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The role of the anterior left hemisphere in real-time sentence comprehension: Evidence from split intransitivity[☆]

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Abstract

We investigate Broca's sentence comprehension as an impairment on normal syntactic composition: the slow-syntax hypothesis (SSH). Experiment 1 examines comprehension of object-relative clauses (Wh-movement). Experiment 2 examines comprehension of sentences with unaccusative verbs (NP-movement), which like passives, base-generate their *theme*-argument in object position. Guided by the SSH, both experiments test the prediction that syntax-dependent effects such as "gap-filling" are observable but in a delayed fashion. Results show that whereas no priming was obtained at the point of the trace, antecedent reactivation emerged 650 and 800 ms after the verb (for Wh- and NP-movement respectively). This shows, contrary to dependency-based generalizations, that Broca's patients are able to successfully implement dependencies, albeit in a protracted manner. Given the localization value provided by Broca's aphasia, this supports the notion that the temporal implementation of syntactic structure formation (i.e., the requirement that it be fast and automatic) depends on the integrity of the anterior left hemisphere.

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1. Introduction

Even though it is widely accepted that the sentence comprehension deficit that results from damage to the left anterior cortical region (roughly Broca's area) should be characterized in terms of a processing limitation, the exact nature of this processing impairment is still under debate. Two distinct approaches have been proposed. The first approach—which we term here the *dependency-relations* approach—attributes the

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comprehension deficit to difficulties that arise during the implementation of certain kinds of dependency relations, namely those that result from NP- and Wh-movement (e.g., passives and relative clauses, respectively). Two generalizations illustrate this approach: the Trace-Deletion Hypothesis and the Double-Dependency Hypothesis. The Trace-Deletion Hypothesis (e.g., Grodzinsky, 1995) describes the comprehension deficit as an inability to access thematic role information contained in NP-/Wh-traces, thus allowing extra-linguistic strategies to be introduced in the comprehension process. The Double-Dependency Hypothesis (e.g., Mauner, Fromkin, & Cornell, 1993), in contrast, claims that the process of coindexation between traces (or other entities that can bear thematic roles) and their antecedents is impaired. According to this generalization, comprehension is impaired (i.e., chance performance will result) whenever more than one such dependency has to be established in a given construction.

The second approach, which we term here the *time-course* approach, takes the comprehension impairment to be a reflection of a restricted processing capacity that crucially affects the syntactic component of the language system. Studies that have investigated Broca's sentence comprehension from this point of view propose that this limitation of processing resources is characterizable as slowed-down syntactic composition. That is, the comprehension deficit manifests itself as an inability to carry out syntactic composition at the normal rate (e.g., Haarmann & Kolk, 1991, 1994; Piñango, 2000b, 2001, in press). As a result, syntactico-semantic processes that depend on a fully formed syntactic structure, such as thematic role assignment, are affected. This is particularly the case in those structures where syntactic representation reverses the canonical order of thematic roles (e.g., agentive passives and object relatives). When this happens, lexical factors, such as the verb's argument structure, are allowed to compete with the order present in syntactic representation, for the purposes of linking arguments to syntactic structure. This competition leads to guessing, which, in off-line tasks, is observed as chance performance.

The *time-course* approach differs from the *dependency-relations* approach in that the former assumes that in the presence of slowed syntactic representation, all aspects of syntactic composition will be affected, including dependency relations such as those formed by NP-movement (e.g., passives, raising constructions), and Wh-movement (e.g., relative clauses, clefts).¹ What is important for our purposes is that whereas the *dependency-relations* approach predicts that the locus of the impairment in aphasia is restricted to mechanisms associated with dependency relations (be they accessing information in the trace, or the inability to establish correct coindexation), the *time-course* approach in its strongest form predicts that once the syntactic representation has been formed, it is indistinguishable from the "normal" representation. Under this view, syntactic knowledge—and its implementation—are intact, so all syntactic effects associated with syntactic structure formation can potentially be observed.

