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The curious case of processing unaccusative verbs in aphasia

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Abstract

Background—Individuals with agrammatic Broca's aphasia (IWBA) exhibit a delay in lexical activation in S-V-O word order sentences and delayed lexical reactivation in sentences that contain syntactic dependencies. This pattern is in contrast to neurologically unimpaired individuals who immediately evince lexical reactivation at the gap in sentences that contain syntactic dependencies. However, in the case of sentences that contain unaccusative verbs, neurologically unimpaired individuals also exhibit a delay in lexical reactivation. This delay provides a unique opportunity to further examine lexical delays in IWBA.

Aim—The purpose of the current studies is to investigate the online comprehension of sentences that contain unaccusative verbs in IWBA and in a group of age-matched control (AMC) individuals.

Methods and Procedures—Cross-modal picture priming was used to test for priming of a displaced lexical item (direct object noun) immediately after the unaccusative verb (at the gap) during the ongoing auditory stream and at three additional time points downstream from the verb (500 ms, 750 ms, and 1,250 ms).

Outcomes and Results—Delayed reactivation of the displaced lexical item downstream from the gap (similar to prior reports of delayed reactivation with younger unimpaired listeners) for both the AMCs and the IWBA was found.

Conclusion—These results provide support that IWBA do not evince a delayed time course of lexical reactivation for unaccusative verbs compared to neurologically unimpaired individuals.

Keywords

Aphasia; sentence processing; syntax; neurolinguistics

A common pattern exhibited by individuals with agrammatic Broca's aphasia (IWBA) is that sentences containing syntactic dependencies are often difficult to understand. Consider:

(1) The woman saw <u>the girl</u> who the boy kicked < ~~the girl~~> yesterday.

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Under a transformational grammar framework, in the object-extracted relative clause in (1), the noun phrase (NP) *the girl* has been displaced from its underlying direct object position occurring after the verb *kicked* to an earlier position in the sentence. In linguistic terminology, the NP that is displaced (*the girl*) is the "antecedent" and is copied at the underlying position and then deleted from the representation (Chomsky, 1981, 1995). In psycholinguistic terminology, the displaced NP is the "filler" and the position from where it was displaced is the "gap". To normally understand this sentence, a listener must compute the relation between these non-adjacent positions. As described in more detail later, neurologically unimpaired individuals compute this filler-gap relation immediately upon encountering the gap (see Love & Swinney, 1996; Love, Swinney, Walenski, & Zurif, 2008; Shapiro, Oster, Garcia, Massey, & Thompson, 1999; Tanenhaus, Boland, Garnsey, & Carlson, 1989; and many others). However, some IWBA demonstrate a delay in filling a gap (Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Love et al., 2008; and references therein), and that delay has been claimed to yield offline disruptions.

Much of the evidence for this processing delay in IWBA comes from the comprehension of sentences that contain transitive verbs, those that allow both a subject and an affected object. However, there is a case where single-argument (intransitive) verbs enter into this discussion. Consider:

(2) The boy sneezed.

(3) The girl disappeared < ~~the girl~~>.

Both (2) and (3) contain one-argument verbs. In (2) the single-argument (the NP *the boy*) serves as the subject of the unergative verb *sneezed*. In (3), however, there is evidence that the single argument has been base generated in object position and then displaced to the subject position occurring before the verb (i.e., the Unaccusativity Hypothesis; see Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984). Furthermore, while (2) and (3) each contains a single argument, the thematic roles assigned to the arguments differ. In (2), the unergative verb (*sneezed*) has a single argument (*the boy*) that performs the action of "sneezing" and is thus assigned an Agent role. In the unaccusative example (3), the single argument (*the girl*) is not responsible for the action but is the recipient of the action, hence assigned the role of Theme or Patient.

Evidence supporting the distinction between unaccusative and unergative verbs has also been demonstrated in the psycholinguistic literature. Friedmann, Taranto, Shapiro, and Swinney (2008) determined the time course of lexical reactivation in sentences containing unaccusative verbs such as (4) and sentences containing unergative verbs such as (5) in a group of neurologically unimpaired college-aged adults:

(4) The tailor[1] from East Orange, New Jersey, mysteriously disappeared < ~~the tailor~~>[2] when it was[3] time to adjust the tuxedos and dresses for the participants in the wedding party.

(5) The surgeon[1] with a brown felt fedora hat and matching coat eagerly smiled[2] when the beautiful[3] actress walked down the corridor to exam room three.

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In (4), *the tailor* is the single argument of the unaccusative verb *disappear* and has been displaced, leaving behind a gap. In (5) *the surgeon* is the single argument of the unergative verb *smile* and no displacement has occurred. Friedmann et al. (2008) used cross-modal priming (CMP), a method in which individuals are presented with sentences aurally and at a strategic point during the temporal unfolding of each sentence, a visual probe that is either related (e.g., “suit”) or unrelated (e.g., “shoe”) to the lexical item of interest (*tailor*) is momentarily presented. The participant is required to listen to the uninterrupted sentence for meaning and to make a binary (yes/no) decision about the visual probe when it occurs. Faster reaction times (RTs) to the related, compared with the unrelated, probes are indicative of priming, suggesting that the target lexical item has been activated at that point in time. CMP was used to determine the time course of lexical activation and reactivation by taking “snapshots” of activation at three distinct time points in the sentence indicated by superscript numerals in the examples earlier.

Similar to what has been demonstrated in other published reports, participants evinced immediate activation (priming) for the NP at noun offset (position 1) for sentences containing either unaccusative verbs (4) or unergative verbs (5). However, only for the sentences containing unaccusative verbs was lexical reactivation of the single argument observed at a post-verb position. These results support the Unaccusativity Hypothesis, and suggest that the single argument of unaccusative verbs is base generated in a post-verb position and displaced to the subject position and leaves behind a gap (see also Bever & Sanz, 1997; Lee & Thompson, 2011; Shetreet, Friedmann, & Hadar, 2010).

Of particular interest in this report is the fact that, for unimpaired individuals, computing the filler-gap relation in sentences containing unaccusative verbs is temporally delayed, unlike that observed for the object relative case. Consider (from Love et al., 2008):

(6) The audience liked the wrestler[1] that the[2] parish priest condemned < ~~the wrestler~~>[3] for [4]foul [5]language.

