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The resolution and recovery of filler-gap dependencies in aphasia: Evidence from on-line anomaly detection ☆

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Abstract

This study examines the on-line processing of sentences with movement using an auditory anomaly detection task (after Boland, Tanenhaus, Garnsey, & Carlson, 1995). Eight agrammatic aphasic participants (four of whom had undergone treatment focused on comprehension and production of filler-gap sentences) and 24 young normal participants listened to sentences and pressed a button when the sentences "stopped making sense." Critical sentences contained an anomaly in object relative clauses or conjoined clauses. Results showed that both young normals and aphasic participants were able to reject anomalous sentences of both types. In addition, both groups showed evidence of filler-gap resolution on-line. Importantly, however, there was evidence of a treatment effect for the aphasic patients: those who received treatment showed better performance than those who had not. Treated patients were more successful than the untreated patients in detecting the anomaly in filler-gap conditions, rejecting the anomalous filler-gap sentences reliably more often than the non-anomalous ones, like the young normals. This effect was not noted for untreated participants, i.e., there was no statistical difference between their rejection of anomalous and non-anomalous filler gap sentences. Further, the reaction time data showed that the treated aphasic patients' rejections came before sentence's end (within 2000 ms), while the majority of responses made by untreated patients did not. These results indicate that individuals with agrammatic aphasia appear to retain some gap-filling capacity and that treatment can improve their ability to make use of this capacity.

1. Introduction

Much previous research on sentence comprehension in aphasia has shown that agrammatic individuals with aphasia have difficulty understanding sentences with movement. In particular, they have difficulty understanding sentences in which arguments do not appear in their canonical order, as in the object relative clause in (1):

(1) I saw the artist who the thief chased.

In (1), *the artist* is understood as being the object of the obligatorily transitive verb *chased*, even though it appears before the verb in the sentence. The standard linguistic analysis of these sentences claims that there is a trace in the syntactic representation of the sentence, occupying the object gap following *chased*, which is ultimately coindexed with *the artist* (Browning, 1987; Chomsky, 1977):

(1′) I saw [the artist](*i*) [who(*i*) the thief chased t(*i*)].

The relative pronoun *who* is moved from its underlying position following *chased* to its surface position

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adjacent to *the artist,* where it is coindexed with the head NP. It is this coindexation relation which allows *the artist* to be understood as the object of *chased* (Chomsky, 1986; see also Mauner, Fromkin, & Cornell, 1993). In comprehending these sentences, it is the language processor's task to identify the gap or trace associated with the moved relative pronoun and resolve the movement relationship, also called a *filler-gap dependency* (Boland et al., 1995; Fodor, 1978; Frazier & Flores d'Arcais, 1989; Sussman & Sedivy, 2003).

Evidence of aphasic individuals' difficulties in comprehending sentences with filler-gap dependencies comes primarily from off-line tasks, most prominently from picture-matching (see Berndt, 1998; Grodzinsky, 2000 for reviews of previous results). Clearly, some part of the process of resolving filler-gap dependencies is disrupted in aphasia: either the representations that aphasic comprehenders are building are somehow defective (Grodzinsky, 1990, 2000; Mauner et al., 1993), the process of mapping those representations onto an interpretation is disrupted (Schwartz, Linebarger, Saffran, & Pate, 1987), or some operation relevant to the gap-filling process is greatly slowed and error-prone (Caplan & Hildebrandt, 1988; Friederici & Frazier, 1992; Kolk & van Grunsven, 1985; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). However, existing off-line results do not clearly decide among these alternative accounts of aphasic comprehension problems. Further, relatively little is known about aphasic comprehenders' success or failure in processing these sentences on-line. There have been a few studies which specifically examine on-line processing of sentences with movement in aphasia (Blumstein et al., 1998; Love, Swinney, & Zurif, 2001; Swinney, Zurif, Prather, & Love, 1996; Zurif et al., 1993), but their results are conflicting, as we will return to below. It remains unclear how or when aphasic comprehenders attempt to assign a structure and an interpretation to the incoming material in movement sentences, or how they fail to resolve the filler-gap dependency.

More work is needed to answer two outstanding questions: Which theory provides the best account of aphasic comprehension deficits, and how do aphasic individuals comprehend sentences with movement online? The current study is designed to address these two questions, using a methodology which may be useful in answering the larger question of how people with aphasia generally comprehend sentences in real time. The study uses an adapted version of a technique commonly used with young normals, the "stop making sense" paradigm (Boland et al., 1995; Mauner, Tanenhaus, & Carlson, 1995). As will be discussed below, this task is less burdensome for aphasic participants than other commonly-used techniques (such as word monitoring), and analogues of it have successfully been used with aphasic participants (Shankweiler, Crain, Gorrell, & Tuller, 1989). Further, the particular version of the task employed here provides a larger window of time for aphasic patients to respond than some other online methodologies (e.g., cross-modal lexical priming). This methodological advantage may be theoretically important, especially if slowed-processing accounts of agrammatic comprehension deficits are correct (Caplan & Hildebrandt, 1988; Friederici & Frazier, 1992; Kolk & van Grunsven, 1985; Zurif et al., 1993).

As mentioned above, there are several theories of agrammatic comprehension deficits. For the most part, they can be divided into three groups. The first claims that the syntactic representations that aphasic comprehenders construct for sentences with movement are somehow deficient. The most prominent exponent of a structural deficit hypothesis is probably Grodzinsky, who has argued that agrammatic patients fail to insert traces in the structural descriptions they assign to sentences (the Trace Deletion Hypothesis; Grodzinsky, 1990, 1995, 2000). In sentences like (1), aphasic comprehenders fail to postulate a trace after *chased*, leaving the relative pronoun *who* without a semantic role and the syntactic and semantic requirements of the obligatorily transitive verb *chase* unfulfilled. Intact knowledge of these syntactic and semantic requirements prompts them to rely on a Default Principle to find an object for the verb and a role for *who*. The Default Principle uses linear order and the semantic properties of the noun phrases involved to make educated guesses regarding what role they should play in the sentence. The Default Principle dictates that the first NP in a clause should be interpreted as the Agent of the event being described if it is animate, and the Patient or Theme argument if it is inanimate. (See Grodzinsky, 1990, ch. 3, for more detailed exposition of the Default Principle.) In (1), the linear order strategy and the animacy of the head of the object relative converge, yielding an incorrect Agent interpretation for *the artist*:[1]

(1) I saw the artist who the thief chased.

In (2), the linear order strategy and the animacy of the head NP conflict, with animacy taking precedence and yielding a correct Theme interpretation for *the chair*:

(2) I saw the chair which the artist repaired.

Grodzinsky states explicitly that the Default Principle is an extralinguistic heuristic, which applies only after

[1] This characterization of the Default Principle ignores the fact that in object relatives, the head of the relative clause is not actually a part of that clause under most analyses of relative clause formation (Browning, 1987; Chomsky, 1986; Cinque, 1990). Strictly speaking, it is the relative pronoun (*who* or a null operator preceding *that* in *that*-relatives) coindexed with the head NP which should receive a thematic role. It is unclear what importance this distinction might have for the formulation and predictions of the Default Principle.

the aphasic language processor has finished generating an incomplete structure for a sentence. It therefore applies quite late in comprehension, as Grodzinsky himself notes: "Hence, the strategy cannot apply anywhere but *after* the parser has completed recovering whatever structural description it is capable of recovering from the input string" (Grodzinsky, 1990: 137, his emphasis).[2]

Another theory of agrammatic comprehension claims that there is a deficit in the way aphasic comprehenders map syntactic structure onto an interpretation. Such mapping deficit models claim that structure building itself is not affected in agrammatism, only the way that a completed structure is assigned an interpretation. This approach is motivated by the fact that agrammatic individuals often show preserved sensitivity to syntactic well-formedness while showing significant impairment in interpreting the same sentences (Linebarger, Schwartz, & Saffran, 1983; but cf., Grodzinsky & Finkel, 1998). Aphasic individuals apply both normal syntax–semantics mapping procedures and extralinguistic heuristics in constructing and interpreting syntactic representations, which often results in an incorrect interpretation (Schwartz et al., 1987). Sentences with movement, where the syntax–semantics mapping is "non-transparent" and therefore presumably more difficult, are more prone to error. Under this approach, aphasic individuals' difficulty in understanding sentences with movement also comes relatively late in comprehension, since they assign a complete and correct syntactic representation to a sentence and only later fail to interpret that structure correctly.

Both the grammatical deficit and mapping approaches described above crucially rely on extralinguistic heuristics in their characterization of agrammatic comprehenders' performance. Such heuristics depend on factors like the linear order of arguments and their animacy. The use of animacy is important in explaining the fact that agrammatic aphasic individuals often show an asymmetry between semantically reversible movement sentences (where all the arguments are animate and are therefore equally plausible as potential Agents of the actions being described) and non-reversible ones. Many agrammatic patients perform poorly in tasks where they are asked to infer the meaning of reversible sentences but significantly better for non-reversible sentences (Carramazza & Zurif, 1976, among others). As described above, animacy information guides aphasic comprehenders to assume that animate entities are Agents and inanimate entities are Patients or Themes, arriving at the correct result for non-reversible sentences. Therefore, under these approaches, the helpful cue provided by animacy (and the resulting difference between reversible and non-reversible sentences) is associated with the late-applying extralinguistic heuristics. Even successful comprehension of non-reversible movement sentences should therefore come relatively late in comprehension for agrammatic aphasics. The issue of reversibility will be returned to in Section 4.