The present study explores the *time-course* approach in greater depth by examining the consequences of slowed syntax formation in constructions containing Wh- and NP-movement during real-time comprehension. In particular, it investigates the

¹ A dependency relation is a connection between the position where an entity is heard in a sentence, and the position where it is interpreted or base-generated. In the sentence: "The boy_i who_i Bill chased (*who*)_i last night is fat," the noun "boy" is heard at the beginning of the sentence, but its interpretation as "chasee" is only obtained further down the sentence, in the complement position of the verb *chased*. The place where "boy" (via the relative pronoun *who*) is putatively interpreted, is signaled with italics. We call the relation between "boy" and the position following the verb (i.e., the gap) a dependency relation, because of the necessary connection that must exist between this gap position (where interpretation takes place) and the noun with which it corefers for the sentence to be interpretable.

hypothesis that well-known reflections of antecedent-trace relations (i.e., “gap-filling”) found during normal comprehension are observed in Broca’s comprehension but in a protracted manner.

It is by now a well-established observation that Broca’s aphasia patients as a group perform at above chance levels in the off-line comprehension of so-called canonical constructions (i.e., constructions where the *agent/experiencer* role appears in the sentence before the *theme/patient* role, such as agentive actives and subject relatives). By contrast, these patients, as a group, display performance within chance levels for the noncanonical counterparts such as agentive passives, object relative sentences, and object clefts (e.g., Caramazza & Zurif, 1976; Schwartz, Saffran, & Marin, 1980; Ansell & Flowers, 1982; Linebarger, Schwartz, & Saffran, 1983; Caplan & Futter, 1986; Grodzinsky, 1989, 1995, 2000; Hagiwara & Caplan, 1990; Hagiwara, 1993; Hickok, Zurif, & Canseco-Gonzalez, 1993; Beretta, Harford, Patterson, & Piñango, 1996; Beretta, Piñango, Patterson, & Harford, 1999; Grodzinsky, Piñango, Zurif, & Drai, 1999). Importantly for present purposes, while this canonical/non-canonical pattern has been observed in several languages, it has been reported almost exclusively from off-line tasks; that is, tasks such as picture-to-sentence matching or act-out, where the patient is able to reflect about the sentence, and the sentence is repeated as many times as the subject requires.

When we look at the effects of the canonical/noncanonical contrast on Broca’s comprehension using on-line tasks such as cross-modal lexical priming, however, we observe a different pattern, one that suggests that more than the interpretation of noncanonical constructions may be compromised in the Broca’s system. Broca’s patients differ from normal controls in that they do not exhibit the well-known “gap-filling” effect (i.e., activation of an antecedent at the point of a gap), not only in object gaps, but also in gaps hypothesized in subject positions (Swinney, Zurif, Prather, & Love, 1996; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). From this it is inferred that Broca’s patients are unable to establish long-distance dependency relations that involve Wh-movement. This interaction of sentence type with task (off-line vs. online) then reveals that tasks that examine the language system as comprehension unfolds (i.e., in real-time) are able to tap the system at a deeper level than off-line comprehension tasks such as picture-to-sentence matching.

In what follows, we present the results of two studies on the real-time comprehension by Broca’s patients of constructions containing Wh- and NP-movement. To forecast, the results will show that whereas Broca’s patients fail to activate the antecedent at the point of the trace (as illustrated by previous reports), they do show priming for the antecedent but only at a later point in the sentence after licensing has occurred. Consistent with the *time-course* approach, these results show that the deficit in the Broca’s system can be characterized in terms of slow-syntax construction: given time, the system is able to carry out all necessary mechanisms that depend on syntactic tree formation (including dependency relations).

2. Experiment 1. Wh-movement

We examine the implementation of Wh-movement by Broca’s patients using the relative construction. Sentences such as *The child wanted the balloon_j [which_{j/i} the clown burst (which)_i]* represent an instance of Wh-movement (in this case out of object position), because the relative pronoun is base-generated in the object position of the relative clause in underlying representation and then moved to the head

position of the subordinate clause (leaving behind a trace). This allows relativization to take place.²

We know of one study that investigates the time-course of the formation of this kind of dependency relations by Broca's aphasia, where trace activation was probed at approximately 600 ms after the trace (Love, Swinney, & Zurif, 2001).³ Consistent with the slow-syntax hypothesis (SSH), Love et al. (2001) report no activation at the trace and activation 600 ms after. Here, we seek to replicate those results.

