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Electrophysiology of Prosodic and Lexical-Semantic Processing During Sentence Comprehension in Aphasia

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Abstract

Event-related potentials (ERPs) were used to examine how individuals with aphasia and a group of age-matched controls use prosody and thematic fit information in sentences containing temporary syntactic ambiguities. Two groups of individuals with aphasia were investigated; those demonstrating relatively good sentence comprehension whose primary language difficulty is anomia (Individuals with Anomic Aphasia (IWAA)), and those who demonstrate impaired sentence comprehension whose primary diagnosis is Broca's aphasia (Individuals with Broca's Aphasia (IWBA). The stimuli had early closure syntactic structure and contained a temporary early closure (correct) / late closure (incorrect) syntactic ambiguity. The prosody was manipulated to either be congruent or incongruent, and the temporarily ambiguous NP was also manipulated to either be a plausible or an implausible continuation for the subordinate verb (e.g., "While the band played the song/the beer pleased all the customers."). It was hypothesized that an implausible NP in sentences with incongruent prosody may provide the parser with a plausibility cue that could be used to predict syntactic structure. The individuals with aphasia were broken into a group of High Comprehenders and a group of Low Comprehenders depending on the severity of their sentence comprehension deficit. The results revealed that incongruent prosody paired with a plausibility cue resulted in an N400-P600 complex at the implausible NP (the beer) in both the controls and the IWAAs, yet incongruent prosody without a plausibility cue resulted in an N400-P600 at the critical verb (pleased) only in healthy controls. IWBAs did not show evidence of N400 or P600 effects at the ambiguous NP or critical verb, although they did show evidence of a delayed N400 effect at the sentence-final word in sentences with incongruent prosody. These results suggest that IWAAs have difficulty integrating prosodic cues with underlying syntactic structure when lexical-semantic information is not available to aid their parse. IWBAs have difficulty integrating both prosodic and lexical-semantic cues with syntactic structure, likely due to a processing delay.

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Keywords

Aphasia; Event related potentials; N400; P600; Sentence Processing; Prosody

1 Introduction

In this paper we describe an experiment that investigates how prosodic and thematic fit information affects sentence processing in individuals with aphasia. Before we do, we describe the relevant sentence processing literature based on neurologically unimpaired adults, setting the stage for a subsequent description of the relevant literature on aphasia.

While comprehending sentences appears to be immediate and effortless, it requires the rapid coordination of a complex set of processes. These processes include building semantic and syntactic representations while also incorporating prosodic information. One important battleground for empirical studies of sentence processing involves apparent and momentary syntactic ambiguities. Neurologically unimpaired listeners can experience momentary comprehension difficulties when processing sentences containing such ambiguities, yet these listeners are typically able to repair and resolve these ambiguities to ultimately comprehend the sentence. For example, consider:

1. While the band played the song pleased all the customers.

Sentence (1) contains a temporary syntactic ambiguity because it is initially unclear whether the noun phrase (NP) *the song*, once encountered in the speech stream, is the direct object of *played* (incorrect interpretation) or the subject of the main clause (correct interpretation). Once the critical verb *pleased* is subsequently encountered, it becomes clear that the structurally ambiguous NP *the song* is the subject of the main clause and not the direct object of *played*. Sentence (1) is an example of early closure syntax where the ambiguous NP (*the song*) serves as the subject of a new clause. Sentences like (1) are often called "garden path" sentences because they lead the reader/listener down the "garden path" to misanalysis, and then reanalysis is required to successfully comprehend the sentence.

Studies examining the impact of lexical-semantic cues have found that they can lessen the garden-path effect. Consider:

2. While the band played the beer pleased all the customers.

Because it is implausible that *the beer* would be *played, the beer* is a poor fit as a direct object or Theme of *played*. Thus, sentences containing an implausible NP like *the beer* in (2) may provide the parser with a lexical-semantic plausibility cue to prefer the correct early closure syntax over the incorrect late closure syntax. In this way lexical-semantic cues in the form of 'thematic fit' may constrain sentence parsing decisions by restricting the array of likely syntactic structures. Thematic fit refers to how well a verb corresponds with its arguments. Some NPs are better continuations for specific verbs than others, and research suggests that processing is briefly disrupted when a transitively-biased verb (a verb that is likely to have a direct object) is followed by an implausible direct object (Staub, 2007).

Prosody – characterized by pitch, loudness and rhythm of language – can also affect the processing of garden path sentences. Intuitively it seems likely that inserting a pause after *played* and before the introduction to the subsequent NP in (1) would immediately disambiguate the syntactic structure and make it clear to the listener that the NP, *the song*, is the subject of the main clause. Below we will briefly review the literature examining how lexical-semantic and prosodic cues are used by both neurologically unimpaired listeners and persons with aphasia.

1.1 Lexical-Semantic and Prosodic Cues in Unimpaired Sentence Processing

Evidence from studies of neurologically unimpaired participants suggests that lexical-semantic plausibility cues such as verb transitivity bias (whether or not a verb prefers a direct object) and thematic fit can disambiguate a sentence before the reader/listener is potentially garden-pathed (Altmann, 1999; Altmann & Kamide, 1999; Arai & Keller, 2013; Trueswell, Tanenhaus, & Garnsey, 1994; Van Berkum, Brown, & Hagoort, 1999). Unlike thematic fit, which refers to plausibility, verb transitivity refers to the syntax; transitively biased verbs are more likely to take a direct object, while intransitively biased verbs are more likely to not take a direct object.