The third approach to agrammatic comprehension does not rely on these sorts of heuristics. Rather, it claims that some process crucial to the on-line comprehension of sentences is disrupted. There is considerable variation in what element is to blame in these models: some claim that either specialized or general working memory capacity is reduced (Caplan & Hildebrandt, 1988; Caplan & Waters, 1995; cf., Miyake, Carpenter, & Just, 1994), others claim that lexical activation is slowed (Zurif et al., 1993; see also Blumstein & Milberg, 2000), and others claim that the process of assigning a structure to incoming material is slowed (Friederici & Frazier, 1992; Kolk & van Grunsven, 1985) or that the decay of already-structured material is accelerated (Haarmann & Kolk, 1991, 1994). These theories differ importantly in their details (see Kolk & Weitz, 1996, for an overview and discussion of the differences) but they are similar in claiming that the element disrupted in aphasia intersects crucially with the processing of filler-gap dependencies. Slowed lexical activation or accelerated decay will create problems for locating and successfully reactivating an antecedent for a trace once it has been identified; slowed processing routines or an overburdened processor may fail when confronted with a memory-intensive filler-gap dependency. Alternatively, automatic processing might eventually succeed but be so slow as to be of little use to the comprehender (see Love et al., 2001). These accounts of aphasic comprehension contrast with the preceding classes of models in that they postulate no deficits in aphasic syntactic representations or in the processes responsible for mapping those representations onto an interpretation. Rather, they claim that agrammatic individuals try to comprehend sentences with movement more or less as normals do, but are slower and less efficient in their processing. Under these models, aphasic indviduals' difficulties in understanding sentences with movement are not particularly delayed compared to other comprehension processes: all processing is slowed and inefficient.

To date, there have been few attempts to test the claims of these models using on-line methodologies, largely because of the difficulties in applying on-line methods used with normal populations to aphasic populations. The most well-established methods of studying normal sentence processing (e.g., self-paced reading; Just, Carpenter, & Woolley, 1982 monitoring eye-movements during reading, Frazier & Rayner, 1982) usually involve reading, which is often impaired in

[2] The Double Dependency Hypothesis of Mauner et al. (1993), which also claims that traces are not assigned their usual grammatical interpretation by aphasic comprehenders, makes different predictions from Grodzinksy's account of agrammatic comprehension. We will return to these predictions in Section 4.

individuals with aphasia. Event-related potentials (ERPs) (e.g., Swaab, Brown, & Hagoort, 1997), word-monitoring (Tyler, 1985, 1989), and on-line grammaticality judgment paradigms (Shankweiler et al., 1989) have all been used to assess some aspects of aphasic auditory language comprehension. However, up to now, the only methodology which has been used to examine the real-time processing of sentences with movement in aphasia is lexical priming. Zurif et al. (1993), Swinney et al. (1996) and Blumstein et al. (1998) present interesting but conflicting results from priming experiments examining the on-line processing of filler-gap dependencies in aphasia. Swinney and colleagues (following up similar results from Zurif et al., 1993) had examined Broca's and Wernicke's aphasic individuals performance in a standard cross-modal lexical priming task with object relatives like (1), testing for priming for the head NP at the position of the trace (after the verb) and a position before the trace (before the verb). For participants with Wernicke's aphasia, Swinney et al. found evidence of reactivation at the trace site: there was reliable priming of words related to the head NP after the verb but not before. In contrast, they found that participants with Broca's aphasia showed no reliable priming in either position. This evidence is consistent with models of Broca's aphasia in which the syntax is disrupted, and the aphasic individuals' syntactic representations lack traces (Grodzinsky, 1990, 2000). It is also consistent with a slowed-processing account of aphasic comprehension, in which aphasic comprehenders postulate a trace but are slow in locating the antecedent or in reactivating the lexical entry associated with it (Swinney et al., 1996; Zurif et al., 1993; see also Love et al., 2001).

Using a slightly different technique, Blumstein et al. (1998) found essentially opposite results. Blumstein and colleagues presented both sentences and probe words auditorily, with the sentence and the probe word being spoken by different talkers. In addition to this modality difference, the Blumstein study had two other differences from the Zurif study: probe words were presented at only one position, the gap site, and both relative clauses and *wh*-questions were used in the study. Blumstein et al. found no evidence of priming at the trace site for Wernicke's aphasic participants with any sentence type, but they found reliable priming of the antecedent for Broca's aphasic and elderly groups. These results are not consistent with any of the models of aphasic comprehension above, though a slowed-processing account might be compatible with them if the particular aphasic participants Blumstein tested did not show delayed processing. However, processing speed was not examined in this study.

If both these results are reliable, it seems difficult to resolve the conflict between them. However, there are problems with both studies which make their results hard to interpret. First, as Balogh, Zurif, Prather, Swinney, and Finkel (1998) point out, Blumstein and colleagues only present a probe at one position, the trace site. This design choice makes it difficult to attribute the priming to reactivation of the antecedent of a trace. Instead, facilitation found at the verb could be due simply to residual activation of the moved element. Standard CMLP results for normals (as well as the CMLP results for Wernicke's aphasics presented by Zurif et al.) have shown that activation of the moved element is low just before the trace and high after, indicating reactivation of the antecedent at the position of the trace. Second, Zurif et al. (1993) do not present independent evidence that their Broca's aphasic participants show lexical priming in single-word contexts within the time window used in their CMLP study. It is possible that the Broca's participants tested were simply slowed in their processing, and would have shown priming of the moved element had they been tested far enough downstream from the trace site. (See Love et al., 2001; Swinney et al., 1996, and for discussion of this possibility.)

The latter problem also highlights a more general problem for CMLP and other existing on-line methodologies used with aphasic individuals. The window of time in which aphasic comprehenders can show evidence of reactivation of an antecedent is quite small: participants must respond to a word presented right at the trace site. If aphasic syntactic or lexical processing is slowed, then aphasic participants might show little evidence of priming immediately at the gap site, either because they are slow in activating the lexical items involved or because they are slow in postulating a trace or locating an antecedent. However, they might show robust effects later on in the sentence, downstream from the trace position. Testing a response to an object which occurs at only one position in a sentence, relatively soon after a point of potential interest, misses the opportunity to find evidence of delayed but otherwise normal responses to the linguistic stimuli involved. The same basic problem arises with word monitoring, which requires that participants monitor for a word which occurs in critical sentences right at the point of interest (usually, the point at which a syntactic or pragmatic anomaly is found; Tyler, 1985, 1989). Delayed but successful processing of the linguistic relation or element of interest could come well after the target word, after it has passed from short-term memory. A task providing participants a larger time window in which to respond would be preferable, especially if slowed processing is affecting aphasic responses to the linguistic stimuli tested.

In addition to these timing problems, both CMLP and word monitoring tasks are burdensome, involving a secondary task which depends on successful lexical priming (CMLP) and lexical access (word monitoring), both of which are potentially problematic for aphasic comprehenders (see Kiran, 2001, for extensive discussion of lexical access and priming in aphasia). A simpler task, especially one in which aphasic comprehenders need only use abilities which are uncontroversially preserved, would be preferable.

Existing results and methodologies thus do not provide definitive answers to the two questions raised above: how do aphasic individuals comprehend (or fail to comprehend) sentences with movement in real time, and which model provides the best account of aphasic comprehension of sentences with movement? The study presented below addresses both of these questions using a novel experimental technique, an adapted version of the *stop making sense* paradigm. This paradigm has been used with young normals to examine the time-course of processing for a variety of sentence types, including sentences with movement (Boland et al., 1995). In versions of this paradigm used with young normals, participants read sentences one word at a time, pressing one button to continue (i.e., view the next word) and another to indicate that the sentence has "stopped making sense." Participants are not directly instructed as to what constitutes "not making sense"; they are simply told to read the sentences for comprehension and press the "stop making sense" button when they feel it is appropriate. The main dependent variable is rejection rate. Anomalous items typically elicit reliably higher rejection rates than non-anomalous control items starting at the first word at which the anomaly could be detected. This technique has been shown to be extremely sensitive to both syntactic and semantic factors (Boland et al., 1995; Mauner & Koenig, 2000; Mauner et al., 1995).

The current study adapts the basic stop-making-sense task in two ways. First, auditory versions of the sentences involved were used rather than written versions, since reading is often a problem for aphasic participants, as noted above. Second, continuous presentation was chosen over word-by-word presentation, with sentences presented at a normal rate in their entirety. Participants were told to press a button when the sentence "started to sound strange" or "stopped making sense," but the button press did not stop presentation of the sentence. Particularly for the aphasic participants, it was felt that stopping the sentence partway through would be unnatural and might prove distracting. Further, allowing participants to hear the sentences in their entirety may have helped prevent strategic response patterns. Previous work with this technique has shown that young normals may delay committing to a possibly anomalous interpretation of a sentence (and therefore rejecting it immediately) if there is a possibility of the sentence's later being resolved in a felicitous manner (Boland et al., 1995). Allowing listeners to hear the entire sentence permitted them to hear that the anomalous sentences were never resolved felicitously, thus guarding against adaptation of response criteria or development of strategies within the experiment.

We refer to this new technique as *auditory anomaly detection*. It has many advantages compared with the existing on-line techniques described above. First, it is a simple task, which simply requires participants to comprehend sentences. No secondary task is involved. Second, the response is based on an ability which is uncontroversially intact in aphasia: the ability to perceive semantic or pragmatic anomaly. Since the work of Carramazza and Zurif (1976), it has been clear that aphasic individuals are able to recognize semantic and pragmatic cues and make use of them in comprehending language (witness the often-noted difference between semantically reversible and non-reversible sentences). Third, it allows unlimited time after an anomaly for a response to be registered. If aphasic participants notice that a sentence with movement is anomalous, they may respond any time during the sentence, even several words downstream from the anomaly. The potential problems of a small response window found in cross-modal lexical priming or word monitoring therefore do not arise with this task. Fourth, it presents sentences in a relatively natural manner, so that normal on-line comprehension strategies and processes may apply. Fifth, there is an analogous technique which has already been used successfully with individuals with Broca's aphasia: on-line grammaticality judgment, mentioned above (Shankweiler et al., 1989). In on-line grammaticality judgment, participants listen to sentences and press a button to indicate that they have noticed a syntactic anomaly. Shankweiler and colleagues found that the aphasic participants they tested were able to detect syntactic anomalies in this task, and that they were able to do so on-line, before the end of the sentence. The success of this similar technique bodes well for the success of the current study.