2.1. Methods

2.1.1. Subjects

Three Broca's aphasia patients participated in the experiments (JB, JC, RD). Each patient suffered lesions to the left frontal region involving Broca's area, while sparing the anterior superior temporal cortex and the right hemisphere. This was confirmed by CT scans and clinical classification based on the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass & Kaplan, 1983). At the time of testing, the patients were medically stable and exhibited the typical symptoms of Broca's aphasia, such as effortful and telegraphic speech. The clinical profiles of the patients are provided in the Appendix A. For each experimental condition, up to ten control subjects were tested, all of whom were right-handed and without known neurological disorder. Control subjects matched the Broca's patients in age (range: 46–77) and educational level.

2.1.2. Procedure

We used the cross-modal lexical decision priming paradigm. In this paradigm, subjects perform two tasks: a comprehension task (primary task) and a lexical decision task (secondary task). Sentences are presented auditorily to the subjects, who are instructed to listen carefully and understand each sentence. To ensure that the subjects pay attention to the sentence material, they have to respond to comprehension questions about the sentence just heard at quasi-random points (breaks are followed by at least two filler sentences, so that the pause does not interfere with the comprehension of the experimental items). In addition to the listening comprehension task, a lexical decision task is carried out. In this task, a letter string (target) is visually presented on a computer monitor at a certain point during the presentation of a given sentence. Subjects are instructed to perform the lexical decision as quickly and as accurately as possible. The response is indicated by pressing a 'yes' or 'no' button on a response box with the nondominant hand, and the reaction time is recorded using Tempo (Motta & Rizzo, 2000). Before the experiment session, each subject participated in a practice session of ten trials.

2.1.3. Materials

Experimental sentences. Twenty-five experimental sentences were created following the constraint that all sentences contained right branching relative clauses (relativized of the object of the matrix clause) with a distance of at most five words between the antecedent and the trace position. An example is provided in (1):

² This type of movement is to be distinguished from NP-movement, because in the Wh-movement case, the landing site of the moved phrase is an A-bar position (i.e., nonargument position), that is, a position where no argument licensed by the verb is base-generated.

³ Love et al. report probing of activation at 500 ms using RTLab. In our experiment, this is equivalent to 600 ms, since Tempo does not have the temporal delay inherent in RTLab.

(1) The kid loved the cheese_j which_{j/i} the brand new microwave *melted*_t yesterday afternoon while the entire family was watching TV.

Targets. Twenty-five pairs of targets were created, with each pair containing a target that is semantically related, and one that is entirely unrelated to the antecedent. Related targets were first selected from free word association norms based on their cue-to-target strength (Nelson, McEvoy, & Schreiber, 1998). Moreover, related and unrelated targets were matched for frequency (Francis & Kucera, 1982) and number of syllables. When the targets could not be matched for frequency, the advantage was given to the unrelated target, and when they could not be matched for number of syllables, the unrelated target had the length advantage (i.e., fewer syllables). Finally, related and unrelated targets were matched based on independent reaction times to the target words in isolation. These reaction times were collected using a list priming paradigm (using Tempo (Motta & Rizzo, 2000)).⁴ The data obtained in this separate experiment were then used to further match target pairs so that the reaction time to the unrelated target was equal to or faster than that to the related target. Again, this selection criterion had the effect of running counter to the hypothesis that related targets elicit a faster reaction time.

Finally, targets (both related and unrelated) were paired with sentences in such a way that there was no relation between the target and any element in the remainder of the sentence. Sample targets for (1) are CHEDDAR (related) and ALBUM (unrelated).

Script. A script was created containing 50 object relative constructions (25 with related and 25 with unrelated targets), 100 fillers matched to word targets, and 200 matched to nonword targets for a total of 350 sentences.

Within the script, the experimental sentences were placed in a quasi-random order. The order of the sentences was counterbalanced across the entire script in such a way that about half the sentences with the related target preceded the sentences with the unrelated target, and vice versa. Filler sentences were distributed so that at least two appeared between experimental sentences. All sentences were recorded by a native speaker of English and digitized at 22,000 samples per second.

Target location. For object relatives three positions were probed: 400 ms before the verb (control position), 100 ms after the verb, and 650 ms after the verb.