Prosody can also serve as a cue to the underlying syntactic structure of a sentence, because prosodic breaks tend to occur at major syntactic boundaries (Cooper & Paccia-Cooper, 1980; Nagel, Shapiro, & Nawy, 1994; Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991). A prosodic break, which can also be referred to as an intonational phrase boundary, is designated by a pause, preboundary lengthening of the word immediately preceding the pause, and a boundary tone at the word preceding the pause. Studies of neurologically unimpaired participants have found that sentence comprehension is aided by prosodic cues that are congruent with syntax, and obstructed when prosodic cues are incongruent with syntactic structure (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2013; Carlson, Frazier, & Clifton, 2009; Kjelgaard & Speer, 1999; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Nagel, Shapiro, Tuller, & Nawy, 1996; Pauker, Itzhak, Baum, & Steinhauer, 2011; Pynte & Prieur, 1996; Schafer, Speer, Warren, & White, 2000; Steinhauer, Alter, & Friederici, 1999)

Only a few studies have examined the interaction of lexical-semantic and prosodic cues during sentence processing (Blodgett, 2004; DeDe, 2010; Itzhak, Pauker, Drury, Baum, & Steinhauer, 2010; Pynte & Prieur, 1996; Snedeker & Yuan, 2008), but most of these have used off-line methods. Off-line tasks cannot provide detailed information about the time course of how and when plausibility and prosodic cues are used in sentence processing, thus the time course of the underlying processes remains unknown. However, Itzhak et al. (2010) used event-related potentials (ERPs) to examine how prosodic cues interact with plausibility cues in the form of transitivity bias. Participants were presented with sentences that either had early closure structure (e.g., [While Billy was playing] [the game seemed simple]) or late closure structure (e.g., [While Billy was playing the game] [the rules seemed simple.]) with correct prosody. They were also presented with garden-path sentences that had early closure syntactic structure with no prosodic cue to aid the parse. Additionally, the transitivity of the subordinate verb was manipulated to either have a transitive or intransitive bias. Their results revealed a larger P600 (P600 effect – an ERP component sensitive to syntactic processing) in sentences without a plausibility cue (transitively-biased) relative to those with a plausibility cue (intransitively-biased verbs) in the garden path sentences with no prosodic cue, which suggested that plausibility immediately influences structural parsing decisions. While Itzhak et al. explored the influence of lexical-semantic information in the form of transitivity bias, our previous study, (Sheppard, Midgley, Love, Shapiro, & Holcomb, Submitted) used ERPs to examine the interaction of prosody and lexical-semantic cues in the form of thematic fit. Sheppard et al. (Submitted) used the same sentence stimuli described in the current study, where sentences with underlying early closure syntactic structure were compared when they had prosody that was either congruent (early closure prosody) or incongruent (late closure prosody) with the syntactic structure. Thematic fit was also manipulated so that the temporarily ambiguous NP was either a good ("While the band played the song…") or a poor continuation ("While the band played the beer…") for the subordinate verb:

3a. [While the band played] [the song pleased all the customers.] Congruent (+) Plausible (+) Pr+TF+

3b. [While the band played] [the beer pleased all the customers.] Congruent (+) Implausible (−) Pr+TF−

3c. [While the band played the song] [pleased all the customers.] Incongruent (−) Plausible (+) Pr−TF+

3d. [While the band played the beer] [pleased all the customers.] Incongruent (−) Implausible (−) Pr−TF−

In a group of college-age adults, Sheppard et al. demonstrated that prosodic and thematic cues interact immediately during syntactic structure building. Incongruent prosody paired with a plausibility cue to help predict the underlying syntactic structure resulted in syntactic reanalysis earlier in the sentence relative to sentences with incongruent prosody and no plausibility cue. Also, congruent prosody immediately disambiguated syntactic structure. Thus, results from this previous study demonstrate that the unimpaired listener can immediately capitalize on prosodic and lexical-semantic cues to aid structure building. Yet it is unclear how these potential cues – thematic fit and prosody – are used by individuals with aphasia, including those who have a comprehension deficit, to help them understand sentences.

1.2 Lexical Cues in Aphasia

There is evidence that individuals with aphasia are sensitive to plausibility information. For example, in a seminal study Caramazza and Zurif (1976) presented individuals with Broca's aphasia with sentences like the following in a sentence-picture matching task:

4. The cat that the dog is biting is black.

5. The book that the girl is reading is yellow.

The results revealed that individuals with Broca's aphasia had difficulty understanding sentences in non-canonical word order with semantically reversible NPs like (4) where both

NPs (*the cat* and *the dog*) are capable of performing the action of *biting*. However, the participants did not have trouble understanding sentences like (5) that contained only one animate NP (*the girl*) that was capable of performing the action of *reading*. Thus, participants had difficulty understanding non-canonical sentences where semantic information (e.g., animacy) was not sufficient to determine which NP was performing the action and which was receiving the action. Lexical-semantic information impacts sentence comprehension in other subtypes of aphasia as well (Caplan, Hildebrandt, & Makris, 1996; Friederici & Graetz, 1987; Gibson, Sandberg, Fedorenko, Bergen, & Kiran, 2015; Peach, Canter, & Gallaher, 1988; Saffran, Schwartz, & Linebarger, 1998). For example, in a more recent study using an act-out task (where comprehension is measured by asking participants to act out sentences with dolls), Gibson et al. (2015) found that, compared to the control group, a group of individuals with different subtypes of aphasia (i.e., Broca's, anomic, conduction, and transcortical motor) relied more heavily on plausibility information across all sentence types. However, they were more likely to use plausibility information in non-canonical passive relative to canonical active constructions.

1.3 Prosodic Cues in Aphasia

Studies examining how and to what extent individuals with aphasia use prosodic cues in sentence processing have found conflicting results. Some studies using end-of-sentence judgment tasks have found that individuals with aphasia have difficulty identifying prosodic contours in sentences (Pell & Baum, 1997). Yet, using this same method, results from a study by Walker, Fongemie, and Daigle (2001) suggested that processing was facilitated by the presence of congruent relative to incongruent or absent prosodic cues. Complicating the picture further is evidence from Baum and Dwivedi (2003) who found slower reaction times in a cross-modal lexical decision task with congruent relative to incongruent prosodic boundaries for individuals with aphasia. Healthy controls revealed no such pattern. Hence, the individuals with aphasia were sensitive to prosody, but did not use the information to disambiguate the structures in the same manner as controls. The authors proposed that perhaps persons with aphasia process prosodic cues but cannot map them onto syntactic structures. Thus, it appears that individuals with aphasia are sensitive to prosodic information, even though they appear to process it differently than neurologically unimpaired participants. However, these studies are limited because they do not measure online processing so it is unclear how and when these cues impact processing during the unfolding of the sentence.

1.4 Interaction of Lexical-Semantic and Prosodic Cues in Aphasia

Only one study to date of which we are aware, DeDe (2012), has examined the interaction of lexical-semantic and prosodic cues in persons with aphasia. A self-paced listening task was used. In this method, listeners are presented with sentences in word-by-word (or phrase-by-phrase) segments. Listeners must press a button to hear the next aurally presented segment, and listening times via button presses are recorded for each segment. Similar to self-paced reading, longer listening times are associated with processing difficulty/interference. Using this task, DeDe (2012) presented participants with early closure sentences where both lexical and prosodic cues were manipulated. Consider:

6a. While the parents danced the child sang a song with her grandmother.