In the current study, participants (both aphasic and young normal) listened to sentences involving movement in an auditory anomaly detection task. Half the experimental sentences involved anomalous verb–object combinations, embedded in either a simple conjoined context ("The girl put on a skirt and her mother *fried a shirt* for her before church today") or a relative clause context ("The girl put on *a shirt* that her mother *fried_* for her before church today"). In the relative clause case, the verb–object combination is mediated by movement. Aphasic participants' responses in the relative clause case should provide an answer to the first question raised above, about how aphasic individuals comprehend (or fail to comprehend) sentences with filler-gap dependencies in real time. Their patterns of responses, both rejection rates and response times, should provide evidence regarding the second question raised above, regarding which model of aphasic comprehension provides the best account of their comprehension of movement sentences. If a structural deficit account is correct (Grodzinsky, 1990), aphasic participants should be less successful in detecting the anomaly in the relative clause case (with movement) than the conjoined clause case (no movement). To the extent that they are successful, their responses should come essentially off-line, after the language processor has assigned an incomplete (traceless) syntactic representation to the sentence and the default heuristics can apply (see Grodzinsky, 1990, and the discussion above). A mapping deficit account (Schwartz et al., 1987) makes the same basic prediction: responses should be less accurate in the "non-transparent" object relative clause condition, and they should come late, after the processor has had a chance to assign a complete syntactic representation to the sentence and has subsequently attempted to assign an interpretation to it. A slowed-processing account (e.g., Zurif et al., 1993) does not make as clear a set of predictions—it simply claims that all processing should be slowed. If this kind of account is correct, responses in both the movement and non-movement conditions should be slow, and responses in the movement cases may be less accurate. However, of the three models, a slowed-processing account would be the most immediately compatible with a result showing that aphasic comprehenders retain some capacity to resolve filler-gap dependencies on-line.

We present two experiments below. The first is with a group of young normal participants, designed to verify that the auditory anomaly detection technique works and that the experimental stimuli are suitably anomalous. The results of this experiment also provide a point of comparison for the results of the second. The second experiment involves the same technique and sentences, but with two groups of agrammatic aphasic participants: one group who had previously participated in treatment focused on the comprehension and production of sentences with movement, and the other who had not undergone such treatment. As it turns out, this distinction had important consequences for their performance, which we will return to in Experiment 2 and Section 4.

2. Experiment 1: Young normal participants

2.1. Participants

Thirty members of the Northwestern University community between the ages of 18 and 35 participated, either as volunteers or in exchange for course credit. Six participants were excluded from the results reported below because they were not native speakers of American English or because they had a previously diagnosed hearing loss. The remaining 24 subjects were all native speakers of American English with normal hearing and no reported history of speech and language or neurological disorders.

2.2. Materials

Participants listened to 24 sentences taken from sets like (3) below, with each item appearing in one of four conditions:

(3) a.The girl put on a shirt that her mother picked for her before church today.
b. The girl put on a shirt that her mother fried for her before church today.
c. The girl put on a skirt and her mother picked a shirt for her before church today.
d. The girl put on a skirt and her mother fried a shirt for her before church today.

The four conditions were created by crossing two factors in a 2×2 factorial design, both factors within subjects and within items. The first factor was *movement*: conditions (a) and (b) involved semantically non-reversible object relative clauses, while conditions (c) and (d) involved conjoined clauses. The second factor was *anomaly*: conditions (b) and (d) involved an anomalous verb–object combination while conditions (a) and (c) involved a non-anomalous verb–object combination. In the (b) condition, the sentence became anomalous at the position of the verb (the gap/trace) in the embedded clause; in the (d) condition, it became anomalous at the position of the object. In both conditions, there was at least one sentence-final adjunct (usually of time or place) following the point at which the anomaly emerged, in order to provide participants sufficient time after the object or gap to respond. In all experimental items, the verb–object combination was the only anomaly in the sentence.

The objects in the critical verb–object combinations remained constant; the relative anomaly of the combination was manipulated via the choice of verb. All verbs were obligatorily transitive or strongly transitively biased, and were selected using the Brandeis Verb Lexicon (Grimshaw & Jackendoff, 1981), supplemented with author intuitions. In addition, all pairs of verbs used in the items were matched for length in syllables and for frequency using the Francis and Kucera (1982) norms. Thus, for (3) above, *fried* and *picked* have the same argument structure preferences, the same number of syllables, and approximate equal token frequency. This balancing was done in order to ensure that any differences between the anomalous and non-anomalous conditions would not be due to any of these lower-level factors. A complete list of experimental items is found in Appendix A.

The 24 experimental sentences were interspersed among 48 filler sentences of similar structure. Approximately half of the fillers also contained relative clauses, and 12 of them contained anomalies. The anomalies found in the fillers were of several different types, including anomalous adjective–noun combinations ("furry water") and tense–adverb mismatches ("she left tomorrow"), but they never involved anomalous verb–object combinations. These fillers helped ensure that participants did not learn to anticipate anomalies in relative clauses, and that they would not expect only verb–object combinations to be anomalous. In addition, 10 practice sentences were created for use in a practice session preceding the main experiment. Half these sentences were anomalous, due to either anomalous subject–verb or adjective–noun combinations or missing arguments. Half involved relative clauses.

The practice, filler and experimental sentences were recorded and digitized for presentation in the experiment. The filler and experimental sentences were read by a female native speaker of American English, and the practice sentences were read by a male native speaker of American English. All sentences were read at a slightly slowed but normal rate, with a mean rate of 334 ms per word (range = 264–441 ms). The experimental sentences were an average of 14.44 words long (range = 12–19 words) and an average of 4801 ms in duration (range = 4090–6200 ms).

The start of each sentence was signaled by a tone. An ISI of approximately 5000 ms was provided between sentences. This additional silence was inserted to ensure that even very slow responses would still be registered, creating as large a response window as possible.

The experimental and filler sentences were put into four lists for presentation in the main experiment. The lists were pseudo-randomized, with at least two fillers intervening between experimental items and between two and four non-anomalous sentences intervening between anomalous (filler or experimental) sentences. The four conditions for the experimental sentences were distributed across the lists according to a Latin square design. Each participant heard each experimental sentence only once, in one condition.

2.3. Procedure

The experiment was presented using SuperLab, version 1.74, on either a PowerMac laptop or a desktop Macintosh G3. Each participant was tested individually in a quiet room, with the experimenter present. Participants were seated in front of the computer during testing and listened to the sentences in the experiment over headphones.

After giving informed consent and reading the instructions for the experiment, participants were given verbal instructions by the experimenter. Participants were told that they should press a button on the keyboard (the space bar, colored red for the purposes of the experiment) if the sentences they were listening to "started to sound strange or stopped making sense." In both the written and verbal instructions, it was stressed that it was not necessary to wait until the end of the sentence to respond. If a sentence started to sound odd in the middle, participants were told to press the button in the middle of the sentence. Participants were explicitly told to press the button only if the sentence sounded odd; no response was necessary if the sentence sounded fine.

Participants were then familiarized with the task in a practice session, using the 10 practice sentences described above. Once they had completed the practice, they were given a chance to ask questions of the experimenter. Participants were then started on the main experiment. Participants were given two opportunities to rest during the experiment. The entire experiment, from the start of the practice to the end of the main experiment, lasted approximately 25 min.

2.4. Results

2.4.1. Rejection rates

There were two main dependent variables in this experiment, rejection rate (the proportion of items which were rejected in a given condition) and response time (the amount of time it took to correctly reject an anomalous sentence). We will discuss the rejection rates first. Mean rejection rates for the young normals are presented by condition in Fig. 1.

All responses which came before the offset of the critical word (the verb in the relative clause conditions, the NP in the conjoined clause conditions) were excluded from the analysis.[3] Rejection rates were submitted to a series of planned comparisons, using single-sample and paired-sample t tests. The two anomalous conditions were rejected reliably more often than chance: the relative clause condition (b) was rejected in 82.6% of trials on average ($t(23) = 8.864$, $p < .001$), and the conjoined clause condition (d) was rejected in 78.5% of trials ($t(23) = 7.214$, $p < .001$). The difference between these conditions was not statistically significant ($t < 1$). The non-anomalous conditions were rejected at a rate reliably below chance: the relative clause condition (a) was rejected in 17.4% of trials ($t(23) = 8.864$, $p < .001$) and the conjoined clause condition (c) was rejected in 23.6% of trials ($t(23) = 5.755$, $p < .001$). Again, the difference between these conditions was not statistically significant ($t(23) = 1.304$, $p > .2$). Not surprisingly, the anomalous relative clause condition (b) was also rejected reliably more often than the non-anomalous relative clause condition (a) ($t(23) = 13.314$, $p < .001$). The anomalous conjoined clause condition (d) was also rejected reliably more often than the

[3] This strict criterion likely had the effect of underestimating the number of rejections by the young normals. Several of these early rejections came within 100 ms of the offset of the critical word, likely after participants had been able to identify the word. However, only 9 of 244 total responses by the young normal participants came before the designated measurement point. Any loss of potentially informative data was therefore small.