In the object relative (6), *the wrestler*, an argument of the verb *condemn*, has been displaced from a post-verb position to a position occurring before the verb, leaving behind a gap. Love et al. (2008) used CMP and presented visual probes at five probe points (superscripted numbers) indicated in (6). Unimpaired individuals revealed lexical activation of the direct object NP *the wrestler* at two critical points during the sentence: at the offset of the lexical item of interest (position 1) and at the syntactically licensed gap (position 3). Thus, as has been demonstrated in numerous prior studies, lexical access of the target word and subsequent reaccess at the gap is immediate.

Consider again the unaccusative example from Friedmann et al. (2008):

(7) The tailor[1] from East Orange, New Jersey, mysteriously disappeared < ~~the tailor~~>[2] when it was[3] time to adjust the tuxedos and dresses for the participants in the wedding party.

Unlike the patterns found at the gap in object relatives (6), immediate reactivation of the displaced argument was not observed at the gap (position 2), but instead was shown to occur 750 ms after verb offset (position 3). A similar delay in reactivation while processing sentences containing unaccusative verbs was reported by Burkhardt, Piñango, and Wong (2003) for both groups of participants, neurologically intact controls, and three participants with Broca's aphasia. Unfortunately, the description of their study suggests that their unaccusative verbs were the "alternating" kind. That is, the verbs allowed both a transitive (as in, "the microwave melted the butter") and intransitive possibility (as in "The butter in the small white dish melted after the boy turned on the microwave"); Friedmann et al. (2008) found variable results for these types of verbs.[1]

Both Friedmann et al. (2008) and Burkhardt et al. (2003) have suggested that the gap-filling delay with unaccusatives could be caused by the lack of an observable surface cue that could signal a gap is forthcoming (see also Fodor, 1993). Unlike object relatives that typically contain an overt complementiser (e.g., *that* in (6)), sentences containing unaccusatives lack such a cue. Listeners cannot know that a gap will occur in sentences containing unaccusative verbs until the verb has been encountered and its relevant (unaccusative) properties are activated. This possibility implies that listeners have immediate access to a verb's properties. Some relevant work in this regard is the finding, for both neurologically healthy participants and those with Broca's aphasia, that once a verb is encountered in a sentence, its argument structure properties (core participants for the verb) are immediately made available, subsequently allowing the arguments in the sentence to receive their proper thematic role assignments (Agent, Patient, Theme, etc.) (see, e.g., Shapiro, Gordon, Hack, & Killackey, 1993; Shapiro, Zurif, & Grimshaw, 1987, 1989; see also Biran & Friedmann, 2012; Shetreet, Palti, Friedmann, & Hadar, 2007). We revisit this possibility in the General Discussion to follow our experiments. For now, the normal delay observed with unaccusatives provides an opportunity to further examine the nature of the sentence comprehension deficit found in individuals with Broca's aphasia. Before we detail these experiments, we discuss some relevant accounts of the comprehension deficit in aphasia, and then further discuss the motivation for the present study.

Dependency Processing in Broca's Aphasia

Unlike unimpaired listeners, IWBA have been reported to have difficulty processing (in real time) and understanding (via final comprehension) sentences containing syntactic dependencies. There have been numerous accounts posited to explain why individuals with Broca's aphasia evince these deficits; we briefly canvas some here. Burkhardt et al. (2008) suggest that syntactic computation is slowed under the conditions that yield a Broca's aphasia (see also Avrutin, 2006), yet they also claim that the syntactic structure, once finally formed, is identical to the normal syntactic system. Thompson and colleagues (Choy & Thompson, 2010; Thompson & Choy, 2009) suggest that syntactic processing routines are intact, but the process that integrates a lexical item into the sentence is disrupted. Grodzinsky's trace deletion hypothesis, likely the most well-known and studied account,

[1]A recent cross-modal priming study by Peristeri, Tsimpli, and Tsapkini (2013) found that their participants with aphasia revealed on time gap filling with unaccusatives. However, concerns about their method (e.g., allowing the visual probes to stay on the screen indefinitely, and stopping the auditory sentence while the lexical decision was made) compromise their findings. That is, because the participants could focus on the lexical decision while the sentence was no longer unfolding, reflection likely occurred (see Nicol et al., 2006). And indeed, lexical decision times were very slow (an average of 2,879 ms for control participants and 3,834 ms for the participants with aphasia; note that the average RTs for the neurologically healthy participants in Friedmann et al. was 640 ms).

suggests that IWBA cannot represent the traces or copies of the displaced arguments in sentences containing syntactic dependencies, leading to impaired thematic role assignment to the displaced NP (e.g., Drai & Grodzinsky, 2006; Grodzinsky, 2006; among many others). Caplan and colleagues suggest an account whereby reduced processing resources combined with pathological variability results in the inability to comprehend sentences that require multiple syntactic operations (Caplan, Waters, DeDe, Michaud, & Reddy, 2007; see also Haarmann, Just, & Carpenter, 1997).

A more recent account, the Intervener Hypothesis, suggests that when an NP intervenes between two elements of a syntactic dependency, comprehension deficits that are a hallmark of Broca's aphasia occur, perhaps as a result of similarity-based interference (see Friedmann & Shapiro, 2003; Sheppard, Walenski, Love, & Shapiro, 2015; Sullivan, Walenski, Love, & Shapiro, 2016). We revisit this hypothesis in the General Discussion to follow our experiments. Another account, the Delayed Lexical Activation (DLA) Hypothesis, posits that lexical access is delayed in Broca's aphasia, and thus the syntactic system that requires lexical items to be inserted into the syntactic configuration of the sentence is also affected. In essence, the claim is that the lexical and syntactic systems are desynchronised, leading to what appears to be a syntactic comprehension disorder in Broca's aphasia (Ferrill, Love, Walenski, & Shapiro, 2012; Love et al., 2008). Consider again the example from Love et al. (2008):

(8) The audience liked the wrestler[1] that the[2] parish priest condemned < ~~the wrestler~~>[3] for [4]foul [5]language.