6b. While the parents watched the child sang a song with her grandmother.

The transitivity bias of the verb was manipulated such that intransitively-biased verbs (*danced* in (6a)) were biased toward the correct early closure interpretation and transitively-biased verbs (*watched* in (6b)) were biased toward an incorrect late closure interpretation. Prosody was also manipulated to bias toward either the early closure (pause after subordinate verb *danced/watched*) or late closure interpretation (no clear prosodic boundary present). The results demonstrated that individuals with aphasia showed longer listening times for the structurally ambiguous NP (*the child*) when lexical and prosodic cues conflicted relative to when they were consistent. The control group showed this effect earlier in the sentence (at the subordinate verb *danced/watched*). Both the patient group and the control group evinced longer listening times at the main verb (*sang*) when both prosodic and plausibility cues biased the listener toward the incorrect interpretation, which was interpreted as indicating that they engaged in syntactic re-analysis. DeDe concluded that while individuals with aphasia are sensitive to prosodic and plausibility cues, they exhibit delayed processing of prosodic and lexical-semantic information. The participants in DeDe's study were selected based on the appearance of anomia (word-finding difficulties), thus it is important to extend those findings to individuals with aphasia *who have a comprehension disorder*. Additionally, self-paced listening requires participants to consciously reflect on each segment of the sentence, which may disrupt ongoing processing. ERPs offer an advantage here because they allow for the unimpeded examination of auditory sentence processing.

1.5 Event-Related Brain Potentials (ERPs) in Sentence Processing

Auditory sentence processing can be examined using ERPs without requiring participants to conduct a secondary task. Moreover, distinct ERP components can be examined, which reflect different aspects of sentence processing. The N400 component is a negative-going waveform that is sensitive to semantic processing (Kutas, 1993; Kutas & Federmeier, 2011; Kutas & Hillyard, 1980). The amplitude of the N400 is modulated by semantic processing effort such that a larger N400 amplitude indexes more difficulty incorporating the word of interest into the preceding sentence context (Holcomb & Neville, 1990; Kutas, 1993; Van Berkum et al., 1999). Some evidence suggests the N400 reflects processes associated with semantic memory (Kutas & Federmeier, 2000), while other research suggests that the N400 reflects the integration of the semantic information of the current word with the meaning from preceding words in an utterance (Brown & Hagoort, 1993; Hagoort, Baggio, & Willems, 2009; Osterhout & Holcomb, 1992). Also, prior work (Osterhout & Holcomb, 1992, 1993; Osterhout, Holcomb, & Swinney, 1994) has revealed that final words in unacceptable sentences elicit an N400-like sentence-final negativity effect relative to final words in acceptable sentences.

In contrast, the P600 component is sensitive to syntactic anomalies (Osterhout & Holcomb, 1992). This positive-going component that typically begins around 600ms after stimulus onset has been suggested to reflect syntactic complexity (Van Berkum et al., 1999) or possibly syntactic integration difficulty (Kaan, Harris, Gibson, & Holcomb, 2000). It is also likely the P600 serves as an index of syntactic reanalysis (Friederici, 2011; Friederici & Kotz, 2003; Friederici & Weissenborn, 2007) when such reanalysis is necessary for successful sentence comprehension.

The P600 has also been elicited in sentences containing plausibility violations (Geyer, Holcomb, Kuperberg, & Perlmutter, 2006; Kuperberg, 2007, 2013; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). For example, Kuperberg et al. (2003) presented participants with sentences like:

7. Every morning at breakfast the boys would only eat toast and jam.

8. Every morning at breakfast the eggs would only eat toast and jam.

In both cases the verb *eat* assigns the thematic role of Agent to the NP (*the boys/the eggs*) in the subject role. In (7) there is a good thematic fit between the verb *eat*, and the NP, *the boys*, because the NP is animate and is a proper subject for the verb *eat*. However, (8) has a poor thematic fit because the inanimate subject NP, *the eggs*, is an implausible subject for the verb. Thematic role violations elicited a significant posterior P600 effect at the critical verb. More recently, this semantic P600 effect has been attributed to processing costs resulting from event prediction error (Kuperberg, 2013). According to this account, the parser makes predictions about specific links between conceptual features and specific thematic roles, and when all of this information is ultimately encountered a full combinatorial analysis occurs where thematic roles are assigned. If the full analysis contradicts the previously formed predictive links, an error is detected, which results in enhanced processing that is reflected by the semantic P600 (Kuperberg, 2013).

ERPs have successfully been used by researchers to examine the auditory comprehension deficit in aphasia (Friederici, Hahne, & Von Cramon, 1998; Kielar, Meltzer-Asscher, & Thompson, 2012). Several ERP studies of sentence comprehension in aphasia have also found that ERPs in this population are modulated by the severity of the comprehension deficit (Hagoort, Brown, & Swaab, 1996; Swaab, Brown, & Hagoort, 1997; Wassenaar, Brown, & Hagoort, 2004). For example, in a study examining ERPs to subject-verb agreement violations, Wassenaar et al. (2004) found that a group of individuals with aphasia with a less severe comprehension deficit showed a significant P600 effect, while those with a more severe deficit did not. Also, Swaab et al. (1997) compared ERPs elicited in sentences with and without a lexical-semantic violation at the final word. The participants with aphasia were divided into a group of High Comprehenders with a mild comprehension deficit and Low Comprehenders with a moderate-severe comprehension deficit. The N400 effect in the High Comprehenders group was similarto the N400 effect in the control group. However, the N400 effect was smaller and delayed in the Low Comprehenders group, which was interpreted as indicating delayed integration of lexical information with the preceding sentence context.