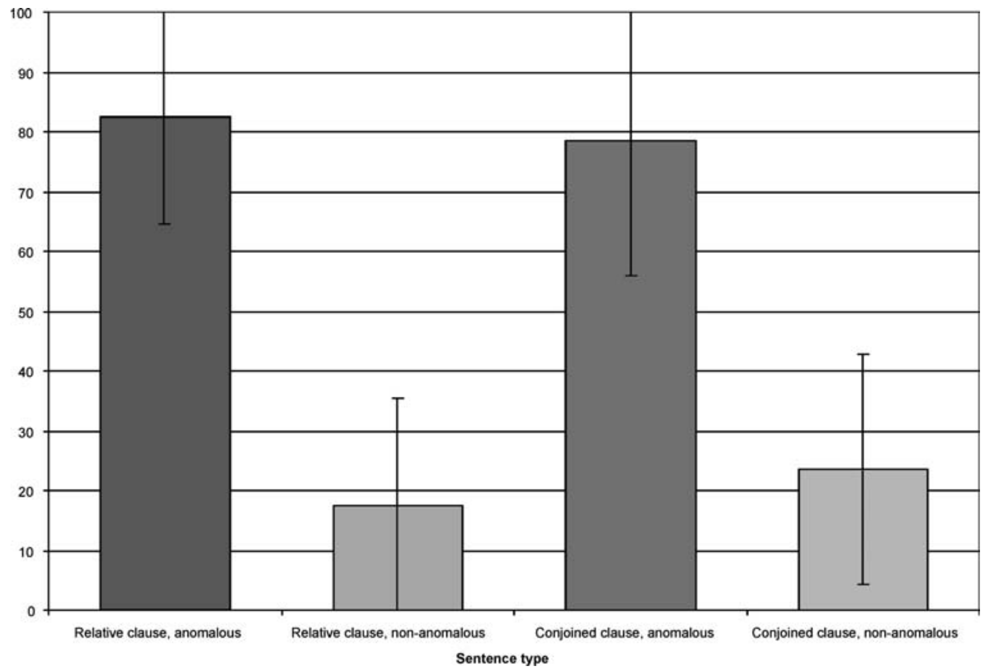

Fig. 1. Mean rejection rates for young normal participants, by condition.

non-anomalous conjoined clause condition (c) ($t(23) = 9.313$, $p < .001$).

2.4.2. Response times

As described above, response times were the amount of time (measured in milliseconds) that it took participants to correctly reject the anomalous sentences, in conditions (b) and (d). Response times were measured from the position in the sentence where the anomaly became apparent, from the offset of the verb in the anomalous relative clause condition (b) and from the offset of the object NP in the anomalous conjoined clause condition (d). Response times are presented in Fig. 2.

Response times for the two conditions were submitted to a planned comparison, using a paired-sample t test. The relative clause condition (b) was rejected more slowly (1001 ms on average) than the conjoined clause condition (d) (807 ms), though this difference only approached statistical significance ($t(23) = 1.603$, $p < .07$, one-tailed test). For both conditions, the majority of the responses came before the end of the sentence for the young normals;190 of 235 total responses (80.9% of responses) came before sentence's end.

2.5. Discussion

The results of Experiment 1 provide evidence that auditory anomaly detection is an effective methodology for studying the on-line processing of filler-gap dependencies. The young normal participants show clear evidence of anomaly detection in both the relative clause (movement) and the conjoined clause (non-movement) condition. There was also little difference in the rejection rates between the movement and non-movement conditions, which is reassuring: it suggests that the young normals treated the anomalous verb–object combinations the same, regardless of whether they were mediated by movement or not. This result is only expected if participants successfully resolved the filler-gap dependency and assigned the correct semantic role to the moved element. The response time results also provide evidence that young normals are able to register their rejection on-line, before sentence's end. They did not wait until the end of the sentence to respond. This result is methodologically encouraging: it suggests that this methodology is able to tap on-line processes, and that young normal participants are able to respond while the sentence is still on-going.

These results also indicate that the stimuli used in the experiment are appropriately anomalous. The young normals rejected the anomalous sentences reliably more often than the non-anomalous ones, and they also did so reliably more often than chance. They did not reject the anomalous sentences all of the time, however, nor did they accept the non-anomalous ones in all cases. This result is not entirely surprising given the nature of the task: participants are allowed to set their own criterion for what "sounds strange" or "doesn't make sense," and this criterion may vary from person to person. Some of the items may simply not have met this criterion for some participants. Interestingly, similar results have been found with standard versions of the stop-making-sense task as well. Results for a parallel set of items from

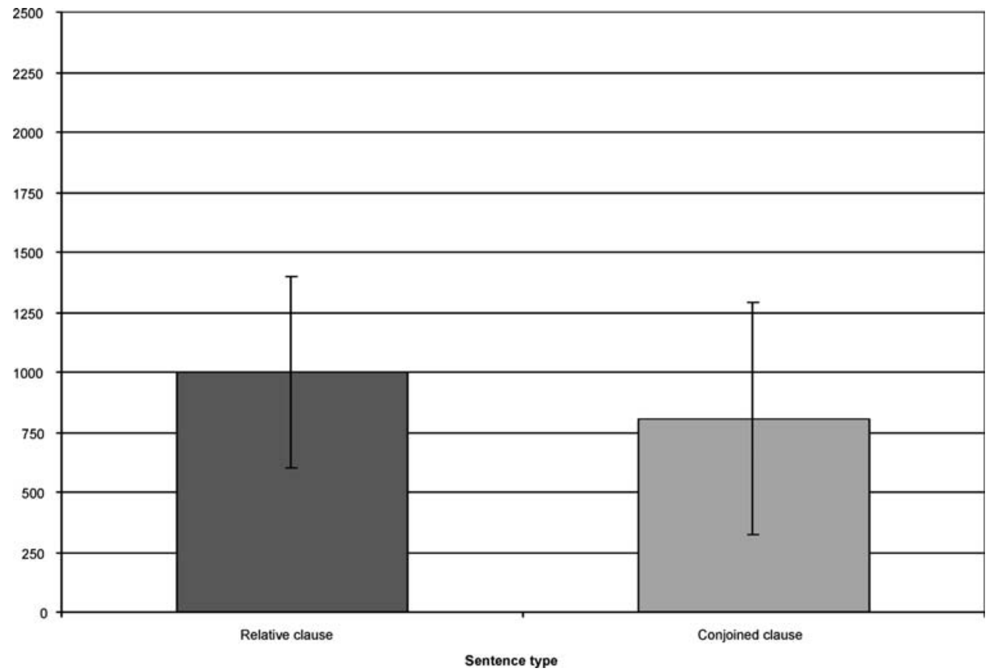

Fig. 2. Mean response times for rejecting anomalous sentences. Young normal participants, by condition.

Boland et al. (1995) show cumulative rejection rates of only around 60% for sentences with obligatorily transitive verbs and anomalous verb–object combinations. If anything, these particular items seem to be perceived as more anomalous than those used by Boland and colleagues. Again, this result is encouraging: it indicates that the verb–object combinations used in the anomalous conditions are indeed odd. If aphasic participants reject these items at a low rate, it cannot be because the items themselves are insufficiently anomalous.

3. Experiment 2: Agrammatic aphasic participants

3.1. Participants

Ten individuals diagnosed with Broca's aphasia, four female and six male, participated in the experiment. One of the participants was identified as non-native speaker of English and another did not provide medical records allowing her diagnosis to be confirmed; their responses are excluded from the results presented below. The remaining eight participants were native monolingual speakers of American English. Of these, only one (Participant 4, MD) was left-handed. All eight had a single lesion in the left hemisphere including Broca's area, resulting from cerebral vascular accident. Some patients (MD, RH, and JG) also had lesions extending to the temperoparietal region. All eight participants were between five and twelve years post-onset at the time of the study (see Table 1).

The eight aphasic participants differed in their treatment status. Four of the eight (MD, MK, JO, and RH) had participated in treatment focused on sentences with filler-gap dependencies. Using a procedure known as Treatment of Underlying Forms (TUF; Thompson, 2001), these patients were trained to successfully comprehend and produce sentences with wh-movement

Table 1
Aphasic participant characteristics

Participant	Age	Gender	Years post-onset	Education (years)
MD	53	M	11	20
MK	56	M	2	20
JO	66	M	8	16
RH	57	M	12	16
CH	50	M	11	15
MH	53	F	7	14
EP	59	F	7	14
JG	65	M	5	13

Note. M, male; F, female; CVA, Cerebrovascular accident; MCA, Middle Cerebral Artery.

(i.e., object relative clauses like the ones used in this experiment and object cleft structures) and those with NP movement (i.e., passives and subject-raising structures). Treatment emphasized the verb and associated thematic roles of sentence NPs, and the movement operations required to form non-canonical sentences (Thompson et al., 1997). The training resulted in success in production and comprehension not only of the trained structures but also untrained, linguistically similar structures (e.g., not only passives but raising structures, and not only object relatives but clefts). Interestingly, the training also resulted in improved spontaneous narrative production, reflected in greater use of correct verb-argument structure (see Thompson et al., 1997 for details). The remaining four aphasic participants did not receive treatment.

3.2. Language testing

Participants were evaluated using the *Western Aphasia Battery* (WAB; Kertesz, 1983). Results for all eight showed behavioral profiles consistent with Broca's aphasia. Aphasia Quotients (AQs) ranged from 30 to 82.3 (see Table 2).

Consistent with the scores above, all participants exhibited hallmarks of Broca's aphasia in their spontaneous speech and interactions with the experimenter (with the exception of JG, who was severely apraxic): slow, effortful, and agrammatic production. To further test whether these participants met the profile for inclusion, the Northwestern University Sentence Comprehension Battery (Thompson, Ballard, & Tait, unpublished) was administered to each participant. This test probes patients' comprehension of semantically reversible active sentences, as well as sentences involving movement (canonical argument order subject relatives and non-canonical passives and object relatives), using a picture-matching task. The results of this test provide evidence regarding whether participants show an "asyntactic" comprehension pattern: above chance performance on canonical argument order sentences (actives and subject relatives) and at or below chance performance on non-canonical sentences (passives and object relatives). Results indicated that all participants (except for JO, one of the treated participants) showed the basic pattern required for inclusion (see Table 3).

3.3. Pre-testing

Prior to the main experiment, all aphasic participants were given a pre-test designed to familiarize them with the experimental task. Participants were read a large number of sentences of differing structure, some of which contained anomalies similar to those found in the main experiment. The participants were asked to point to either an 'X' or a check-mark to indicate whether the sentences sounded "strange" or "OK." They were given unlimited time to respond and could ask to have the sentences repeated once.