Unlike the neurologically unimpaired group's immediate activation of the displaced argument *the wrestler* (position 1) or immediate reactivation upon encountering the gap (position 3), IWBA did not evince lexical activation of *the wrestler* until 300 ms downstream from the lexical item of interest in the unfolding sentence (position 2), and reactivation was not observed until 500 ms downstream from the gap (position 5). The initial delayed activation of the noun is not a by-product of some version of sentence complexity, as it has also been demonstrated in canonical word order (S-V-O) sentences that do not contain syntactic dependencies (Ferrill et al., 2012). Furthermore, with such object-extracted sentences, there was a direct association between delayed gap-filling and poor offline comprehension (Love et al., 2008; see also similar patterns for *Wh*-questions in Sheppard et al., 2015).

While few studies have employed real-time methods to investigate how individuals with Broca's aphasia process unaccusative verbs during sentence processing, offline studies have demonstrated that IWBA do not have difficulty with the final comprehension of such sentences (Lee & Thompson, 2004; McAlister, Bachrach, Waters, Michaud, & Caplan, 2009; Piñango & Grodzinsky, 2000). In a recent offline study examining the comprehension of sentences containing unaccusative verbs, we (Sullivan et al., 2016) used a sentence-picture matching task with the same participants with Broca's aphasia included in our current study. Non-alternating unaccusative verbs were embedded in two different sentence constructions, complement phrase constructions (9) and subject-extracted relative clauses (10):

(9) The girl observed that the boy disappeared < ~~the boy~~> into the trees.

(10) The girl that observed **the boy** disappeared < ~~the girl~~> into the trees.

In both (9) and (10) the single argument of the unaccusative verb has been underlined. In (9)—the complement phrase construction—no NP occurs between the single argument of the unaccusative verb, *the boy* and the position from which it has been displaced. However, in (10)—the subject-extracted relative clause construction—an NP (***the boy***) occurs between the two elements of the dependency chain. Results revealed above chance comprehension of the complement phrase construction (9) but comprehension suffered for the subject-extracted relative clauses (10).

We discuss these results further in our General Discussion to follow our experiments, but for now we are left with the following puzzle: In object-extracted sentences and some *Wh*-questions, a delay in lexical activation is associated with poor offline comprehension by participants with aphasia, but with unaccusatives, a delay in lexical activation does not necessarily give way to poor offline comprehension, as evinced by neurologically unimpaired who reveal a delay yet have no observable offline deficits (Friedmann et al., 2008). Thus, to understand the relation between online and offline comprehension, we need to also carefully examine the online processing of sentences containing unaccusative verbs in individuals with aphasia, and comparatively, to neurologically unimpaired control participants. We now turn to our first experiment.

Experiment 1: The time course of lexical reactivation of unaccusatives in neurologically unimpaired adults

We examined the time course of lexical reactivation in sentences containing non-alternating unaccusative verbs in older neurologically unimpaired individuals. This study sought to replicate the Friedmann et al. (2008) findings of delayed reactivation and to establish an age-match comparison for our subsequent study using participants with Broca's aphasia (Experiment 2). Here, we predicted that AMCs would perform similarly to those in Friedmann et al. (2008); that is, we predicted significant priming would not be observed at verb offset, but instead would be observed downstream from the gap.

Method

Participants—Eleven AMC participants were included in this study (mean age at time of testing: 60 years; range: 42–74 years). All of the AMC participants were monolingual native English speakers with normal or corrected-to-normal visual and auditory acuity, with no reported history of active or significant alcohol and/or drug abuse, active psychiatric illness or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). All of the participants were tested at the Language and Neuroscience Group Laboratory at San Diego State University and were paid $15 per session.

Task—We used a cross-modal picture priming task (e.g., Swinney & Prather, 1989). Participants listened to uninterrupted auditory sentences and made binary, alive (YES)/not alive (NO), decisions about visually presented black and white line drawings (visual probes) during sentence comprehension. Each experimental sentence (see (14)) had two visual probes (each requiring a YES response): A <u>related</u> probe that was a representation of the displaced NP, and a <u>control</u> probe that was unrelated to any word in the sentence yet served as a related item in another stimulus set (see Figure 1).

In this task, the visual probes are presented at key times during the ongoing sentence. Response choice (yes/no) and RTs to the visual probes are measured with millisecond accuracy. Faster RTs to related relative to unrelated probes yields a priming effect, indicating that the NP of interest has been activated. Importantly, priming effects in cross-modal tasks reflect activation of the lexical item of interest at that point in the ongoing auditory sentence, not the integration of the visual probe into the sentence (Nicol, Swinney, Love, & Hald, 2006).

Materials—Sixteen non-alternating unaccusative verbs were selected based on their behaviour with respect to three linguistic diagnostics: occurrence in *there*-constructions, ungrammaticality with a direct object, and inability to undergo passivisation (see also Friedmann et al., 2008):

(11) There disappeared three students after class.

(12) *The teacher disappeared three students after class.

(13) *Three students were disappeared after class (by the teacher).

Thirty-two experimental sentences with the following structure were created (See Appendix A for a full list):

(14) <u>The queen</u> with the bad temper vanished < ~~the queen~~>[*1] during [*2] the [*3] spectacu[*4]lar fireworks show.

As shown in Figure 1, the experiment employed a switched target design in which the related probe for one experimental sentence appeared as a control probe for a different experimental sentence, and vice versa. Thus, over all of the sentences, the set of related probes was identical to the set of control probes, minimising the possibility that any observed priming effects are due to aspects of the pictures that might influence participants' RT (e.g., visual complexity differences).

To establish the time course of activation of the single argument, the related and control visual probes were presented at four positions during the ongoing auditory sentence (indicated approximately by the superscript numerals in (14). Unlike the Friedmann et al. (2008) study, we only tested at post-verb positions. Probe position (PP) 1 and 3 were at the same time points found in Friedmann et al. (2008); PP1 (verb offset) and PP3 (750 ms downstream). However, because of prior reports of delayed gap filling in IWBA, two additional PPs were tested; PP2 (500 ms from verb offset, the time point of lexical reactivation found in Love et al., 2008) and PP4 (1,250 ms downstream from verb offset). This last PP serves to test for the possibility that IWBA will demonstrate a delay beyond what was found with unimpaired controls.