In sum, ERPs allow researchers to measure the impact of semantic (N400), and syntactic interference (P600) as the sentence is being processed. ERPs can thus be used to determine how experimental manipulations affect distinct language processing mechanisms. Importantly, studies of neurologically unimpaired listeners have demonstrated that an N400 effect followed by a P600 effect are often elicited at the disambiguation point in garden-path sentences, including studies examining prosody-driven garden-path effects (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2010; Pauker et al., 2011; Steinhauer et al., 1999). The presence of N400 and P600 effects (N400-P600 complex) at the disambiguation point indicates how garden-path effects can disrupt both lexical-semantic and syntactic processing. The N400 reflects initial semantic integration difficulty and the P600 reflects subsequent syntactic reanalysis, which suggests that participants are able to recover from the garden-path effect. Also, studies examining the interaction of plausibility and prosodic cues have found evidence that a plausibility cue can elicit a P600 effect in sentences with incongruent or absent prosody when compared to sentences with congruent prosody (Itzhak et al., 2010; Sheppard et al., Submitted). Yet, no studies to date of which we are aware have used ERPs in individuals with aphasia to examine the interaction between thematic fit plausibility cues and prosodic cues on the processing of garden-path sentences.

1.6 Current Study

The current study used ERPs to study how prosodic and lexical cues impact sentence processing in individuals with aphasia, a method that allows us to investigate online sentence processing with millisecond-level temporal resolution. Additionally, this experiment used a natural speech paradigm without any behavioral response required during sentence processing, which is a significant advantage of ERPs.

We seek to understand how individuals with aphasia process prosodic and lexical-semantic (thematic fit) cues during the processing of garden-path sentences, compared to a group of neurologically intact age-matched control participants using ERPs. We investigated two groups of individuals with aphasia (IWA); those demonstrating relatively good sentence comprehension whose primary language difficulty is anomia (word finding) (Individuals with Anomic Aphasia (IWAA)), and a group of individuals who demonstrate impaired sentence comprehension whose primary diagnosis is Broca's aphasia (Individuals with Broca's Aphasia (IWBA) (details of participants below). Consider the sentences in Table 1. The first verb in each sentence (*played*) is optionally transitive, thus it has the option of taking a direct object or not. This optionality creates a temporary syntactic ambiguity in each sentence. The thematic fit of the temporarily ambiguous NP following the optionally transitive verb was manipulated to form either a plausible (Pr+TF+, Pr−TF+) or implausible (Pr+TF−, Pr−TF−) direct object. Prosody was also manipulated to either be congruent (Pr +TF+, Pr+TF−) or incongruent (Pr−TF+, Pr−TF−) with the syntactic structure. Specifically, sentences with congruent prosody (Pr+TF+, Pr+TF−) included a pause after the subordinate verb *played* ("While the band played (pause) the song pleased all the customers."), and sentences with incongruent prosody (Pr−TF+, Pr−TF−) included a pause after the temporarily ambiguous NP *the song/beer* ("While the band played the song/beer (pause) pleased all the customers."). These manipulations yielded a 2 (Sentence Type: plausible thematic fit, implausible thematic fit) × 2 (Prosody: congruent, incongruent) design.

1.6.1 Questions and Predictions of Current Study

Question 1: Can individuals with aphasia use plausibility cues to predict syntactic structure? - Predictions at Ambiguous NP (the song/the beer): Sentences with incongruent prosody and an implausible NP (Pr−TF−: [While the band played the beer] [pleased all the customers.]) were compared to sentences with incongruent prosody and a plausible NP (Pr−TF+: [While the band played the song] [pleased all the customers.]). Recall that *the beer* in Pr−TF− sentences is a poor thematic fit for the subordinate verb *played*, and this poor thematic fit may provide a plausibility cue to aid syntactic processing. We predicted that the poor thematic fit between *played* and *the beer* (in Pr−TF− sentences) would trigger syntactic reanalysis at the ambiguous NP, which is before the critical verb *pleased*. Thus we expected to find an N400 immediately followed by a P600 in the comparison of sentences with incongruent prosody between the implausible NP *beer* (Pr−TF −) vs. the plausible NP *song* (Pr−TF+) in the age-matched controls. The N400 effect would confirm that incongruent prosody caused the parser to initially attempt to analyze the structurally ambiguous NP as the direct object of the verb *played*, but did not consider the NP *the beer* to be a good thematic fit with *played*. Hence, the presence of an N400 in this comparison would indicate semantic integration difficulty in Pr−TF− (*the beer*). In contrast *the song* is a plausible direct object for *played*, thus we did not anticipate evidence of semantic integration difficulty. The presence of a P600 effect in Pr−TF− vs. Pr−TF+ sentences at the ambiguous NP would indicate that the poor thematic fit between *played* and *the beer* in Pr−TF− sentences triggered syntactic reanalysis.

Given that the only studies that have examined the interaction of prosodic and thematic cues during sentence processing in patients with aphasia have used behavioral methods such as self-paced listening (DeDe, 2012), it is more difficult to predict ERP effects in this group. However, in DeDe’s study, which manipulated prosody and plausibility in the form of the subordinate verb transitivity, conflicting prosodic and plausibility cues yielded longer listening times in a group of individuals with anomia (corresponding with our IWAA group), though this effect was delayed relative to control participants. Thus for the IWAAs, we predicted delayed N400 and P600 effects at the temporarily ambiguous NP (*beer*) in Pr-TF- sentences. Recall that in an ERP study of individuals with aphasia investigating subject-verb agreement violations, Wassenaar et al. (2004) found that individuals with good comprehension exhibited a P600 effect, whereas those with a comprehension disorder did not. Thus, based on this, we anticipated we would find a delayed N400 but no P600 in the IWBA group, who display a sentence comprehension deficit.

Question 2: Does incongruent prosody result in garden-path effects at the critical verb in individuals with aphasia? -Predictions at Critical Verb (Point of Disambiguation): Garden-path effects can cause interference to both lexical-semantic and syntactic integration, thus many ERP studies in neurologically unimpaired populations find an N400 effect followed by a P600 effect (N400-P600 complex) at the disambiguation point. A mismatch between prosody and syntax can lead to garden-path effects, which is reflected by the presence of both of these components (Bögels et al., 2010; Pauker et al., 2011; Steinhauer et al., 1999). Thus we predicted finding both N400 and P600 effects in the neurologically unimpaired age-matched control participants in the classic garden-path comparison of Pr−TF+ sentences where both prosodic and plausibility cues would bias the listener toward the incorrect parse. Since we anticipated finding this N400-P600 complex at the ambiguous NP (prior to the critical verb) in Pr−TF− sentences with incongruent prosody and a plausibility cue, we did not anticipate also finding N400 and P600 effects at the critical verb in this comparison.