Table 2
Aphasic participants' language profiles, based on Western Aphasia Battery (WAB)

	Participant							
	Treated				Untreated			
Western Aphasia Battery:	MD	MK	JO	RH	CH	MH	EP	JG
Aphasia Quotient (AQ):	82.3	79.9	77.5	69.3	81.6	55.4	60.8	30
Fluency	5	5	5	5	6	5	5	1*
Comprehension	10	9.4	9.45	7.9	7.9	7.4	9.8	8.1
Repetition	7	10	7.4	7.9	9	5.9	0**	1.2*
Naming	9	7.6	7.9	5.9	8.9	4.4	7.6***	.7*

* Patient presented with severe apraxia.
** Not tested due to mild to moderate apraxia.
*** Naming subtests performed in written modality, due to mild to moderate apraxia.

Table 3
Aphasic sentence comprehension characteristics, based on Northwestern University Sentence Comprehension Battery

	Participant							
NWU Sentence Comprehension Battery:	MD	MK	JO	RH	CH	MH	EP	JG
Active	80	85	80	80	80	85	70	70
Passive	65	70	85	65	45	20	50	40
Subject relative	70	90	95	85	80	70	70	75
Object relative	40	65	80	65	70	55	60	45

Percentage correct comprehension, by sentence type.

Responses were not recorded, but feedback was provided. All participants reported being comfortable with the task and all of them rejected at least some of the sentences.

3.4. Materials

The same practice, filler, and experimental materials were used in this experiment as in Experiment 1.

3.5. Procedure

Testing for the aphasic participants was carried out over 2 sessions, separated by between 3 and 14 days. In the first session, the pre-test described above was administered, along with any necessary language testing. In the second session, a hearing screening was administered, followed by the experiment. The hearing test was administered in order to determine whether participants had sufficient hearing sensitivity to accurately hear the items in the experiment. All participants were found to have normal or near-normal hearing in at least one ear.

For the experiment, the procedure used with the aphasic participants was very similar to that used with the young normal participants of Experiment 1. The aphasic participants were given a slightly simplified set of instructions, which were read aloud to them. They also were given the chance to repeat the practice if they so desired. Otherwise, the same procedure was followed as in Experiment 1.

3.6. Results

3.6.1. Rejection rates

Mean rejection rates for the aphasic participants are presented by condition in Figs. 3 and 4.

Fig. 3 presents the rejection rates for the four aphasic participants who received treatment. Fig. 4 presents rejection rates for the untreated aphasic participants. As can be seen in the figures, the two groups presented quite different response patterns. Consequently, their group results will be presented separately.

Rejection rates were submitted to a series of planned comparisons, using single-sample and paired-sample t tests. The treated group showed results similar to those of the young normals. The two anomalous conditions were fairly consistently rejected: the relative clause condition (b) was rejected in 75.0% of trials on average (not significantly more often than chance, $t(3) = 2.325$, $p < .11$), and the conjoined clause condition (d) was rejected in 87.5% of trials (significantly more often than chance, $t(3) = 4.704$, $p < .02$). The difference between these conditions was statistically significant ($t(3) = 3.000$, $p < .03$, one-tailed test). The non-anomalous conditions were rejected less frequently than chance: the relative clause condition (a) was rejected in 8.4% of trials ($t(3) = 8.860$, $p < .001$) and the conjoined clause condition was rejected in 25.0% of trials ($t(3) = 5.755$, $p < .001$). The difference between these conditions was not significant ($t < 1$). As with the young normals, the anomalous relative clause condition (b) was also rejected reliably more often than the non-anomalous relative

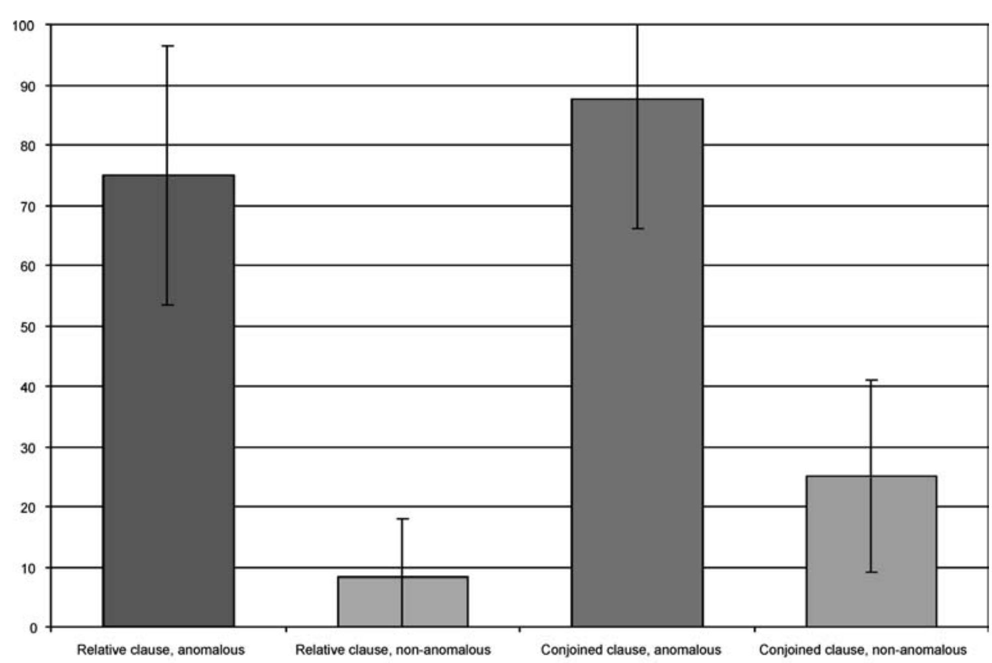

Fig. 3. Mean rejection rates for aphasic participants, treatment group, by condition.

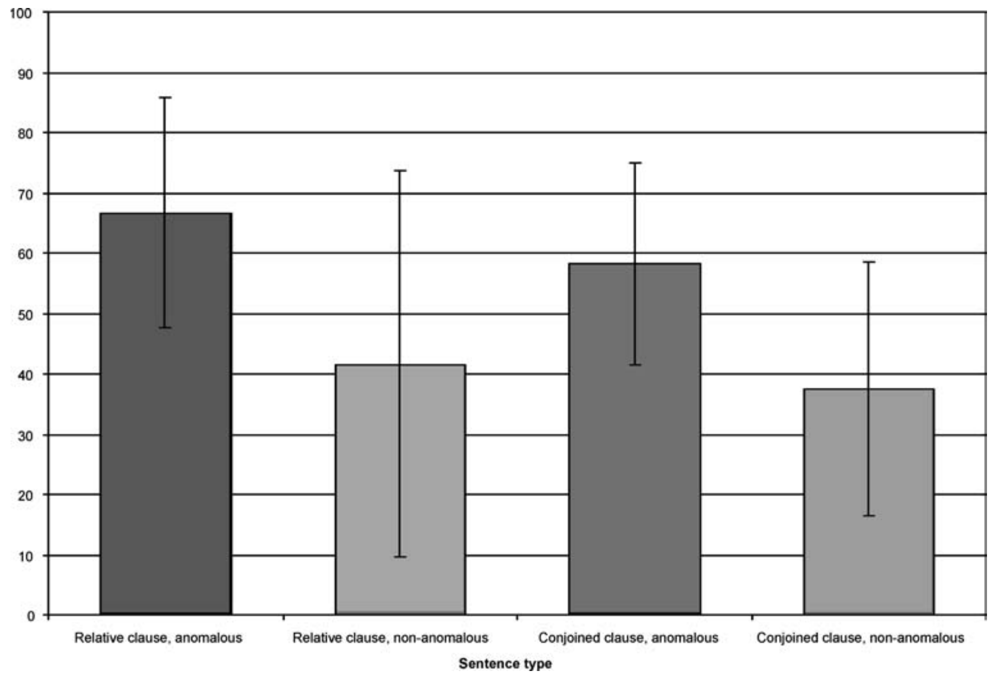

Fig. 4. Mean rejection rates for aphasic participants, untreated group, by condition.

clause condition (a) ($t(3) = 9.805$, $p < .001$, one-tailed test). The anomalous conjoined clause condition (d) was also rejected reliably more often than the non-anomalous conjoined clause condition (c) ($t(3) = 7.839$, $p < .001$, one-tailed test).

In contrast, the untreated group showed results quite different from those of the young normals. The two anomalous conditions were not rejected more often than chance: the relative clause condition (b) was rejected in 66.7% trials on average ($t(3) = 1.732$, $p < .2$), and the conjoined clause condition (d) was rejected in of 58.3% of trials ($t(3) = 1$, $p > .3$). The difference between these conditions was not statistically significant ($t < 1$). The non-anomalous conditions also did not differ from chance: the relative clause condition (a) was rejected in 41.6% of trials ($t < 1$) and the conjoined clause condition (c) was rejected in 37.5% of trials ($t(3) = 1.192$, $p > .3$). The difference between these conditions was also not statistically significant ($t < 1$). In contrast to the results for the young normals and the treatment group, the anomalous relative clause condition (b) was not rejected significantly more often than the non-anomalous relative clause condition (a) ($t(3) = 1.516$, $p > .1$, one-tailed test). However, the difference between the anomalous conjoined clause condition (d) and the non-anomalous conjoined clause condition (c) was reliable ($t(3) = 2.607$, $p < .05$, one-tailed test).

3.6.2. Response times

Response times for the treatment group are presented in Fig. 5, and for the untreated group in Fig. 6.