In addition to the 32 experimental sentences, 28 filler sentences were created and were paired with an inanimate picture probe (requiring a "No" response). As is standard practice in CMP tasks, the position of the visual probe varied for the filler sentences, with probes appearing equally often near the beginning, middle, and end of the sentences so that appearance of the probe could not be anticipated. Finally, eight practice sentences (also balanced for the type of response) were added to the beginning of each script to familiarise the participant with the task as well as to allow the experimenter the opportunity to monitor the participants' responses thus ensuring that they understood the task. After the 8 practice items, the remaining 60 sentences (32 experimental; 28 filler) were presented in a pseudorandom order such that no more than 3 sentences in a given condition or with a particular response occurred sequentially. The sentences were recorded by a female native English speaker at a normal rate of speech (5.32 syllables per second). Recording and editing were performed using Adobe Audition 3.0 software.

Design—We used a 4 × 2 within-subjects design. The four PPs, combined with the related/control variable, yielded eight conditions. In this design each participant heard every sentence and saw every picture in every condition, and these were counterbalanced across sessions so that no one sentence or picture was repeated in any given session. This design resulted in 8 separate testing sessions where the order of presentation was counterbalanced across participants. Sessions were separated by at least 1 week.

Procedure—To ensure that our participants were performing reliably on the binary picture decision task and that they understood this dual task, a training session was given before the experimental script at each of the eight visits. Participants were told that a picture would appear in the middle of the screen and that they were to identify whether the picture was of an object that was alive or not by pressing a button labelled "yes" for animate or "no" for not animate, as quickly as possible. The list consisted of 20 items: 10 animate and 10 inanimate. None of the pictures used in the training task were repeated in the experimental scripts.

Once the experimenter felt that the participant understood the binary decision task, participants were then given the instructions for the experimental task. Participants were instructed that they would be listening to sentences for comprehension and responding to a picture probe that would appear centrally on a screen at a given point during the unfolding of a sentence. When they saw the picture, they were to make a YES/NO (alive/not alive) decision as quickly and accurately as possible by using a two-button response box. To encourage attention to the sentences and keep participants on task, participants were told that it was important for them to listen carefully to each of the sentences, as they would be asked comprehension questions at various points during the session. These questions bore only on the setting or general topic of the sentence and were intended only to reinforce the need for the participants to attend to the sentences. Tempo (Version 2.1.5) software was used to control the timed presentation of auditory and visual stimuli and the collection of participant responses. Each visual probe was presented for 1,000 ms, or until a response was made. Responses were recorded for up to 2,000 ms following the appearance of the picture probe, for a total possible time of 3,000 ms. An interstimulus interval of 2,000 ms followed each sentence.

Analysis

The AMC participants responded to the button press decision with >99% accuracy (*M* = 99.4%; *SD* = 0.63%; range 98–100%). Before analysis, incorrect responses (wrong button press or no response) were removed (0.61% of data). A < 300 ms and >2,000 ms RT screening was also performed (0.04% of data). A two standard deviation screening per participant by condition of the remaining data was then performed to reduce item variance (4.5% of data).

One item was eliminated from further analyses, as >10% of data were removed after screenings, and because a switched target design was used, the item that it served as a switched target match was also eliminated.

Analysis of the RTs of the remaining 30 items was conducted using restricted maximum likelihood in a mixed-effects model. Included in this model were the crossed-random effects on the intercept of participant and sentence and fixed effects of PP (1 vs. 2 vs. 3 vs. 4), relatedness versus control, and their interaction.[2] The models were fit with an unstructured covariance matrix for each random effect. Follow-up models examined the interaction of PP and relatedness separately for each pair of PPs and are presented in the Results section accordingly. Type III *F*-tests are reported for main effects and interactions. All analyses were conducted using SAS Version 9.4 software. While the fixed and random effect terms were entered into the model per our design and hypotheses, we also examined the justification of the crossed-random effect structure using the Bayesian information criterion (BIC; Schwarz, 1978) to evaluate model fit (a relative measure in which smaller values indicate better fit). With no random effects, the overall model (i.e., including both levels of PP) had BIC = −888.2, which improved to BIC = −2,139.3 when the random effect of participant was added, and improved again to BIC = −2,169.8 when the additional random effect of sentence was added, thus justifying the inclusion of both random effects. The follow-up models on pairs of PPs showed similar improvements to model fit. Note that differences in BIC values >10 (such as those found when adding in both random effects of participant and item) constitute very strong evidence of a better fit for the model with the smaller (more negative) score (Kass & Raftery, 1995). For planned comparisons of related and control probes at each PP, we computed *t*-tests of the differences of the least square means from the full model. All *p*-values are reported two-tailed. Degrees of freedom (reported in the *t*-tests below) were computed using the Satterthwaite approximation. Note that the degrees of freedom are large because in these models, they are based on the number of data points, not the number of participants or items. For further discussion of these statistical methods, see Baayen (2004, 2008)) and Littell, Milliken, Stroup, Wolfinger, and Schabenberger (2006).

Results

Mean RTs and standard errors for each condition are shown in Table 1.

There was a main effect of relatedness, $F(1, 2460) = 5.62$, $p = 0.02$ and a main effect of probe point, $F(3, 2459) = 7.8$, $p < 0.0001$. However there was no overall interaction between

[2]This model combines traditionally separate F1 and F2 analyses into a single statistical test.

PP and relatedness F(3, 2459) = 0.45, $p = 0.72$. Planned comparisons of the RTs for related and control probes for each PP are of primary importance to address the question of when (at which PP) any priming effects reach significance. These planned comparisons revealed significant priming (control minus related) at only **PP3**; 19 ms; $t(2,459) = 2.13$, $p = 0.03$; 95% CI: [0.002, 0.05]. No significant priming effect was found at **PP1**; 5 ms; $t(2,459) = 0.7$, $p = 0.48$; 95% CI: [−0.02, 0.03], **PP2;** 2 ms; $t(2,459) = 0.74$, $p = 0.46$; 95% CI: [−0.01, 0.03] or **PP4**; 11 ms; $t(2,459) = 1.16$, $p = 0.25$; 95% CI: [−0.01, 0.04].