DeDe (2012) found longer listening times at the critical verb in participants with anomia when both prosodic and plausibility cues biased the listener toward the incorrect interpretation. DeDe interpreted these findings as suggesting that participants with anomia were garden-pathed and engaged in syntactic reanalysis at the critical verb when prosodic and plausibility cues biased toward the incorrect parse. Thus, in the IWAA group we anticipated finding N400 and P600 effects at the critical verb (*pleased*) in Pr−TF+ sentences, where both prosodic and plausibility cues bias the listener to the incorrect parse. It was more difficult to make predictions for the IWBA group given that the interaction of prosodic and plausibility cues has not been investigated in these individuals by any other study to date. However, previous ERP studies have found that while N400 effects are evoked in individuals with aphasia exhibiting a comprehension deficit, P600 effects across different experimental paradigms are either diminished or completely absent (Wassenaar et al., 2004; Wassenaar & Hagoort, 2005, 2007). Because the P600 component is indicative of syntactic processing, these findings correspond with studies showing that individuals with Broca's aphasia have difficulty processing sentences with more complex syntax (e.g., Caramazza & Zurif, 1976; Friedmann & Shapiro, 2003; Grodzinsky, 1989, 2000; Schwartz, Linebarger, Saffran, & Pate 1987). Thus, we anticipated finding N400 but no P600 effects in the IWBA group.

Question 3: Do individuals with aphasia show sensitivity to prosody and plausibility manipulations at the sentence-final word?: Osterhout and Holcomb (1992; 1993) demonstrated that in neurologically healthy participants the final word in garden-path sentences, those deemed to be unacceptable by participants, elicits an N400-like negativity effect that is sustained beyond the traditional N400 time window. Hence, we predicted both conditions with incongruent prosody (Pr−TF+, Pr−TF−) would elicit a sentence-final negativity effect in healthy controls over a long time window. We also expected that both groups of individuals with aphasia to be sensitive to the prosody manipulation, and therefore anticipated they would also show a sentence-final negativity, though this effect could be delayed relative to controls (DeDe, 2012), and potentially with a larger amplitude in the group of IWAAs with good comprehension, compared to the IWBAs with poor comprehension.

2 Materials and Methods

2.1 Participants

Age-matched Control Participants—The group of age-matched controls was comprised of 20 adults (13 females; 7 males; mean age = 61 years; range: 41–82 years) who were right-handed monolingual speakers of American English (mean education in years: 16.1 years; range 12–21 years). As indicated by self-report, all participants had normal or corrected-to-normal visual and auditory acuity, and were neurologically and physically stable at the time of testing with no history of psychiatric illness, drug or alcohol abuse, or other significant brain disorder or dysfunction. Additionally, all age-matched control participants were administered the Mini-Mental State Exam (MMSE) (Folstein, Folstein, &

McHugh, 1975), and the Wide-Range Intelligence Test (WRIT) (Glutting, Adams, & Sheslow, 2000) assessment of neurocognitive functioning to screen for dementia or cognitive disorders. In order to participate, the age-matched controls were required to score no lower than one standard deviation below the mean on both the MMSE and WRIT exams. Age-matching between the controls and patient groups was established statistically with a two-tailed independent samples t-test ($t(33) = 1.47$, $p = .549$).

Participants with Aphasia—Fifteen adults with aphasia (5 females; 10 males; mean age = 55 years; range: 37–77 years) participated in this study (see Table 2). All participants experienced a single unilateral left hemisphere stroke, were monolingual native speakers of English, and had normal or corrected-to-normal auditory and visual acuity. All participants were neurologically and physically stable (i.e., at least 6 months post onset) with no reported history of alcohol or drug abuse, psychiatric illness, or other significant neurological disorder or dysfunction. Participants were diagnosed with aphasia based on the convergence of clinical consensus from our speech-language pathologists and the results of the Boston Diagnostic Aphasia Examination (Goodglass, Kaplan, & Barresi, 2001).

Because we were interested in examining how prosodic and thematic fit information affects sentence comprehension in aphasia, we split our participants into two groups, with one evincing relatively good comprehension skills (n = 6) with primarily a word-finding disorder (anomia) (IWAA), and the other including individuals with a Broca's aphasia who exhibit a comprehension disorder (n = 9) (IWBA) (for a similar approach, see Ferrill, Love, Walenski, & Shapiro, 2012; Sheppard, Walenski, Love, & Shapiro, 2015; Sullivan, Walenski, Love, & Shapiro, 2017a, 2017b). Sentence comprehension was assessed by the SOAP (Subject-relative Object-relative Active and Passive Test of Auditory Sentence Comprehension; Love & Oster, 2002) with the IWAA group evincing better-than-chance accuracy across the test, while the IWBA group evincing at- or below-chance performance (Table 2). Importantly, ERP waveforms can vary in individuals with aphasia based on the severity of the comprehension deficit (Hagoort et al., 1996; Kawohl et al., 2009; Swaab et al., 1997; Wassenaar et al., 2004). The results of each analysis for the entire patient group as a whole, the IWAA and the IWBA groups, are reported.

2.2 Materials

The materials were identical to those described in Sheppard et al. (submitted). The experimental sentences shown in Table 1, repeated below for ease of reading, included the following:

9a. [While the band played] [the song pleased all the customers.] (Pr+TF+)

9b. [While the band played] [the beer pleased all the customers.] (Pr+TF−)

9c. [While the band played the song] [pleased all the customers.] (Pr−TF+)

9d. [While the band played the beer] [pleased all the customers.] (Pr−TF−)

To create the materials, sentences (9a–9b) were recorded using naturally produced early closure prosody. The following sentences were recorded using naturally produced late closure prosody:

9e. [While the band played the song] [the beer pleased all the customers.]

9f. [While the band played the beer] [the song pleased all the customers.]

A waveform editor (Adobe Audition) was used to form sentences (9c-9d). The initial portions of (9e-9f) were cut at the end of the pause (located after *the song/ beer*) and spliced to replace the same portion of the sentence in (9a-9b). Sentences (9e-9f) were used as filler sentences in this experiment. These manipulations were designed to allow us to determine whether prosody can bias listeners toward a specific parse even when the lexical cues (whether the NP is a plausible or implausible direct object) conflict with the argument structure of the verb.[1] Sixty of each type of experimental sentence (9a-9d) and filler sentence (9e-9f) were created yielding 60 sentence frames of six sentences each for a total of 360 sentences (240 experimental and 120 filler sentences). The 360 sentences were split into two experimental lists in in a pseudorandom order such that no more than two sentences in a given condition occurred sequentially. There were two data collection sessions where one list was presented per session, in counterbalanced order. All sentences were recorded in a soundproofed environment at a regular rate of speech (4–6 syllables/second). NPs were counterbalanced across the different verbs.