Predictions. The SSH predicts that whereas no group should show activation at the control position, only the neurologically intact group (control) should elicit reactivation of the prime at 100 ms after the verb. According to the SSH, at the time the target is presented, the syntactic representation that should facilitate the lexical decision for the target (i.e., the structure that licenses the gap) is not fully formed in the Broca's system. By the same token, the SSH predicts that only the Broca's group should show antecedent reactivation at 650 ms after the verb, since at this time the gap has been licensed in the Broca's system but has decayed in the normal one.⁵

⁴ The purpose of the list priming paradigm is to measure automatic priming effects. The list priming paradigm used for this pretest is a unimodal paradigm during which subjects are asked to perform a single task, that of making lexical decisions to letter strings (see for instance Prather, Zurif, Love, & Brownell (1997) and references therein). The letter strings are continuously displayed on a computer screen, and as each letter string is presented, subjects must decide as quickly and accurately as possible whether the string represents a real word of English. In order to obtain the bare priming effects for the experimental target pairs, pairs of semantically related words are presented consecutively within a script of otherwise randomly distributed words and nonwords.

⁵ The calculation of the position of the target for this third point of interest was guided by the lexical activation findings from Prather et al. (1997).

Table 1
Object relatives: priming effects in milliseconds and *p*-values

	Control position	100 ms	650 ms
Control subjects	+12 ms, <i>p</i> = .36	+31 ms, *<i>p</i> = .03	+22 ms, <i>p</i> = .25
Broca's patients	+7 ms, <i>p</i> = .31	–	+130 ms, *<i>p</i> = .01

2.2. Results

For the statistical analysis only data pairs that elicited a correct response entered the final computation. Data discarded included incorrect response (saying “no” to a word), timed-out response (responding after the limit of 2500 ms), and falling outside three standard deviations from the mean. This resulted in the exclusion of 9.8% (control group) and 17% (Broca's group) of the total data pairs, equally distributed across subjects and conditions. Finally, subjects' datasets were excluded from the statistical analysis altogether whenever they failed to respond correctly to at least a third of the experimental targets or whenever the difference in variance between the two conditions was larger than four times the lower number (Howell, 1992). Three of the 28 control subjects had to be excluded under this constraint.

The results for the control group are the following. No significant priming effect was observed at the control position ($t(7) = -0.35$, $p = .36$). This is important because we wanted to ensure that prior to the presentation of the verb the antecedent is not activated. For the 100 position, subject analysis reveals a statistically significant priming effect ($t(8) = -2.12$, $p = .03$) suggesting that the antecedent was reactivated at the point of the Wh-trace. Finally, for the 650 ms position, statistical analysis indicates no priming effect ($t(8) = -0.68$, $p = .25$), suggesting that at this point, the normal window for antecedent reactivation no longer exists. In sum, the control data provide evidence that neurologically intact subjects establish a dependency relationship between a gap and its antecedent only at 100 ms after the verb in object relative constructions. Table 1 presents the priming effects for each point of interest (priming effects were calculated by subtracting the mean reaction time to the related target condition from that to the unrelated target condition).

The results for the Broca's aphasia group are as follows. For the control position, no main effect is observed ($t(2) = -0.56$, $p = .31$), just as in the control group. By contrast, comparison between the two conditions (related and unrelated) shows a statistically significant priming effect at 650 ms after verb ($t(2) = -5.66$, $p = .01$). We interpret this priming effect as an instance of antecedent reactivation. This suggests that at this point, the portion of the syntactic tree that allows for this dependency has been formed so that associated mechanisms can take place.⁶ Moreover, these results support the idea that Broca's are able to fully form the syntactic representation (including correct coindexation patterns) of constructions for which they fail to show proper comprehension. These findings thus constitute the baseline from which we investigate NP-movement below.

⁶ Capitalizing on the findings by Zurif et al. (1993) where it is shown that Broca's are unable to reactivate the antecedent immediately after the verb, we did not test the Broca's group in the 100 position. We tested this position in the control group because we needed to show that the sentences could elicit a normal gap-filling effect. In this way, the first part of the experiment represents a partial replication of Zurif et al. (1993).