Discussion

The purpose of this experiment was twofold: to chart the time course of lexical reactivation of the displaced argument in sentences containing unaccusative verbs, with older neurologically unimpaired individuals, and to offer a comparison to our age-matched participants with Broca's aphasia (Experiment 2, to follow). Recall that Friedmann et al. (2008) found that gap filling was delayed with sentences containing unaccusative verbs in college-aged neurologically unimpaired participants, unlike what is observed with, for example, object-extracted relatives (Love et al., 2008, and references therein). In the present experiment, no significant priming effects were observed at the gap, but were observed 750 ms downstream. Thus gap filling was delayed for our older neurologically unimpaired participants, similar to the delayed gap filling evinced with college-aged individuals found in Friedmann et al. (2008). We agree with the suggestion made by Friedmann et al. (2008) that the lack of an overt cue signalling an upcoming gap could be responsible for the delay in lexical reactivation with unaccusative verbs. We now move to Experiment 2, which investigates the impact of Broca's aphasia on the lexical reactivation of displaced NPs in sentences that contain unaccusative verbs.

Experiment 2: The time course of lexical activation of unaccusatives in individuals with Broca's aphasia

There are a few possibilities for our IWBA regarding activation patterns in sentences containing unaccusative verbs. The first is that they could exhibit lexical reactivation with a time course similar to what has been demonstrated with IWBA with other types of syntactic dependencies; that is, 500 ms downstream from the gap. Consider again an object-extracted clause from Love et al. (2008):

(15) The audience liked the wrestler[1] that the[2] parish priest condemned < ~~the wrestler~~>[3] for [4]foul [5]language.

Recall that neurologically unimpaired individuals exhibited immediate lexical reactivation of the displaced argument at the gap (PP3). Individuals with Broca's aphasia did not immediately exhibit lexical reactivation at the gap but instead, reactivation of the displaced argument was observed at PP5, 500 ms downstream from the gap.

A second possibility is that our participants with Broca's aphasia would exhibit the same delay in lexical reactivation with unaccusatives as observed with college-aged neurologically unimpaired individuals in Friedmann et al. (2008) and with the AMCs in our current Experiment 1; 750 ms downstream from the gap. Both of these possibilities would indicate that individuals with Broca's aphasia are able to take advantage of the inherent delay of unaccusative verbs and would also indicate that IWBA exhibit a time course of lexical reactivation that is similar to neurologically unimpaired individuals. The final possibility we entertained is that IWBA may evince lexical reactivation with a time course that is delayed compared to neurologically unimpaired individuals, and thus observed at the1,250 ms post-gap position.

Method

Participants—Seven individuals with Broca's aphasia met criteria for inclusion in this study (mean age at time of testing: 58 years; range: 39–75 years). Demographic information for these participants is presented in Table 2.

All participants with Broca's aphasia experienced a single, unilateral left-hemisphere (LH) stroke, were native English speakers with normal or corrected-to-normal visual and auditory acuity, and were right-handed before their stroke. The clinical diagnosis of Broca's aphasia was made based on the administration of standardised language testing to determine the extent and severity of each participant's language impairment; specifically in the areas of fluency and auditory comprehension ability. Testing included the Boston Diagnostic Aphasia Examination—Third Edition (BDAE—3; Goodglass, Kaplan, & Barresi, 2000), and Subject-relative Object-relative Active and Passive (SOAP) Test of Auditory Sentence Comprehension (Love & Oster, 2002). Participants with Broca's aphasia were included in this study if they met clinical consensus and demonstrated comprehension deficits, which we defined as at- or below-chance performance on comprehension of sentences with non-canonical word order (object relatives and passives) as assessed by the SOAP. All participants were neurologically and physically stable (i.e., at least 6 months post onset), with no reported history of active or significant alcohol and/or drug abuse, active psychiatric illness or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). All of the participants were tested at the Language and Neuroscience Group Laboratory at San Diego State University and were paid $15 per session. A review of treatment history reveals that six of our seven participants had treatment for sentence-level deficits, though the extent of treatment (number of sessions, type of treatment, treatment response) were not available.

Task, Materials, Design, and Procedure—The same Task, Materials, Design, and Procedure as those used in Experiment 1 were used. See Sections 2.1.2–2.1.5 for details.

Analysis

The IWBA responded to the button press decision with >99% accuracy (M = 99.6%; SD = .24%; range 99.2–100%). Before analysis, incorrect responses (wrong button press or no response) were removed (.42% of data). A < 300 ms and >2,000 ms RT screening was performed, but no data were removed as no RTs were outside this range. A two standard deviation screening per participant by condition of the remaining data was then performed to reduce item variance (4.72% of data).

The same item eliminated from analyses for the AMCs was also removed here as 20% of the data were eliminated for the IWBA. As a switched target design was used, the item that it served as a switch target match was also eliminated.

Similar to the analyses performed in Experiment 1, analysis of the RTs of the remaining 30 items was conducted using restricted maximum likelihood in a mixed-effects model (see Section 2.2). Included in this model were the crossed-random effects on the intercept of participant and sentence and fixed effects of PP (1 vs. 2 vs. 3 vs. 4), relatedness versus control, and their interaction. With no random effects, the overall model (i.e., including both levels of PP) had BIC = −1,049, which improved to BIC = −2,156.2 when the random effect of participant was added, and improved again to BIC = −2,188.3 when the additional random effect of sentence was added, thus justifying the inclusion of both random effects. Refer to Experiment 1 for the details of this analysis.

Results

Mean RTs and standard errors for each condition for IWBA are shown in Table 3.

There was a main effect of PP, $F(3,1552) = 12$, $p < 0.0001$, but no main effect of relatedness, $F(1,1552) = 0.05$, $p = 0.82$. A significant overall interaction between PP and relatedness was observed, $F(3,1552) = 2.98$, $p = 0.03$. Planned comparisons of the RTs for related and control probes for each PP are of primary importance to address the question of when (at which PP) any priming effects reach significance.

As shown in Figure 2, these planned comparisons between the RTs for related compared to control picture probes revealed significant priming, 17 ms, at only **PP2**, $t(1,552) = 2.2$, $p = 0.03$; 95% CI: [0.003, 0.05]. No significant priming was found at **PP1**, $t(1,553) = 0.82$, $p = 0.41$; 95% CI: [−0.01, 0.03], **PP3**, $t(1,552) = -1.59$, $p = 0.11$; 95% CI: [−0.04, 0.004] or **PP4**, $t(1,552) = -0.98$, $p = 0.33$; 95% CI: [−0.03, 0.01].