2.3 Procedure

After the participants were fitted with an electrode cap, they were presented with sentences over headphones while sitting in a comfortable chair in a dimly lit sound-attenuated room. Concurrent with the onset of each word in a sentence, a code specifying the condition of the word was sent to the computer digitizing the EEG data. This allowed for precise time-locking of the EEG with word onset across the various conditions. A fixation cross was presented in the center of the screen simultaneous with the start of each sentence. The fixation cross disappeared 1000ms post-sentence offset and was replaced by a question mark signaling the participant to make an acceptability judgment about the sentence they just heard by button press to ensure they were paying attention to the task and processing the sentences for meaning (Figure 1). Once the participant selected a response, the experiment advanced to the next trial. Participants attended two 1-hour data collection sessions (an average of 2.5 weeks apart), where 180 sentences were presented in each session. Each participant was presented with a block of 10 practice items prior to each experimental session in order to familiarize them with the procedure. Each participant was compensated $15 per hour.

2.4 EEG Recording Procedure

The electroencephalogram (EEG) was recorded from 29 active tin electrodes at the scalp (Electrode-Cap International). Additional electrodes were attached below the left eye (VE, used to monitor blinks), to the side of the right eye (HE, to monitor horizontal eye movements), over the right mastoid bone, and the left mastoid bone (A1, reference electrode). The eye electrode impedances were maintained below 10 kΩ, with the remaining

[1]Acoustic analyses, described in Sheppard et al. (submitted), confirm that the sentences contained the intended prosodic manipulations. The intonational phrase boundary in each sentence was marked by a pause, lengthening of the word preceding the pause, as well as a boundary tone at the pre-pause word.

electrode impedances maintained below 5 kΩ. The EEG signal was amplified by a Neuroscan Synamp RT system using Curry data acquisition software. Recording bandpass was DC to 200 Hz and the EEG was continuously sampled at a rate of 500 Hz throughout the duration of the experiment. ERPs were averaged from artifact free trials time-locked to critical target word onset with a 1200ms epoch.

2.5 ERP Data Analysis

ERPs were time-locked to critical points in each sentence (details will be provided in the Results section). All EEG trials with muscle movement or amplifier blocking artifacts were rejected from analysis prior to averaging. Independent component analysis (ICA) was performed on continuous data for each participant to correct for blink artifacts (Jung et al., 2000). Participants were only included if they maintained at least 30 trials in each experimental condition for every comparison of interest. Our ERPs were averaged from the trials remaining after artifact rejection and were bandpass filtered at .1–30 Hz. Unless otherwise noted, comparisons were made using a 100ms pre-stimulus baseline.

A subset of 15 of the 29 scalp sites (Figure 2) were selected to be included in data analyses. Analyses were conducted at three points in the sentence: (1) the ambiguous NP between the two conditions with incongruent prosody, Pr-TF- vs. Pr−TF+ sentences; (2) between all four conditions at the critical verb, *pleased*, and (3) at the sentence-final word. The analyses at the ambiguous NP contained two levels of thematic fit/plausibility (Plausible vs. Implausible). Analyses at the critical verb *pleased*, and the sentence-final word *customers* contained factors of two levels of Prosody (Congruent vs. Incongruent) and two levels of Plausibility (Plausible vs. Implausible). Each analysis also contained scalp distribution factors: Five levels of Laterality (left, mid-left, midline, mid-right, right), and three levels of Anteriority (frontal, central, parietal).

Mean voltages (the area under the waveform within a specified epoch) were calculated and analyzed in separate mixed ANOVAs with Plausibility, Prosody, Laterality, and Anteriority as within-subjects variables and Group (age-matched control vs. individuals with aphasia) as a between-subjects variable. In cases where the mixed ANOVAs indicated differences between groups, follow up analyses were conducted within each participant group with factors of Plausibility, Laterality, and Anteriority for analyses at the ambiguous NP, and Plausibility, Prosody, Laterality, and Anteriority, at the critical verb and final word as described in the Results section. In the participants with aphasia, within group analyses were also conducted for both the IWAAs and IWBAs. Between groups analyses were not used to investigate differences between the IWAA and IWBA groups due to the small group sizes (n = 6 in the IWAA; n = 9 in the IWBA), and because the groups were not equal in size. The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom in the numerator in order to address violations of sphericity.

3 Results

3.1 Question 1: Does the parser use plausibility cues to predict syntactic structure?

Onset of Temporarily Ambiguous NP (song/beer)—Here we compared N400 and P600 effects elicited at the ambiguous NP in conditions with incongruent prosody (Pr−TF+, Pr−TF−). The statistically significant results from between-group analyses of age-matched controls vs. individuals with aphasia are summarized in Table 3 and the results from within-group analyses of all four participant groups at the ambiguous NP (*song/beer*) are summarized in Table 4. As expected, the analyses indicated that waveforms differed significantly between the group of controls and the group of all of the individuals with aphasia. As shown in Figure 3A, the implausible NP (*beer*) in Pr−TF− sentences elicited a large N400 effect distributed widely across the scalp, followed by a P600 effect at posterior sites in age-matched controls. However, in the group including all of the individuals with aphasia, a small N400 effect at posterior sites was revealed, while no significant P600 effect was found. Although, examination of the subgroups of individuals with aphasia indicated significant N400 and P600 effects to the implausible NP (*beer*) in IWAAs (Figure 3C), but no evidence of either N400 or P600 effects were found in IWBAs (Figure 3D). Rather the implausible NP (*beer*) evoked more positive-going waveforms within the N400 time window in IWBAs. The presence of N400 and P600 effects in the controls and IWAAs suggests that when they heard the implausible NP (*beer*) they experienced semantic integration difficulty (N400) followed by subsequent syntactic reanalysis (P600). Thus, the prosodic and plausibility cues immediately interacted to influence syntactic structure building in these groups, but not in the group of IWBAs. Also, while the P600 effect in the age-matched controls and IWAAs had a similar scalp distribution, the N400 effect was distributed differently in these two groups.