3. Experiment 2. NP-movement

In this experiment we examine the implementation of NP-movement, that is, movement of a nominal phrase to an argument position (in this case the subject position). To this end, we examine the real-time comprehension of active sentences using unaccusative verbs. We define these verbs in the context of the Split Intransitivity Hypothesis (e.g., Perlmutter, 1978, 1983; Zaenen & Maling, 1984; Burzio, 1986; Grimshaw, 1987; Levin & Rappaport-Hovav, 1995).

The Split Intransitivity Hypothesis (or Unaccusative Hypothesis) proposes that intransitive verbs divide into two subgroups, unergatives and unaccusatives, based on the semantic traits of the verb and its arguments. In particular, unaccusative verbs select arguments that display properties of the role of an undergoer (e.g., *The door **opened**, The man **choked***), and unergative verbs select arguments that exhibit properties of an agent (e.g., *The man **laughed**, The girl **runs***). These semantic traits have syntactic consequences that are reflected in the way unaccusatives and unergatives base-generate their arguments: unergatives, which are assumed to select an external argument, base-generate their argument in preverbal position (see (2.a)), while unaccusatives are described as selecting only an internal argument, which is base-generated postverbally. This internal argument is then required to undergo movement to the subject position in order to satisfy Case requirements in languages like English as (2.b) illustrates:

(2.a) Unergative verb:	underlying representation:	$[\text{NP } [_{\text{VP}} \text{V}]]$
	surface representation:	$[\text{NP } [_{\text{VP}} \text{V}]]$
(2.b) Unaccusative verb:	underlying representation:	$[\text{e } [_{\text{VP}} \text{V NP}]]$
	surface representation:	$[\text{NP}_i [_{\text{VP}} \text{V } t_i]]$

As the representations in (2) demonstrate, the surface representations of unergative and unaccusative constructions appear to be very similar in that they both consist of a noun phrase followed by a verb phrase. However, they are derived from two distinct underlying representations, and only the argument of an unaccusative verb leaves a trace in postverbal position. The following example sentences demonstrate this again:

(3.a) Unergative:	The teenager jumped.
(3.b) Unaccusative:	The window _i broke t _i .

Since the two types of intransitive verbs differ with respect to the presence or absence of a postverbal trace, they allow us to probe the time-course of activation of dependency relations. In this respect, online sentence processing studies provide evidence that the antecedent of an argument trace (such as that obtained in unaccusative constructions) is reactivated postverbally (e.g., Bever & McElree, 1988; Nicol & Swinney, 1989; MacDonald, 1989; Piñango & Wong, 2001). It is therefore expected that such a priming effect is observed sometime after licensing for the unaccusative, but not for the unergative constructions.

To summarize, Experiment 2 focuses on NP-movement involving unaccusative verbs. These are compared to constructions with unergative verbs, which do not exhibit postverbal argument traces. Again, guided by the SSH, we expect to observe a slowed-down formation of syntactic dependencies. As a result, delayed antecedent activation in postverbal position is expected only for unaccusatives, not for unergatives (see also Piñango (2000a) for offline findings on unaccusative comprehension).

3.1. Methods

3.1.1. Subjects

Two Broca's patients JB and JC were tested. Matching control subjects were distributed in the following manner: 5 participated in the control position, 9 in the 100 position and 9 in the 650 position. Some of the control subjects participated in more than one position.

3.1.2. Procedure

Same as in Experiment 1. However, due to small number of subjects, patients were tested twice on some of the conditions, and the means for each pair were averaged.

3.1.3. Materials

Experimental sentences. Fifty experimental sentences were constructed (25 with unergative verbs and 25 with unaccusative verbs). Verbs were matched for frequency (Francis & Kucera, 1982). In those cases where the frequency ratings could not be matched precisely, the frequency for the unergative verb was larger than that for the unaccusative. This selection was guided by the notion that if verb frequency has a facilitating effect, such a processing advantage would be given to the unergative condition, against our predictions regarding antecedent reactivation for this condition. In addition, all sentences were matched for number of words between the antecedent and the verb, and for total length. Regarding total sentence length, we took into consideration the possibility of end-of-sentence effects (Balogh, Zurif, Prather, Swinney, & Finkel, 1998). As a result, we added enough material to the sentence after the verb so probing positions would be clearly within the boundaries of the sentence. The examples in (4) below illustrate the constraints described:

- (4.a) Unergative: The graduate with a passion for movies *celebrated* after the last of the official ceremonies was over.
 (4.b) Unaccusative: The butter_i in the small white dish *melted* t_i after the boy turned on the brand new microwave.