Discussion

The purpose of this experiment was to chart the time course of lexical reactivation of the displaced argument in sentences containing unaccusative verbs, with individuals who have a Broca’s aphasia and a comprehension deficit. Both groups revealed delayed reactivation with unaccusative verbs at points downstream from the gap. Specifically, in Experiment 1, our neurologically unimpaired participants evinced priming 750 ms post gap, replicating the effect shown with neurologically unimpaired college-aged participants in Friedmann et al. (2008). Recall also that in prior studies investigating gap filling with participants with Broca’s aphasia (e.g., Love et al., 2008), there is evidence for both delayed lexical access and delayed reaccess (i.e., delayed gap filling), both of which have been revealed through CMP experiments like the present one, with some further evidence from eye tracking-while-listening tasks (Thompson & Choy, 2009).

We offered the following predictions: The normally inherent delay observed with unaccusatives would match the inherent lexical access delay, culminating in similarly delayed patterns between our participants with Broca’s aphasia and the neurologically unimpaired participants from Friedmann et al. (2008) and Experiment 1. Alternatively, we surmised that our participants might reveal an even longer delay with unaccusatives, suggesting that the normal delay and the aphasia lexical (re)access delay would be compounded. We observed strong evidence for the former prediction: Significant priming was observed downstream from the gap but not at the farthest downstream point.

Interpretation of these results relative to the extant literature is not straightforward. For example, both the DLA and the slowed syntax accounts can explain these patterns. The DLA suggests delayed access when a noun is encountered and delayed reaccess of that NP at gap positions (Love et al., 2008). In the present study we observed activation of the displaced NP temporally downstream from the gap. The slow syntax approach, likewise, predicts late activation of the single argument of unaccusatives, given that gap filling may be a syntactically driven process (Burkhardt et al., 2003). One interpretation that is clear from these results is that IWBA who have sentence comprehension deficits are sensitive to the argument structure properties of verbs (see Shapiro et al., 1993; Shapiro & Levine, 1990); otherwise they would be insensitive to the unaccusativity property. We discuss this further in the General Discussion.

General discussion

We examined the comprehension of sentences containing non-alternating unaccusative verbs in a group of AMCs and in participants with agrammatic Broca's aphasia who also have a comprehension deficit. We took our initial cue from Friedmann et al. (2008), who found that college-aged neurologically healthy adults delay reaccess of the single argument of unaccusatives, unlike what is observed with, for example, transitive verbs inserted into object-extracted relatives (Love et al., 2008, and references therein). We observed a replication of the Friedmann et al. (2008) results with our AMC participants—activation of the displaced object of unaccusative verbs was observed at a 750 ms post-gap position. For our IWBA, we also found delayed reactivation of the displaced object of the unaccusative verb, but at 500 ms post gap and not at 750 ms. It is possible that if Friedmann et al. (2008) had tested at a PP that was 500 ms post gap instead of just 750 ms, they may have demonstrated effects beginning at 500 ms post gap. Of course we cannot be sure of this. Even so, this difference in timing (between 500 and 750 ms) occurs over a very small segment, perhaps 1–2 syllables at most, and thus does not alter our overall conclusion—both unimpaired and agrammatic Broca's participants are not showing immediate reactivation of the antecedent at the gap; reactivation is occurring downstream. Our participants with agrammatic Broca's aphasia do not exhibit a delayed time course of lexical reactivation with sentences containing unaccusative verbs compared to neurologically unimpaired indviduals.

These patterns, then, beg the question: Why do syntactic dependencies such as object relatives and *Wh*-questions yield immediate reactivation of the displaced argument in neurologically unimpaired participants, while unaccusatives yield late gap filling in both neurologically unimpaired and impaired participants? One possibility, as discussed in our Introduction, based on Friedmann et al. (2008), is that *Wh*-questions and relative clauses contain an explicit surface cue early in the sentence that signals that a gap position will be forthcoming. The cue for *Wh*-questions is the *Wh*-word (e.g., *Which* boy did the girl kiss < ~~which boy~~> yesterday?) and the cue for relative clauses is the complementiser *that* or *who* (e.g., The audience liked the wrestler *that* the priest condemned < ~~the wrestler~~> for foul language). There are no surface cues that a gap will be forthcoming for unaccusatives and thus a listener cannot predict that a gap will occur until the unaccusative verb itself is encountered. At that point the parser—having access to the verb's properties—would "know" to posit a gap, and then form the dependency chain between the gap and the displaced argument, which would take longer with unaccusative sentences than structures that contain early and explicit cues.

Of considerable interest is that individuals with Broca's aphasia who show late gap filling with *Wh*-questions and object relatives also do poorly on offline comprehension of those structures, as discussed in our Introduction. Yet, though late gap filling is observed for unaccusatives (similar to that found with unimpaired listeners), offline comprehension remains unimpaired.[3] One possibility is that there is no direct relation between online behaviour and offline final comprehension in aphasia. We believe this conclusion is too strong. Another possibility that we have recently investigated is the Intervener Hypothesis. An intervener is an NP that interrupts the dependency chain between the displaced NP and its gap; if the two NPs are structured similarly (e.g., DET *N*), similarity-based interference occurs, decreasing comprehension performance.

Recent findings from our lab support the intervener account (Friedmann & Shapiro, 2003; Sheppard et al., 2015; Sullivan et al., 2016). As discussed in our Introduction and repeated and extended here, Sullivan et al. (2016) used a sentence-picture matching task with the seven participants with Broca's aphasia included in the current Experiment 2. Non-alternating unaccusative verbs were embedded in two different sentence constructions, complement phrase constructions (16) and subject-extracted relative clauses (17):

(16) The girl observed that the boy disappeared < ~~the boy~~> into the trees.

(17) The girl that observed **the boy** disappeared < ~~the girl~~> into the trees.