The N400 in the controls was distributed widely across the scalp, while it was focused primarily at central and posterior sites in the IWAAs.

3.2 Question 2: Does incongruent prosody result in garden-path effects at the critical verb?

Waveforms time-locked to the critical verb (e.g., *pleased*; the disambiguation point in all four experimental conditions), were compared to examine whether incongruent prosody elicited garden-path effects. A 100 post-stimulus onset baseline interval was used to compensate for the P600 effect in condition Pr-TF-, described in the previous section, that immediately preceded the critical verb. Table 3 summarizes the statistically significant results from between-group analyses of age-matched controls vs. individuals with aphasia, and Table 5 shows the significant results from within-group analyses for all participant groups at the critical verb (*pleased*). Waveforms in conditions with incongruent prosody (Pr−TF+, Pr−TF−) were significantly more negative-going relative to those with congruent prosody (Pr+TF+, Pr+TF−) in both age-matched controls and the group with all of the individuals with aphasia. Once again, as expected, significant differences were found between the controls and individuals with aphasia. In both groups, incongruent prosody evoked an N400 effect. However, the scalp distribution of the N400 effect to incongruent prosody differed by group, where it was distributed primarily at posterior midline and left-hemisphere sites in controls (Figure 4A) but at posterior right-hemisphere sites in the individuals with aphasia (Figure 4B). This suggests that the underlying neural generators contributing to the N400 effect may differ between controls and individuals with aphasia. Additionally, visual inspection of the voltage maps in Figure 4B demonstrates that the N400 effect was much more prominent in Pr−TF− sentences with both incongruent prosody and a plausibility cue in individuals with aphasia. Moreover, a P600 effect was only found in Pr−TF+ sentences (which do not contain a plausibility cue) in both the control and individuals with aphasia groups. This P600 effect in Pr−TF+ sentences was larger in the control group where it was bilaterally distributed across both hemispheres. In contrast, the P600 effect was primarily centered at left-hemisphere sites in the group of individuals with aphasia, which again suggests different neural generators.

Analyses of the subgroups of individuals with aphasia (IWAA and IWBA groups) revealed distinctive patterns within each group. In the IWAA group, an implausible NP (*beer*) evoked a right-lateralized N400 effect in the N400 and P600 time windows. Prosodic effects emerged within the P600 window, where incongruent prosody in Pr−TF+ and Pr−TF− sentences elicited a right-lateralized sustained negativity relative to sentences with congruent prosody (Figure 5A). Thus, the IWAAs showed some sensitivity to incongruent prosody and implausibility in the form of semantic integration difficulty (N400 effects), but did not engage in syntactic reanalysis (absence of P600 effects). In contrast, in the IWBAs both sentence types with incongruent prosody (Pr−TF+ and Pr−TF−) evoked a positivity in the 300–600ms epoch. This positivity was sustained throughout the 600–1200ms epoch in Pr−TF+ sentences (Figure 5B). The absence of N400 and P600 effects suggests that IWBAs were not able to detect and repair incongruent prosody in the same manner as the healthy controls.

3.3. Question 3: Do individuals with aphasia show sensitivity to prosody and plausibility manipulations at the sentence-final word?

ERPs time-locked to the sentence-final word in each condition were compared. The statistically significant effects and interactions are listed in Table 3 for between-group analyses and Table 6 for within-group analyses. In both the age-matched controls and all individuals with aphasia, incongruent prosody (Pr−TF+, Pr−TF−) resulted in sentence-final negativities, that were largest in the right-hemisphere. These sentence-final negativities were significant across both the 300–600ms and 600–900ms time windows in controls, but were delayed in the individuals with aphasia as they only emerged in the 600–900ms window. Also, visual inspection indicated that in age-matched controls, Pr−TF− sentences, with both a prosodic and plausibility violation, elicited the largest negativity. Overall, the amplitude of these effects was smaller with a more posterior distribution in the group of individuals with aphasia. Moreover, analyses of the subgroups of individuals with aphasia revealed distinct sentence-final negativity effects between the IWAA and IWBA groups. Specifically, only Pr−TF− sentences elicited a sentence-final negativity in IWAAs, and it was only sustained during the early time window (300–600ms). Whereas in the IWBAs, sentence-final negativities were elicited by both sentences with incongruent prosody (Pr−TF+, Pr−TF−), but only in the later time window (600–900ms). This suggests that IWAAs only show sensitivity to prosodic violations when they are paired with a plausibility cue (Pr−TF−). In contrast, IWBAs show sensitivity to prosodic violations (Pr-TF+, Pr-TF-), even in the absence of plausibility cues, but in a delayed manner relative to healthy controls.

4 Discussion

4.1 Question 1: Can individuals with aphasia use plausibility cues to predict syntactic structure?

In this study we investigated the effects of prosody and thematic fit/plausibility on sentence processing using ERPs in a group of individuals with aphasia and an age-matched controls. In the age-matched control group we predicted finding significant N400 and P600 effects in the comparison between the implausible NP (*the beer*) and the plausible NP (*the song*) in sentences with incongruent prosody:

[While the band played the song] [pleased all the customers.] (Pr−TF+)

[While the band played the beer] [pleased all the customers.] (Pr−TF−)

Recall that the NP occurring after the subordinate verb *played* is structurally ambiguous; it can either serve as the direct object of *played*, or the subject of a matrix clause, as in all of the experimental sentences in this experiment. In Pr−TF− sentences the NP *the beer* is a poor thematic fit as the direct object of *played*, which may provide plausibility information to the parser that *the beer* is the subject of the upcoming main clause (the correct interpretation). However, in Pr−TF+ sentences, *the song* is a good thematic fit with the subordinate verb *played*, thus no plausibility cue is present to signal the correct syntactic structure. We found a significant N400-P600 complex in the controls, suggesting that the poor thematic fit between *played* and *the beer* resulted in semantic integration difficulty (indexed by the N400) that triggered the parser to engage in syntactic reanalysis (indexed by the P600) to build or choose the correct syntactic structure. It is possible this P600 effect is similar to the semantic P600 described by Kuperberg (2013), which is elicited by event prediction errors.