In these examples, the base-generated postverbal position of the argument is indicated by the trace *t* in (4.b). Prior to recording, experimental sentences were tested on native speakers for grammaticality and acceptability.

Properties of targets. Same as in Experiment 1.

Script. Similar to Experiment 1, the order of the sentences within both sentence type (unaccusative–unergative) and target type (related–unrelated) was counterbalanced across the entire script in such a way that, for instance, half of the time, the sentence with the related target preceded the sentence with the unrelated target, and half of the time the sentence with the related target followed its counterpart with the unrelated target. An additional set of sentences was created as fillers and matched with either word targets or nonword targets. The nonword targets were constructed to comply with English phonotactic and orthographic rules. Target positions for the filler sentences were assigned randomly. The 100 experimental sentences were tested in one script including 200 filler sentences (50 with word targets, 150 with nonword targets) for a total of 300 sentences.

Predictions. Results from experiment 1 provide a platform from which to examine sentence construction effects in NP-movement structures. We were interested to see if a slowing-down of processing effect could also be observed in unaccusative structures. Guided by findings of the reactivation pattern of NP-traces in young unimpaired subjects where a priming effect was not registered immediately at the trace

position, but at a significantly later point in time,⁷ the current experiment measured a priming effect for unaccusative verbs at 650 ms after the licensing of the trace in the elderly control subjects. The question was then at which point in the course of Broca's patients' processing priming could be observed.

3.1.4. Experiment 2.a: The 'normal' pattern

In experiment 1, unimpaired subjects showed priming at 100 ms after the verb for object relative constructions, and we were now concerned to locate the point at which priming would occur in unaccusative constructions. We expected to find priming for unaccusative traces at a later point than observed for object relatives, since it has been observed that Wh-traces and NP-traces do not entirely pattern alike in terms of the time course of antecedent reactivation. That is, Wh-traces are observed to have a more immediate reactivation effect than NP-traces (e.g., Nicol & Swinney, 1989). It has been proposed that what distinguishes NP- from Wh-traces is that in Wh-trace constructions, there is an active "filler" (the relative pronoun) looking for a structurally legitimate gap position. In contrast, there is no such filler in the NP-trace construction. As a result, it takes the parser longer to "notice" that a gap has been licensed, which would cause the observed delay in reactivation effects.

We first examined reactivation effects for the neurologically intact group, in order to determine the target position for the Broca's group. To this end, we investigated priming effects of unaccusative and unergative sentences at the following three positions: a preverbal control position, 100 ms after the verb, and 650 ms after the verb. (Prior to statistical analysis, 11% of the data were excluded due to incorrect responses or failure to fall within three standard deviations from the mean.) For the unaccusative sentences, means for the two conditions (related vs. unrelated) show a significant priming effect but only at 650 ms ($t(8) = -1.90$, $p = .04$) (see Table 2). Crucially, no significant priming effect is observed for any of the other positions tested with unaccusatives. The preverbal control position registered a faster, yet nonsignificant, response for the unrelated condition ($t(4) = 0.23$, $p = .41$), and statistical analysis of the data recorded at 100 ms after the verb reveals no priming effect either ($t(8) = -0.62$, $p = .27$).⁸ The finding that a significant priming effect is observable at 650 ms after the unaccusative verb is compatible with data from young subjects reporting late priming for NP-traces in passives (Piñango & Wong, 2001) as well as for NP-traces in unaccusatives (Friedmann, pc).

Turning to the results elicited by the unergative sentences, it can first be observed that, as expected, they do not pattern with the unaccusatives. As indicated above, the Split Intransitivity Hypothesis advocates the idea that unaccusative and unergative verbs differ syntactically with regard to their underlying representations, and as a consequence, we conjectured that only unaccusatives, which generate their argument in postverbal position, would show priming for the antecedent. And in fact, the

⁷ Recent research on passives with college-aged subjects has found priming 500 ms after the verb ($t(14) = -2.28$, $p = .03$) (Piñango & Wong, 2001). In addition, Friedmann (pc) observed antecedent reactivation for unaccusatives as late as 750 ms after the verb.