In both (16) and (17) the single argument of the unaccusative verb has been underlined. In (16)—the complement phrase construction—no NP occurs between the single argument of the unaccusative verb, *the boy* and the position from which it has been displaced. However, in (17)—the subject-extracted relative clause construction—an NP (***the boy***) occurs between the two elements of the dependency chain. Results revealed above chance comprehension of the complement phrase construction (16) but comprehension suffered for the subject-extracted relative clauses (17). These results provide support for the Intervener Hypothesis, which claims that the sentence comprehension deficits observed in individuals with Broca's aphasia occur as a result of interference among structurally similar NPs. For example, in (17) above, the NP *the girl*, once displaced, crosses over the intervening NP *the boy*, and both are NPs that result from the merging of a Determiner and a Noun. The similar structure causes similarity-based interference and negatively impacts comprehension. Thus, we suggest that the reason why unaccusative verbs are relatively easy to understand even for

[3]We have observed a similar finding in aphasia with sentences containing verb phrase ellipsis (e.g., The fireman defended the policeman, and the lawyer did too, according to someone who was there). Here, the verb phrase from the initial clause—*defended the policeman*—is reconstructed at the elided position (after *did*), yet is either not found reactivated in some participants (Poirier, Shapiro, Love, & Grodzinsky, 2009) or found reactivated at 750 ms after the elided position (Walenski et al., submitted). However, offline performance was very good.

participants with Broca's aphasia who have sentence comprehension impairments and exhibit a delay in lexical activation is that there is no possibility of an intervener interfering with interpretation in most sentence types; unaccusatives are single-argument verbs. Delayed lexical activation only results in comprehension difficulties for IWBA when a structurally similar NP intervenes between a gap and its filler.

One issue we have ignored thus far is whether the effects we have observed are specific to participants with a Broca's aphasia who evince a sentence comprehension deficit, or is a general pattern characteristic of LH damage. That is, do participants with agrammatic Broca's aphasia who do not have a comprehension disorder, or participants without Broca's aphasia, reveal similar or different patterns? We cannot be sure because we did not test a group of participants with brain damage who have non-agrammatic aphasia, and so ultimately this question remains unresolved. There is some reasonable evidence that people with a fluent, Wernicke's like aphasia do not show late gap filling that is observed in agrammatic Broca's aphasia (e.g., Love et al., 2008; Zurif, Swinney, Prather, Solomon, & Bushell, 1993), and do not show sensitivity to argument structure (necessary to understand unaccusative verbs; see Russo, Peach, & Shapiro, 1998; Shapiro et al., 1993). Yet, we recognise that participants with a Wernicke-like aphasia are dissimilar behaviourally (and neurologically) to participants with damage to other cortical and subcortical areas, including damage to LH regions more closely associated with agrammatic aphasia. Thus, further work is required to examine the generalisability of our approach.

To conclude, we conducted an experiment examining the online comprehension of sentences containing unaccusative verbs in a group of IWBA with a demonstrated comprehension deficit, and in a group of neurologically unimpaired age-matched individuals. We found reactivation of the displaced NP at a position downstream from the gap in both groups, though at slightly different temporal points. We have suggested that the source of the delay is the lack of a surface cue to the gap (based on Friedmann et al., 2008). While studies examining other types of syntactic dependencies in individuals with Broca's aphasia reveal that late gap filling gives way to poor offline performance, for unaccusative verbs late gap filling does not result in impaired offline comprehension, except when sentences contain an intervener between a filler and its gap. The delay in lexical activation observed in IWBA only has repercussions to sentence comprehension for constructions that include a structurally similar NP that intervenes between two elements of a filler-gap syntactic dependency.

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Appendix A. Stimuli used in Experiment 1 and 2

Sentence	Unaccusative verb
The runner with the funny accent thrived until the last semester of the undergraduate programme.	Thrived
The fireman from the next county fell during an obnoxiously noisy motorcycle race.	Fell
The electrician with bushy eyebrows survived during the devastating Category 3 storm.	Survived
The director from the tiny province remained after the extravagant charity function.	Remained
The tailor from East Orange, New Jersey disappeared after the ridiculously uninspiring self-help seminar.	Disappeared
The queen with the bad temper vanished during the spectacular fireworks show.	Vanished
The tourist on the unshaded side of the street languished after the paddleboarding tour of the cove.	Languished
The umpire from the neighbouring city arrived after the horrifying automobile accident.	Arrived
The musician with the expensive jewellery emerged with a large and boisterous entourage.	Emerged
The captain with the worst attendance flourished after the vitally important discovery.	Flourished
The chef from the wealthy family arose after the obnoxious shrill of the alarm clock.	Arose
The goalie from the suburbs of Charlotte departed before dawn for a long overdue vacation.	Departed
The skateboarder with the navy blue socks soared through the fluffy clouds for several minutes.	Soared
The dentist from the suburbs of Detroit awoke before the high intensity kick boxing class.	Awoke
The actor with a collection of stamps lived during the undeniably life altering internet boom.	Lived
The janitor from the private high school appeared after the grand opening of the department store.	Appeared
The gymnast with a green and white Dodge Caravan thrived during the wheelbarrow racing competition.	Thrived
The golfer with thirteen pet guinea pigs fell in the middle of the surprise birthday party.	Fell
The plumber with a grey scraggly beard survived during the incredibly hectic final exam week.	Survived
The teacher with the wire framed glasses remained after the extremely emotional performance.	Remained
The lawyer with an appetite for sweets disappeared before the first act of the Broadway show.	Disappeared
The surgeon with the coin collection vanished in the middle of the community crime watch meeting.	Vanished
The librarian from West Virginia languished after the first day of the semester.	Languished
The roofer from Sacramento arrived during the third period of the basketball game.	Arrived
The farmer with the curly hair emerged after the televised singing competition.	Emerged
The girl from the small town in Maine flourished after the dance academy graduation.	Flourished
The jockey from Minnesota arose after the tremendously inconsiderate telephone call.	Arose
The barber with three small children departed before the seventh inning of the baseball game.	Departed
The reporter with the purple jumpsuit soared past the cliffs above the populated beach.	Soared
The bartender with reflective shoelaces awoke after several hours of restful sleep.	Awoke
The illustrator from Madison, Wisconsin lived after the notably influential French Renaissance.	Lived
The cowgirl with the large emerald necklace appeared after the heroic rescue of the kitten.	Appeared