Again, the two groups show different patterns. For the treatment group, as for the young normals in Experiment 1, the relative clause condition (b) was rejected more slowly (1981 ms on average) than the conjoined clause condition (d) (1294 ms). Perhaps surprisingly, this difference was fully reliable for the treatment group ($t = 2.541$, $p < .05$, one-tailed test), while it was not for the young normals. In contrast, for the untreated group, responses for the relative clause condition (b) were faster than responses for the conjoined clause condition (d) (2204 vs. 2471 ms). However, this difference was not statistically significant ($t(3) = 1.874$, $p < .08$).

The relative proportion of on-line responses also revealed differences between the two groups. For the treatment group, 20 of 49 total responses (40.8%) came before the sentence's end, and all four participants had at least some on-line responses. (In fact, one treatment group member, JO, had 83.3% on-line responses.) For the untreated group, only 5 of 23 responses (21.7%) came before sentence's end, and one of the four participants had no on-line responses at all.

As has often been noted, group comparisons when dealing with aphasic participants can often be misleading. However, comparing pairs of participants matched for relative severity of impairment reveals similar differences to those found above. For example, MD (WAB AQ = 82.3) and CH (WAB AQ = 81.6) were very similar in their severity. However, MD (of the treatment group) rejected 66.7% of the anomalous relative clause sentences and 0% of the non-anomalous cases, while CH (of the non-treatment group) rejected 83.3% of the

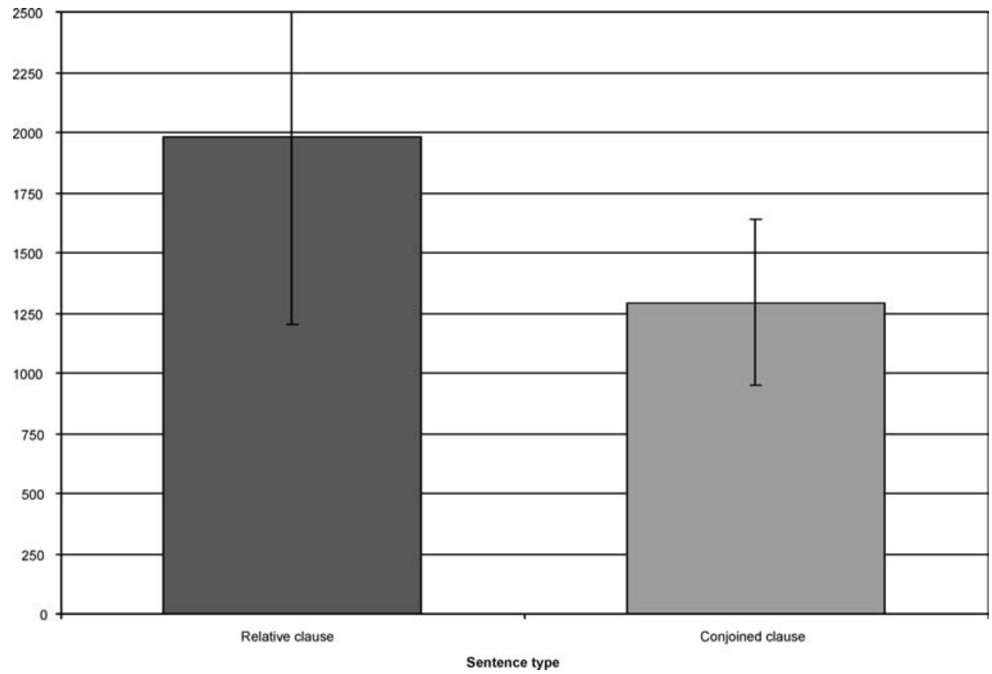

Fig. 5. Mean response times for rejecting anomalous sentences. Aphasic participants, treatment group, by condition.

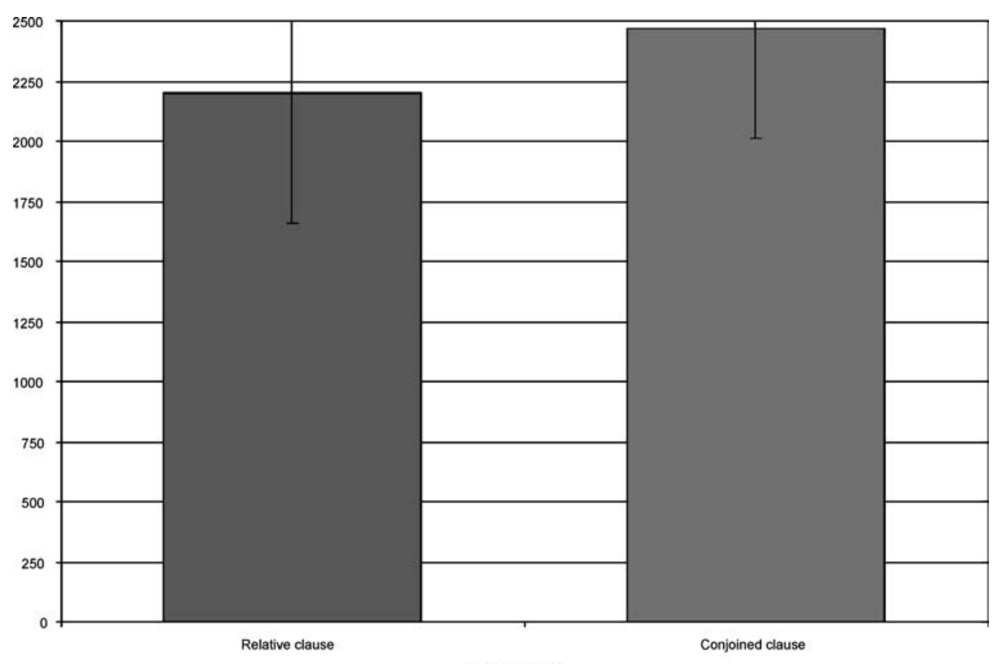

Fig. 6. Mean response times for rejecting anomalous sentences. Aphasic participants, untreated group, by condition.

anomalous relative clause sentences but also rejected 66.7% of the non-anomalous relative clause items. Further, MD had a mean response time of 1788 ms for the anomalous relative clause condition (b) and a response time of 985 ms in the conjoined clause condition (d). CH had response times of 3020 and 3071 ms for conditions (b) and (d), respectively. Interestingly, MD and CH also listened to the same list of stimuli—they heard exactly the same sentences, in exactly the same order—so any differences between them cannot be due to the particular items they heard.

3.7. Discussion

The results of Experiment 2 reveal two different patterns. Aphasic participants in the treatment group responded quite similarly to the young normals in Experiment 1. They showed evidence of successful anomaly detection in both the relative clause (movement) and the conjoined clause (non-movement) condition. However, there was some difference between the movement and non-movement cases: the rejection rate for relative clauses differed only marginally from chance, and there was a reliable difference between the rejection rates for the movement and non-movement conditions. These results suggest that even for semantically non-reversible movement structures like the ones tested here, the aphasic participants experienced some difficulty in successfully interpreting the sentence containing movement. Nevertheless, they clearly showed evidence of comprehending these sentences and accurately rejected anomalous or implausible sentences, even when those sentences involved relative clauses.

The response time results provide evidence that participants in the treatment group were able to register their rejection on-line, before sentence's end. While their responses were slower than the young normals', members of the treatment group clearly did not wait until the end of the sentence to respond. The pattern of response times for the treatment group was also similar to that of the young normals: they rejected anomalous relative clause sentences more slowly than anomalous conjoined clause sentences.

Aphasic participants in the untreated group showed a noticeably different pattern. While they did reject anomalous relative clause sentences relatively often, they rejected non-anomalous relative clause sentences as well, almost as often. Further, their high rejection rate for non-anomalous sentences appeared to be especially pronounced for sentences with movement: rejection rates for the anomalous and non-anomalous conjoined conditions differed significantly, while rejection rates for the relative clause conditions did not. These results suggest that the untreated aphasic participants tended to reject sentences with movement regardless of whether the filler-gap relation in them was resolved implausibly. We will return to the implications of this finding in Section 4.

The untreated aphasic participants' response time data also showed a different pattern from the treatment group's (and from the young normals' in Experiment 1). The untreated group showed little evidence of rejecting anomalous sentences on-line, with almost none of their responses coming before the end of the sentence. The pattern of response times for the two anomalous conditions also differed from the pattern seen for the other groups. There was a marginally reliable difference in the opposite direction, with responses for the relative clause condition (b) being faster than responses in the conjoined clause condition (d). The untreated group's response times were also considerably slower than the treatment group's, 300–1200 ms slower. Together, these results suggest that even the untreated group's correct rejections were little related to on-line comprehension processes.

To summarize the results of this experiment: two patterns of results emerged, one for the treatment group of aphasic participants and a different one for the untreated group. The treatment group showed significant evidence of gap-filling capacity, displaying an ability to reject anomalous sentences on-line, even if those sentences involved movement. The untreated group showed little capacity to reject anomalous sentences on-line, even when the sentences did not involve movement. Further, these participants exhibited a tendency to reject any movement sentences, regardless of the relative anomaly of the filler-gap relation involved. These results have important implications concerning the mechanism of recovery in patients who show improvement in their sentence production and comprehension after treatment. They also have implications for competing theories of agrammatic comprehension, which we will turn to in Section 4.

4. General discussion

Two related and unresolved questions were posed in Section 1: how do agrammatic aphasic individuals comprehend (or fail to comprehend) sentences with movement on-line, and which model of agrammatic comprehension provides the best account of their understanding of sentences with filler-gap dependencies? The results of Experiment 2 provide answers to the first question, and the same results (in comparison with those of Experiment 1) shed light on the second.

Experiment 1 with young normals revealed a pattern quite similar to results found with other experimental paradigms, such as standard stop-making-sense paradigms (Boland et al., 1995), self-paced reading (Clifton & Frazier, 1989), ERPs (Garnsey, Tanenhaus, & Chapman, 1989), cross-modal lexical priming (Hickok, Canseco-Gonzalez, Zurif, & Grimshaw, 1992), and head-mounted eyetracking (Sussman & Sedivy, 2003). Young normals resolved filler-gap dependencies quickly and accurately, showing evidence of having resolved and rejected anomalous filler-gap dependencies within 1000 ms of the gap site (the obligatorily transitive verb).