⁸ The unaccusative sentences tested in this experiment are entirely comprised of alternating unaccusatives (e.g., *The glass on the small wooden table broke ...*). Initially, subjects were also tested on nonalternating unaccusatives (e.g., *The cabbage in the beige refrigerator decayed ...*); however, after preliminary results indicated that Broca's did not show a clear pattern for this subtype, we decided to concentrate on the alternating condition in the present study and explore the factors affecting the processing of nonalternating unaccusatives in a separate study. It should still be noted however that up to that point, neurologically intact subjects showed the same pattern of antecedent reactivation for nonalternating and alternating unaccusatives: statistically significant priming at 650 ms after the verb ($t(5) = -2.96$, $p = .01$), and no effect at the preverbal control position ($t(2) = 0.27$, $p = .40$).

Table 2
Unaccusatives and unergatives: priming effects in milliseconds and p -values

		Control position	100 ms	650 ms	800 ms
Control subjects	unergatives	+63 ms, $p = .13$	+42 ms, *$p = .01$	+14 ms, $p = .24$	–
	unaccusatives	–7 ms, $p = .41$	+14 ms, $p = .27$	+35 ms, *$p = .04$	–
Broca's patients	unergatives	+58 ms, $p = .17$	–	–1 ms, $p = .13$	–9 ms, $p = .43$
	unaccusatives	+10 ms, $p = .33$	–	–7 ms, $p = .42$	+37 ms, $p = .06$

unergative structures do not reveal a significant priming effect at 650 ms after the verb, the position at which the unaccusative constructions exhibit priming. A statistical analysis on the reaction times to the related and unrelated unergative conditions at 650 ms shows no main effect ($t(8) = -0.71$, $p = .24$). Likewise, an analysis of the data registered at the preverbal control position does not show a significant effect ($t(4) = -1.29$, $p = .13$). However, the response times obtained at 100 ms after the verb are at first surprising, since the unergatives register a statistically significant priming effect at this position for the neurologically intact control subjects ($t(8) = -2.59$, $p = .01$).

Can this finding be reconciled with the assumptions of the Split Intransitivity Hypothesis? We think it can and suggest that the priming effect that is measured at 100 ms after the unergative verb (but critically, not after the unaccusative verb) results from the VP-internal subject position, where the argument of the unergative verb is base-generated. This goes back to the VP-internal subject hypothesis (e.g., Fukui & Speas, 1986; Koopman & Sportiche, 1991; or Fillmore (1968) for an early version), which claims that subjects originate in the specifier position of VP, from which they raise into Spec-IP in English ($[_{IP}NP_i[_{VP}t_i V]$). Accordingly, since any constituent that undergoes movement leaves a trace behind, we expect to find priming for the antecedent of this VP-internal NP-trace. From a processing perspective the notion that a preverbal trace would be licensed after the verb has been introduced, makes sense if one considers that the VP (including its specifier position) can only be triggered after the verb has been retrieved. Given this, we propose that the priming effect observed for unergatives at 100 ms is a consequence of a trace position located immediately before the verb whose window of activation is open at least 100 ms after the verb has been heard.

In light of these findings we proceed to examine the processing patterns in the Broca's group. Guided by the behavior of the neurologically intact subjects, we predict that, like matching control subjects, Broca's patients will not show a priming effect at the preverbal control position. Second, given the SSH, we predict that Broca's patients, unlike matching control subjects, will not show activation of the antecedent at 650 ms after the unaccusative verb. This is due to the assumption that in order for reactivation to occur, syntactic representation is required to be fully formed. Consequently, this should be reflected in the priming patterns for unaccusatives, since we take Broca's patients' sentence comprehension deficit to be one of delayed structure formation.

The results obtained confirm our predictions. 15.6% of data pairs were excluded due to incorrect, too long or timed-out responses. Statistical subject analysis on reaction time performance of the Broca's patients at the control position reveal neither a significant effect for the unaccusative condition ($t(1) = -0.57$, $p = .33$) nor for the unergative condition ($t(1) = -1.59$, $p = .17$) similar to the control group.

