourt Assessment, Inc.

Kolk, H. H., & Van Grunsven, M. M. (1985). Agrammatism as a variable phenomenon. *Cognitive Neuropsychology*, 2(4), 347-384.

Kudo, T. (1984). The effect of semantic plausibility on sentence comprehension in aphasia. *Brain and Language, 21*(2), 208-218

Levy, R. (2008a). Expectation-based syntactic comprehension. *Cognition*, 106, 1126–1177.

Levy, R. (2008b) A noisy-channel model of rational human sentence comprehension under uncertain input. *Proceedings of the 13th Conference on Empirical Methods in Natural Language Processing* (Association for Computational Linguistics,

Stroudsburg, PA), pp 234–243.

Levy, R., Bicknell, K., Slattery, T., & Rayner, K. (2009). Eye movement evidence that

readers maintain and act on uncertainty about past linguistic input. *Proceedings of

the National Academy of Sciences*, 106(50), 21086-21090.

Linebarger, M. C., Schwartz, M. F., & Saffran, E. M. (1983). Sensitivity to grammatical

structure in so-called agrammatic aphasics. *Cognition*, 13(3), 361-392.

Love, T., & Oster, E. (2002). On the categorization of aphasic typologies: the SOAP (A

tests of syntactic complexity). *Journal of Psycholinguistic Research*, 31(5), 503-

529.

MacDonald, M. C. (1989). Priming effects from gaps to antecedents. *Language and

Cognitive Processes,* 4(1), 35-56.

MacWhinney, B., & Bates, E. (1989). *The crosslinguistic study of sentence processing*.

Cambridge University Press, Cambridge UK.

MacWhinney, B., Bates, E., & Kliegl, R. (1984). Cue validity and sentence interpretation

in English, German, and Italian. *Journal of Verbal Learning and Verbal Behavior*,

23(2), 127-150.

MacWhinney, B., Osmán-Sági, J., & Slobin, D. I. (1991). Sentence comprehension in

aphasia in two clear case-marking languages. *Brain and Language*, 41(2), 234-

249.

McDonald, J., & MacWhinney, B. (1989). Maximum likelihood models for sentence

processing research. In B. MacWhinney & E. Bates (Eds.), *The crosslinguistic

study of sentence processing* (pp. 397-421). New York: Cambridge University

Press.

Miyake, A., Carpenter, P. A., & Just, M. A. (1994). A capacity approach to syntactic comprehension disorders: Making normal adults perform like aphasic patients. *Cognitive Neuropsychology*, 11(6), 671-717.

O'Grady, W., & Lee, M. (2005). A mapping theory of agrammatic comprehension deficits. *Brain and Language*, 92(1), 91-100.

Prather, P., Shapiro, L., Zurif, E., & Swinney, D. (1991). Real-time examinations of lexical processing in aphasics. *Journal of Psycholinguistic Research*, 20(3), 271-281.

Saffran, E. M., & Schwartz, M. F. (1994). Impairment of sentence comprehension. *Philos Trans R Soc Lond B Biol Sci, 346*(1315), 47-53.

Saffran, E. M., Schwartz, M. F., & Linebarger, M. C. (1998). Semantic influences on thematic role assignment: Evidence from normals and aphasics. *Brain and Language,* 62(2), 255-297.

Salis, C., & Edwards, S. (2009). Tests of syntactic comprehension in aphasia: An investigation of task effects. *Aphasiology*, 23, 1215–1230.

Schwartz, M. F., Saffran, E. M., & Marin, O. S. M. (1980). The word order problem in agrammatism, I. Comprehension. *Brain and Language* 10, 249-262

Shankweiler, D., Crain, S., Gorrell, P., & Tuller, B. (1989). Reception of language in Broca's aphasia. *Language and Cognitive Processes*, 4(1), 1-33.

Shannon. C. (1948) A mathematical theory of communication. *Bell Systems Technical*

Journal, 27, 623–656.

Tanenhaus, M. K., & Trueswell, J. C. (1995). Sentence comprehension. In P. Eimas, & J. L. Miller (pp. 217-162), *Handbook of Perception and Cognition: Language*, New York: Academic Press.

Warren, T., Liburd, T., & Dickey, M. W. (2014, October). *Sentence comprehension in aphasia: A noisy channel approach*. Paper presented at the 52nd Annual Meeting of the Academy of Aphasia, Miami, FL.

Wulfeck, B. B. (1988). Grammaticality judgments and sentence comprehension in agrammatic aphasia. *Journal of Speech, Language, and Hearing Research*, 31(1), 72-81.

Wulfeck, B., & Bates, E. (1991). Differential sensitivity to errors of agreement and word order in Broca's aphasia. *Journal of Cognitive Neuroscience*, 3(3), 258-272.

Acknowledgements

Appendix: Materials

Active/Passive materials (1 list)

Plausible Actives

1. The man drove the truck.

2. The father sharpened the saw.

3. The woman lost the diamond.

4. The husband called the wife.

5. The wife ignored the husband.

Implausible Actives

1. The ball kicked the nephew.

2. The bike crashed the brother.

3. The door opened the niece.

4. The oven cleaned the grandmother.

5. The train rode the granddaughter.

Plausible Passives

1. The table was set by the mother.

2. The cake was eaten by the son.

3. The hammer was stolen by the boy.

4. The airplane was destroyed by the missile.

5. The boy was pushed by the girl.

Implausible Passives

1. The girl was worn by the watch.

2. The daughter was folded by the blanket.

3. The grandfather was broken by the bowl.

4. The sister was closed by the window.

5. The uncle was sailed by the boat.

Double-Object (DO) / Prepositional-phrase Object (PO) materials

4 lists in a Latin Square design. We provide all four conditions for only the first item. For the remaining items we provide only the plausible PO version. The others can be computed from this one.

1.   a. Plausible PO: The sister mailed the letter to the brother.

        b. Plausible DO: The sister mailed the brother the letter.

        c. Implausible PO: The sister mailed the brother to the letter.

        d. Implausible DO: The sister mailed the letter the brother.

2. The mother offered the candle to the daughter.

3. The uncle gave the truck to the father.

4. The nephew sent the book to the aunt.

5. The father showed the car to the son.

6. The brother gave the bike to the sister.

7. The son gave the saw to the uncle.

8. The niece offered the seat to the grandmother.

9. The woman sent the package to the man.

10. The grandmother sent the blanket to the granddaughter.

11. The grandson handed the hammer to the grandfather.

12. The girl tossed the apple to the boy.

13. The husband mailed the card to the wife.

14. The daughter handed the bowl to the mother.

15. The aunt offered the cake to the niece.

16. The grandfather mailed the watch to the nephew.

17. The man showed the helicopter to the woman.

18. The wife showed the table to the husband.

19. The boy handed the pencil to the girl.

20. The granddaughter tossed the ball to the grandson.