Experiment 2 revealed two different patterns for the aphasic individuals tested here. Aphasic participants who had previously received treatment behaved similarly (though not identically) to young normals. They rejected sentences containing anomalous verb–object combinations with considerable accuracy, even when a movement dependency mediated the connection between verb and object. However, they were somewhat less accurate in detecting anomalies in movement contexts than in simple contexts without movement, in contrast to the normals. They were also slower to detect anomalies (in both movement and non-movement cases) than young normals, taking almost 2000 ms to register their rejection after the gap. Nevertheless, their response time patterns were similar to those of the young normals in Experiment 1 (detection of anomalies slower in movement contexts than in non-movement contexts) and they show evidence of rejecting anomalous sentences on-line, before sentence's end. In contrast, aphasic participants who received no treatment showed little or no evidence of being able to reject sentences on-line, and their rejection patterns were quite different from those of the young normals. They were almost as likely to reject a non-anomalous sentence with movement as an anomalous one.

Aphasic individuals who have not received treatment thus appear to differ qualitatively from young normals in this task. As a group, they showed little or no evidence of resolving filler-gap dependencies or of comprehending sentences with movement, especially on-line. Their behavior is therefore consistent with models of agrammatic comprehension in which Broca's aphasics are simply unable to represent movement dependencies, like Grodzinsky's (1990, 2000) Trace Deletion Hypothesis and Mauner et al.'s (1993) Double Dependency Hypothesis. These theories claim that either traces are missing completely from the syntactic representations aphasic comprehenders compute for these sentences (Grodzinsky) or the mechanism for relating a trace to moved antecedent is lacking (Mauner et al.). Such a radical deficiency could certainly explain the untreated aphasic comprehenders' poor performance with movement. The behavior of the untreated group is also potentially consistent with mapping approaches to agrammatic comprehension (Schwartz et al., 1987), which claim that the process of mapping a syntactic structure onto an interpretation is disrupted. This problem could explain the difficulty the untreated aphasic participants had in deciding whether a sentence with movement had a sensible interpretation or not.

However, these approaches differ in their accounts of how aphasic individuals deal with the particular movement sentences tested here. All of the object relatives used in this experiment were semantically non-reversible: 22 of the 24 experimental sentences had inanimate objects in the critical verb–object combination (as in "The girl put on *a shirt* that her mother picked/fried for her"), and all of the sentences were strongly implausible under interpretations in which the object was combined with the critical verb. Assuming that aphasic comprehenders are sensitive to such semantic and pragmatic cues in doing the mapping from syntax to semantics (Schwartz et al., 1987), the results for the untreated aphasic participants are surprising under mapping accounts of agrammatic comprehension. Such accounts have no explanation for why such semantic and pragmatic information did not help these aphasic participants mapping from syntax to interpretation, the crux of agrammatic comprehension difficulties in mapping models. Under existing formulations of these models, such information should help, and the fact that it clearly did not (for either plausible or implausible movement sentences) raises questions for mapping models.

Grodzinsky's Trace Deletion model encounters similar problems in explaining the untreated group's results. Grodzinsky claims that a Default Principle is responsible for assigning an interpretation to representations without traces, and the Default Principle is specifically sensitive to semantic information like animacy. The Default Principle assigns an Agent semantic role to clause-initial animate NPs and a Patient or Theme role (consistent with the NP's being an object) otherwise. In the sentences tested here, the animacy information should have guided the aphasic participants to a correct object interpretation of the relative clauses, resulting in better performance.

Mauner et al.'s Double Dependency model is potentially more compatible with the untreated group's results. Mauner and colleagues claim that it is coindexation which is disrupted in Broca's aphasia: aphasic comprehenders fail to automatically coindex a moved element (the relative operator or pronoun in the case of relative clauses) and its trace. As discussed in Section 1, it is this coindexation relation which allows the head NP to be understood as the object of the relative clause in the object relative cases tested here. Mauner et al. claim that in the absence of an appropriate coindexation relation, aphasic comprehenders coindex elements in a sentence at random, sometimes assigning a moved object and its trace the same index, and sometimes assigning the clause's subject and the trace the same index. Under the assumption that subjects are also moved to their surface position (creating double movement dependencies in clauses with object movement; see discussion in Mauner et al., 1993), the subject and its trace would also be subject to random coindexation. In the object relatives tested here, random coindexation would have the effect of sometimes incorrectly assigning the object role to the animate surface subject and the subject role to the inanimate head NP. This configuration would make both anomalous and non-anomalous relative clause sentences implausible (under the assumption that inanimate NPs make implausible Agents), leading to rejection of both. Such a state of affairs would result in roughly equal rejection of the non-anomalous and anomalous conditions, which is what was found for the untreated group.[4]

Slowed-processing accounts of agrammatic comprehension are also compatible with the untreated group's results. Such accounts claim that some aspect of normal sentence processing is dramatically slowed and less effective in aphasia, resulting in an inability to retrieve information crucial to resolving a filler-gap dependency in a timely manner. The untreated aphasic participants' responses were certainly slow compared to young normals' responses (as well as those of the treatment aphasic group), consistent with this general claim. In addition, the particular sentences tested here were quite long, which could have resulted in difficulty in quickly locating and reactivating the antecedent at the gap site.[5] Such difficulty could result in relatively low rejection rates for the anomalous relative clause cases and relatively high rates for the non-anomalous ones: in both cases, aphasic comprehenders should be relatively ineffective in retrieving the filler and deciding whether the verb–object combination it crates via the gap is anomalous. Again, this pattern is roughly what was found for the untreated aphasic participants.[6]

[4] This characterization of aphasic coindexation tacitly assumes that aphasic comprehenders ignore semantic information in dealing with the output of random coindexation, i.e., that they will accept a coindexation in which an inanimate moved object is coindexed with a subject trace. It is not clear whether Mauner and colleagues would share such an assumption, at least for off-line performance. However, it is possible that the time pressure imposed by the current on-line task—in which participants were instructed to respond as quickly as possible—prompted the aphasic participants to be more accepting of such coindexations that they would be in an off-line task without time pressure. That is, the aphasics may have accepted the first coindexation they arrived at and based their rejection decision on that, rather than revising their coindexation based on semantic or pragmatic information. This latter description attributes strategic reanalysis capacities to agrammatics in the absence of time pressure, a move which seems necessary to reconcile Mauner, et al's random coindexation with the fact that aphasic patients show better offline performance with non-reversible movement sentences (Carramazza & Zurif, 1976, among others).

[5] This characterization of the untreated group's difficulties tacitly assumes a gap-driven model of filler-gap processing (Fodor, 1978): perceivers first locate a gap and than initiate a search for an element to fill it. Normal gap-filling has consistently been shown to be filler-driven, in contrast (Frazier & Flores d'Arcais, 1989): perceivers identify a filler and then actively search for a gap to associate it with. This distinction might be part of what differs between normals and aphasic comprehenders: perhaps normal gap-filling is filler driven, while aphasic gap-filling is gap driven. We leave this interesting possibility open here.

[6] A slowed-processing account, in which length crucially affects aphasic performance, might also explain another contrast between the two aphasic groups: the untreated aphasic participants were also less accurate (and slower) in rejecting anomalous conjoined cases, without movement. They were also more likely to reject the non-anomalous conjoined cases. As noted above, the experimental sentences were quite long, and the processing burden imposed by them may have interfered with the untreated aphasic participants' ability to judge the plausibility of even local verb–object combinations, especially if those combinations came late in the sentence. Neither mapping accounts (Schwartz et al., 1987) nor grammatical deficit accounts (Grodzinsky, 1990; Mauner et al., 1993) have any explanation for this behavior in non-movement conditions.

A slowed-processing account is also compatible with the performance of the aphasic participants in the treatment group. They differed only quantitatively from the young normals of Experiment 1: they showed evidence of resolving filler-gap dependencies successfully, correctly judging most of the anomalous relative clause sentences anomalous and almost all the non-anomalous ones plausible. In addition, they did so on-line in many cases, before the sentence's end. Further, while they rejected the anomalous sentences more slowly than the young normals, they showed the same basic response time pattern as the young normals. This is directly in line with the predictions of slowed processing models described in Section 1: processing routines in aphasia are very similar to those used by normals, just slower and potentially less accurate (as the treated aphasic participants were, especially in the anomalous relative clause condition).

The Trace Deletion and mapping models also fare better with the treatment group's performance than with the untreated group's. The semantic and pragmatic information that drives the Default Principle and assists with the mapping process did appear to have an effect for the treatment group. In terms of these models, they were able to employ animacy information to arrive at correct interpretations for the non-anomalous relative clause sentences, rejecting these cases much less often than the untreated group, even under the time pressure of the on-line task. However, the speed with which the treatment group was able to use this information is potentially problematic for mapping and Trace Deletion accounts. As discussed in Section 1, these models both predict relatively late effects of the kinds of information that drive the processes responsible for aphasic interpretation of movement sentences. Grodzinsky is quite explicit about this issue: he claims that the Default Principle can only apply *after* a full representation for the sentence has been constructed (see Section 1). The mapping process (the site of aphasic failure in mapping models) is also logically dependent on a full syntactic representation being constructed for a sentence. As discussed earlier, both theories therefore predict that aphasic success or failure in comprehension of movement sentences results after off-line analysis. The on-line success of the treated aphasic participants is at odds with this prediction.