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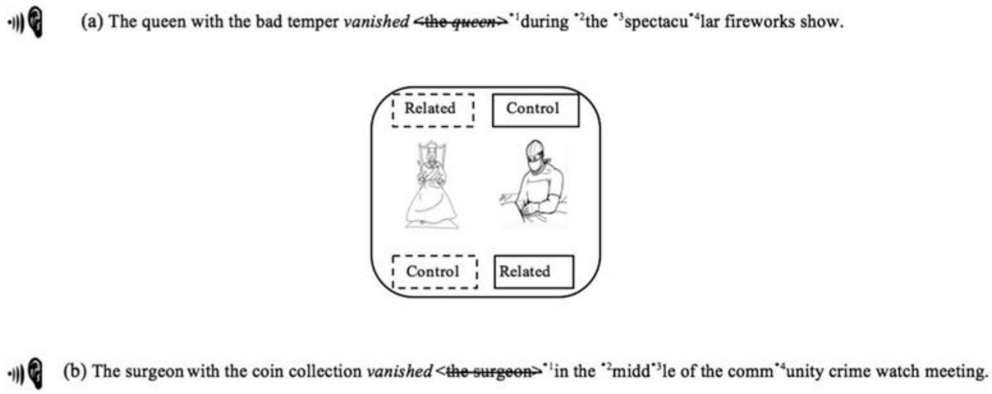

Figure 1.

(a) A sample sentence and corresponding probe pictures from the online cross-modal picture priming task for Experiments 1 and 2. The sentence was presented auditorily at a normal speech rate. Probe pictures were presented at the offset of the verb, at the gap, in each sentence (italics) and at three subsequent test points. Approximate probe positions in each sentence are indicated by *. Probe pictures for the related and control conditions are depicted, though only one probe picture was presented on each individual trial. (b) The paired sentence that had the same probe pictures to depict counterbalancing of related and control probes. In this matched sentence design, the pictures related to the displaced argument for one sentence were used as the unrelated control pictures for the displaced argument of another sentence (e.g., as indicated by the dashed box around queen), so that over all items, the related and control sets of pictures were identical, avoiding response time confounds due to differences between pictures.

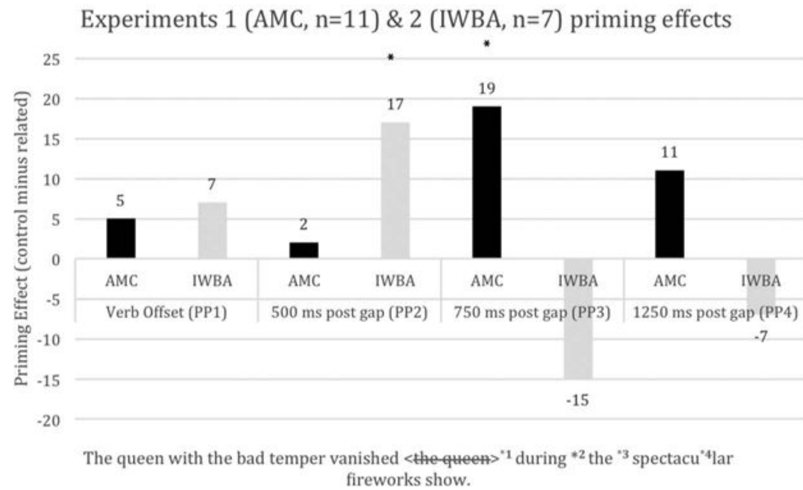

Figure 2.

Priming effects for AMC group (Experiment 1) and IWBA group (Experiment 2) across four probe positions.

Table 1

Experiment 1: Mean reaction times (and standard error) in milliseconds to control and related probes at each probe position for AMC participants ($n = 11$).

	PP1 Verb offset	PP2 500 ms post gap	PP3 750 ms post gap	PP4 1,250 ms post gap
Control	657(7)	649(8)	654(7)	639(8)
Related	652(7)	647(8)	635(6)	628(8)
(Control-Related)	5 ms	2 ms	19 ms*	11 ms

*$p < .05$.

Table 2

Demographic information for individuals with agrammatic Broca's aphasia.

Participant	Gender	Years post stroke	Lesion location[^]	Age at testing	Education in years	BDAE[*] severity level	SOAP[#] Canonical	SOAP[~] non-canonical
LHD009	M	13	LH lesion involving inferior frontal gyrus (BA44, 45)	53	17	3	75%	55%
LHD101	M	7	LH lesion involving posterior inferior frontal gyrus (BA44) with posterior extension	64	20	2	95%	35%
LHD130	M	5	L IPL with posterior extension sparing STG	61	16	4	95%	65%
LHD132	M	9	LH lesion involving inferior frontal regions with extension to the anterior two thirds of STG and MTG	50	16	4	85%	55%
LHD140	F	13	L MCA infarct secondary to occlusion of L proximal CA	39	16	2	80%	30%
LHD142	M	3	L MCA infarct	75	8	4	100%	65%
LHD159	F	3	L MCA infarct	61	14	3	100%	70%
		Mean = 8		*M* = 58	*M* = 15	*M* = 3	*M* = 90%	*M* = 54%
		SD = 4		*SD* = 11	*SD* = 4	*SD* = 1	*SD* = 10	*SD* = 15

^L = left; LH = left hemisphere; BA = Brodmann area; IPL = inferior parietal lobule; STG = superior temporal gyrus; MTG = middle temporal gyrus; MCA = middle cerebral artery; CA = cerebral artery.

*BDAE = Boston Diagnostic Aphasia Examination (0 = no usable speech or auditory comprehension, 5 = minimal discernable speech handicap).

#SOAP Canonical = Average percent correct of active and subject relative items on SOAP Test of Auditory Sentence Comprehension.

~SOAP Non-Canonical = Average percent correct of passive and object relative items on SOAP Test of Auditory Sentence Comprehension.

Table 3

Experiment 2: Mean reaction times (and standard error) in milliseconds to control and related probes at each probe position for participants with Broca's aphasia ($n = 7$).

	PP1 Verb offset	PP2 500 ms post gap	PP3 750 ms post gap	PP4 1,250 ms post gap
Control	727(10)	698(8)	711(9)	693(8)
Related	720(10)	681(7)	726(10)	700(8)
(Control-related)	7 ms	17 ms*	−15 ms	−7 ms

*$p < .05$.