This again is of importance as it allows us to establish that no statistically significant contrast exists between the related/unrelated pair as well as between the two conditions up to the point of the verb. In contrast to the neurologically intact group, Broca's showed no priming effect at 650ms after the verb for the unaccusative condition ($t(1) = 0.23$, $p = .42$) or the unergative condition ($t(1) = 2.18$, $p = .13$). Table 2 provides the priming effects for both groups.

The final question we wanted to address was whether Broca's patients would show antecedent activation for NP-traces at a delayed position in the unaccusative construction.

3.1.5. Experiment 2.b: The Broca's pattern

In experiment 1, we observed a slower-than-normal priming effect in Broca's patients for the Wh-trace of object relative sentences in comparison to the priming effect elicited by the control subjects. Consequently, we predicted that Broca's comprehension of unaccusatives would pattern alike and that they would hence show a delay in priming for NP-traces as well. Since unimpaired subjects show priming for unaccusatives as late as 650ms after the verb, while Broca's patients' performance does not indicate activation of the antecedent at this position, we further conjectured that Broca's patients would show an even longer delay in activation—relative to the position of the trace—for operations involving NP-movement than for operations involving Wh-movement. Antecedent activation was thus probed at 800ms after the verb for the unergative and unaccusative conditions. (Note that given the constraints on the sentences, this position is still within the sentential boundaries thus avoiding end-of-sentence effects.)

Results. Both patients clearly showed the expected pattern of delay in the formation of syntactic structure: reaction times for JB and JC reveal a strong tendency in the predicted direction with a priming effect at 800ms ($t(1) = -4.79$, $p = .06$). Crucially, this effect was found for unaccusative sentences, but not for unergative sentences ($t(1) = 0.22$, $p = .43$).

4. General discussion and conclusion

The focus of these experiments was to examine the SSH for Broca's sentence comprehension through the lens of the "gap-filling" effect. The slow-syntax hypothesis—a generalization that represents the *time-course* approach to Broca's comprehension—posits that if the comprehension deficit observed in Broca's aphasia patients results from a delay in syntactic composition, this delay should be observed as a slower-than-normal activation of Wh-traces in the relative clause condition and slower-than-normal activation of object-NP traces in the unaccusative condition. The results from the two studies presented here support these predictions. Moreover, the results suggest that even though brain damage to the anterior left hemisphere affects dependency relations, this deficit does not result from an inability to access information in traces or establish proper coindexation as the dependency-based generalizations propose. Rather, the results suggest that dependency relations are affected because the basic syntactic processes by which they are instantiated have been slowed down. Nevertheless, the results also suggest that once syntactic activation is underway, all associated mechanisms will take place, including establishing long-distance dependencies in noncanonical constructions.

In its strongest form, the claim put forth here proposes that Broca's patients are fully capable of building complete syntactic structures, however, the temporal constraints imposed on the normal syntactic structure formation seem to be lost. From

this it follows that once the syntactic tree is finally formed in the impaired brain, it is indistinguishable from the tree built in the intact brain. Consequently, and given the localization value of Broca's aphasia, we infer that it is not just the establishment of long-distance dependencies, but the formation of syntactic structure (i.e., merge operation), that is dependent on the integrity of Broca's area. Thus, a model of the functional distribution of language emerges, suggesting that such distribution is carried out along linguistically motivated distinctions that separate syntax from other language sub-systems.

Appendix A. Clinical profiles of Broca's patients

Name	Lesion site information
JB	JB is a female who suffered a left CVA in 1996. A CT scan taken shows a large left fronto-parietal lesion involving all of the inferior frontal gyrus including all of Broca's area and the white matter underlying it. The lesion is also described as involving insular cortex and the lateral putamen with posterior extension across the anterior temporal isthmus. The temporal lobe however is spared.
JC	JC is a female who suffered a stroke in 1995. A CT scan taken that year indicates a large left fronto-parietal lesion.
RD	RD is a male who suffered two left CVAs—one in 1976 and one in 1977. A CT taken in 1978 indicates two lesions, one in Broca's area with deep extension to left frontal horn and involving lower motor cortex (face and lip regions) and the other in the left temporal lobe sparing Wernicke's area but encompassing the anterior portion of BA22.

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