It is unclear how the Double Dependency model would account for the treatment group's results, especially the difference between their results and the untreated group's. If the Double Dependency model is correct, the random coindexation which resulted in near-chance rejection rates for both anomalous and non-anomalous relative clause cases for the untreated group must have been overridden by the treated aphasic participants. They must have employed animacy information to reject those random coindexations in which the subject trace and the moved object were coindexed and arrived at the correct coindexation. This latter coindexation is the one they must have used to make the rejection judgment, particularly in the non-anomalous relative clause condition, where they performed quite well (only 8.4% rejections). Here again, the speed of this process is perhaps surprising: it suggests that even under time pressure, the treated aphasic participants were able to compute multiple coindexations, reject one based on animacy information, and make the rejection decision, all before the end of the sentence in many cases. The additional processing routines needed to repair a faulty agrammatic representation appears to be engaged with remarkable speed, applying on-line (as incoming material is still being processed).

However, there is an alternative possibility: Such post-linguistic repair operations may not be relevant to characterizing the treatment group's performance. Perhaps treatment qualitatively changed the manner in which the treated aphasic participants comprehend these sentences. As noted above, the general pattern of performance for the treatment group is quite similar to that of the young normal group in Experiment 1. It could be that treatment specifically targeting filler-gap constructions and their syntactic representation restored access to the underlying representations involved. With this restored grammatical knowledge in place, the treated aphasic participants were able to assign a normal, well-formed syntactic representation to the movement sentences and interpret them, albeit more slowly than young normals. If this characterization is correct, then the theories of agrammatic comprehension outlined in Section 1 (with the possible exception of slowed-processing accounts) are not relevant to treated aphasic comprehenders. Post-treatment, these individuals process language quite similarly to normals. Such a possibility deserves more careful examination, but it receives support from recent fMRI studies suggesting that treatment may stimulate development of right-hemisphere homologues to Broca's area, areas which may be recruited in syntactic processing (Thompson, Fix, Gitelman, Parrish, & Mesulam, under review). Such processes could be the concrete mechanisms which underlie recovery in the treatment group.

The results of this study also highlight two important factors in the study of aphasia more generally. The first is a methodological factor, related to the discussion in Section 1. The task developed here, auditory anomaly detection, appears to be useful for studying the time course of not only normal but impaired sentence processing. It provided clear evidence regarding both the success and timing of filler-gap dependency resolution, which shed light on long-standing theoretical issues regarding aphasic comprehension. It also successfully avoided the time window problem noted for many other methodologies commonly used with aphasic individuals: it provided the aphasic participants with ample time to respond, even well after the point of immediate interest. Given the often long-delayed nature of the effects found in the study, as well as the possible slowed-processing account of them, this methodological advantage was crucial.

The second important factor was the effect of treatment. As discussed above, the treated and untreated groups showed fundamentally different patterns of behavior. The aphasic participants who had received treatment were strikingly similar to the young normals in their behavior, while the untreated aphasic participants were quite different from the normals. While this result needs to be interpreted with caution—this comparison is post hoc, and we do not have pre-treatment data with this task for the treatment group—it is interesting and encouraging. This clear difference suggests that linguistically motivated treatment can significantly improve aphasic command of even the most complex structures, even during on-line sentence processing.

Appendix A. Experimental materials used in Experiments 1 and 2

(1) a.The janitor cleaned the wall that the child smacked during recess this afternoon.
b.The janitor cleaned the wall that the child chased during recess this afternoon.
c.The janitor cleaned the floor and the child smacked the wall during recess this afternoon.
d.The janitor cleaned the floor and the child chased the wall during recess this afternoon.

(2) a.The busboy wiped up some water that the chef spilled during lunch today.
b.The busboy wiped up some water that the chef chopped during lunch today.
c.The busboy wiped up the counter and the chef spilled some water during lunch today.
d.The busboy wiped up the counter and the chef chopped some water during lunch today.

(3) a.The woman looked at the portrait that the artist sketched during the gallery's reception.
b.The woman looked at the portrait that the artist chewed during the gallery's reception.
c.The woman looked at the statue and the artist sketched the portrait during the gallery's reception.
d.The woman looked at the statue and the artist chewed the portrait during the gallery's reception.

(4) a.The customer picked up the package that the employee wrapped in the customer service department.
b.The customer picked up the package that the employee drilled in the customer service department.

c.The customer picked up the boxes and the employee wrapped the package in the customer service department.
d.The customer picked up the boxes and the employee drilled the package in the customer service department.

(5) a.The children threw away the oranges that the mother squeezed during breakfast this morning.
b.The children threw away the oranges that the mother kissed during breakfast this morning.
c.The children threw away the egg shells and the mother squeezed the oranges during breakfast this morning.
d.The children threw away the egg shells and the mother kissed the oranges during breakfast this morning.

(6) a.The woman opened the windows that the maid wiped in the front room this morning.
b.The woman opened the windows that the maid weighed in the front room this morning.
c.The woman opened the curtains and the maid wiped the windows in the front room this morning.
d.The woman opened the curtains and the maid weighed the windows in the front room this morning.

(7) a.The accountant deposited some money that the banker earned in the stock market last year.
b.The accountant deposited some money that the banker solved in the stock market last year.
c.The accountant deposited some receipts and the banker earned some money in the stock market last year.
d.The accountant deposited some receipts and the banker solved some money in the stock market last year.

(8) a.The man examined the hole that the plumber fixed under the house today.
b.The man examined the hole that the plumber pushed under the house today.
c.The man examined the pipe and the plumber fixed the hole under the house today.
d.The man examined the pipe and the plumber pushed the hole under the house today.

(9) a.The little girl put on a shirt that her mother picked for her before church today.
b.The little girl put on a shirt that her mother fried for her before church today.
c.The little girl put on a skirt and her mother picked a shirt for her before church today.
d.The little girl put on a skirt and her mother fried a shirt for her before church today.

(10) a.The woman picked up the hose that the gardener dropped in the yard this afternoon.
b.The woman picked up the hose that the gardener killed in the yard this afternoon.
c.The woman picked up the rake and the gardener dropped the hose in the yard this afternoon.
d.The woman picked up the rake and the gardener killed the hose in the yard this afternoon.

(11) a.The vet helped the kitten that the little boy petted in the waiting room of the clinic.
b.The vet helped the kitten that the little boy tackled in the waiting room of the clinic.
c.The vet helped the puppy and the little boy petted the kitten in the waiting room of the clinic.
d.The vet helped the puppy and the little boy tackled the kitten in the waiting room of the clinic.

(12) a.The girl used the pencils that the boy sharpened during art class this afternoon.
b.The girl used the pencils that the boy erased during art class this afternoon.
c.The girl used the crayons and the boy sharpened the pencils during art class this afternoon.
d.The girl used the crayons and the boy erased the pencils during art class this afternoon.

(13) a.The smuggler surrendered the ship that the navy boarded in the harbor.
b.The smuggler surrendered the ship that the navy cancelled in the harbor.
c.The smuggler surrendered the cargo and the navy boarded the ship in the harbor.
d.The smuggler surrendered the cargo and the navy cancelled the ship in the harbor.

(14) a.The boy put on a sweater that the old woman knitted in the retirement home.
b.The boy put on a sweater that the old woman pronounced in the retirement home.
c.The boy put on his mittens and the old woman knitted a sweater in the retirement home.
d.The boy put on his mittens and the old woman pronounced a sweater in the retirement home.

(15) a.The lawyer interviewed the prisoner that the guard abused in the dining hall.
b.The lawyer interviewed the prisoner that the guard emptied in the dining hall.
c.The lawyer interviewed the officer while the guard abused the prisoner in the dining hall.
d.The lawyer interviewed the officer while the guard emptied the prisoner in the prison dining hall.

(16) a.The cameraman photographed a butterfly that the scientist captured during the expedition.

b.The cameraman photographed a butterfly that the scientist dated during the expedition.
c.The cameraman photographed the wildlife and the scientist captured a butterfly during the expedition.
d.The cameraman photographed the wildlife and the scientist dated a butterfly during the expedition.

(17) a.The politician visited the city that the army destroyed during the war.
b.The politician visited the city that the army published during the war.
c.The politician visited the front and the army destroyed the city during the war.
d.The politician visited the front and the army published the city during the war.

(18) a.The assistant held the board that the carpenter measured on the back deck.
b.The assistant held the board that the carpenter achieved on the back deck.
c.The assistant held the nails and the carpenter measured the board on the back deck.
d.The assistant held the nails and the carpenter achieved the board on the back deck.

(19) a.The secretary listened to the phone call that the boss received after the meeting.
b.The secretary listened to the phone call that the boss carried after the meeting.
c.The secretary listened to the message and the boss received the phone call after the meeting.
d.The secretary listened to the message and the boss carried the phone call after the meeting.

(20) a.The accountant examined the error that the businessman uncovered during the company review.
b.The accountant examined the error that the businessman imported during the company review.
c.The accountant examined the records and the businessman uncovered the error during the company review.
d.The accountant examined the records and the businessman imported the error during the company review.

(21) a.The reporter interviewed the protesters that the police arrested during the rally.
b.The reporter interviewed the protesters that the police resisted during the rally.
c.The reporter interviewed the onlookers and the police arrested the protesters during the rally.
d.The reporter interviewed the onlookers and the police resisted the protesters during the rally.

(22) a.The boy looked at some postage stamps that the old man collected for his nephew.
b.The boy looked at some postage stamps that the old man adopted for his nephew.
c.The boy looked at some baseball cards and the old man collected some postage stamps for his nephew.
d.The boy looked at some the baseball cards and the old man adopted some postage stamps for his nephew.

(23) a.The judge looked up the rule that the attorney violated during the trial.
b.The judge looked up the rule that the attorney imitated during the trial.
c.The judge looked up the case when the attorney violated the rule during the trial.
d.The judge looked up the case when the attorney imitated the rule during the trial.

(24) a.The charity used the money that the celebrity raised during the fund drive.
b.The charity used the money that the celebrity dropped during the fund drive.
c.The charity hired the workers and the celebrity raised the money during the fund drive.
d.The charity hired the workers and the celebrity dropped the money during the fund drive.

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