Within the group of individuals with aphasia, we predicted delayed N400 and P600 effects for this comparison in the IWAA group, based on the findings from DeDe (2012) where individuals with aphasia presenting with anomia displayed processing delays. For the IWBA group we predicted a delayed N400 but no P600 effect. In the group of all individuals with aphasia we found evidence of a small N400 effect, but no P600 effect. However, analyses of the aphasia subgroups revealed significant N400 and P600 effects for the IWAAs, but only a positivity in the 300–600ms time window (the N400 window) for the IWBAs. These results suggest that both the age-matched controls and the IWAAs were sensitive to thematic fit information and were able to use plausibility cues to engage in syntactic reanalysis before reaching the critical verb. The participants in the IWBA group in our study do not show this same sensitivity and are not able to use plausibility and prosodic cues in the same manner as controls and IWAAs.

These results demonstrate that the IWAAs, those primarily with word-finding difficulties, have retained the ability to immediately capitalize on plausibility cues during on-line processing to aid structure building, whereas the IWBAs with Broca's aphasia have lost this ability. Recall that previous studies using off-line methods have found that individuals with various subtypes of aphasia often capitalize on plausibility cues to aid sentence comprehension, particularly in sentences with more complex syntax (Caramazza & Zurif, 1976; Gibson et al., 2015; Saffran et al., 1998). Yet, our results demonstrate that individuals with Broca's aphasia who have a comprehension deficit do not integrate plausibility information with syntactic structure building on-line. Thus, in light of our findings it is likely that the results from previous off-line studies examining the impact of plausibility on sentence processing reflect compensatory strategies used by individuals with Broca's aphasia to aid **final** sentence comprehension.

Additionally, while N400 and P600 effects were revealed in both the controls and IWAAs, visual inspection revealed the N400 effect had a different distribution between these two groups. Specifically, the N400 in the controls was widely distributed across the scalp, but was constrained primarily to central and posterior sites in the IWAAs. Given the relatively opaque relations between scalp electrode placements and the neural generators responsible for the EEG patterns (Luck, 2014), we tentatively suggest that the N400 effect had a smaller distribution on the scalp in the IWAAs due to compensatory mechanisms that utilized slightly different neural generators compared to the controls.

4.2 Question 2: Does incongruent prosody result in garden-path effects at the critical verb?

Our next set of analysis compared all four sentence types at the critical verb, *pleased*:

[While the band played] [the song pleased all the customers.] (Pr+TF+)

[While the band played] [the beer pleased all the customers.] (Pr+TF−)

[While the band played the song] [pleased all the customers.](Pr−TF+)

[While the band played the beer] [pleased all the customers.] (Pr−TF−)

The critical verb (*pleased*) is the point in the sentence where, regardless of preceding prosodic and lexical-semantic cues, it becomes clear that the NP (*the song/the beer*) is the subject of the verb *pleased*. In both the controls and group of IWAA we predicted we would find N400 and P600 effects Pr−TF+ sentences where both prosodic and plausibility cues would bias the listener toward the incorrect parse. We did not expect to find N400 or P600 effects in Pr−TF− sentences where plausibility cues at *the beer* in Pr−TF− would bias the listener toward the correct parse before reaching the critical verb. In other words, because we anticipated finding a biphasic N400-P600 at *the beer* in Pr−TF− sentences, we did not expect to find another N400-P600 complex at *pleased*. In the group of IWBA, we anticipated finding N400 but not P600 effects at the critical verb because the P600 component is an index of syntactic processing and these individuals have particular difficulty processing sentences with complex syntax (Friedmann & Shapiro, 2003; Grodzinsky, 1989, 2000a, 2000b).

Our predictions for the controls were confirmed. In the age-matched controls we found an N400-P600 complex in the Pr−TF+ sentences, but only an N400 in the Pr−TF− sentences. This same pattern was revealed in the group of all individuals with aphasia. We also found differences in scalp distribution between the control group and the group of all individuals with aphasia for the N400 and P600 effects. The N400 effect elicited by incongruent prosody was primarily distributed at left-lateralized and midline posterior sites in controls, but was right-lateralized at posterior sites in the individuals with aphasia. The P600 in Pr −TF+ sentences was distributed bilaterally in controls, but in the left-hemisphere in individuals with aphasia. This difference in scalp distribution suggests that the underlying neural generators contributing to the N400 and P600 effects are different in controls and individuals with aphasia. Again, this could result from compensatory strategies utilizing different cortical regions during sentence comprehension in individuals with aphasia.

More to the point of our investigation, examination of the subgroups of individuals with aphasia revealed distinct ERP patterns between the IWAA and IWBA groups. For the IWAA group, we found evidence of a delayed N400 effect but no P600 effect in Pr−TF+ sentences (incongruent prosody without a plausibility cue) at the critical verb (*pleased*). Thus, the IWAAs were not sensitive to the prosody-driven garden-path effect in sentences without plausibility cues. However, in Pr−TF− sentences (incongruent prosody paired with a strong plausibility cue) we did find a sustained N400 effect that emerged in the N400 time window and continued throughout the P600 time window. The lack of sensitivity to prosodic errors when plausibility cues were absent was surprising given that the IWAA group presented primarily with a word finding deficit. It is likely that in typical sentence processing, both plausibility and prosody are important cues to comprehension (as observed with our group of control participants here and in Sheppard et al., submitted). Yet for our IWAA group of individuals with aphasia, a trade-off is occurring whereby plausibility takes preference over prosody. Unfortunately we cannot be sure of this possibility given the current study, and so further investigations are warranted.

Furthermore, while we did not find evidence of a P600, required for syntactic reanalysis, at the critical verb in IWAAs, in the IWBAs both sentence types with incongruent prosody (Pr −TF+, Pr−TF−) elicited a sustained positivity in the N400 and P600 time windows. This went against our predictions of finding an N400 effect at the critical verb in this group. This sustained positivity likely does not reflect a true P600 effect because it begins in the 300–600ms epoch before a typical P600 is predicted to occur. Kielar and colleagues (2012) found a similar pattern in a group of participants with agrammatic aphasia, a group similar to our IWBA group. In Kielar et al., verb argument structure violations elicited a biphasic N400-P600 in controls but only a P600 effect in individuals with agrammatic aphasia. They interpreted these results to suggest that comprehension difficulties in agrammatic aphasia may be caused by incomplete access to verb lexical information, and impairments in integrating lexical information with the preceding sentence context (see also Choy & Thompson, 2010; Mack, Ji, & Thompson, 2013; Thompson & Choy, 2009). The lack of N400 and P600 effects in the IWBA group in the current study suggests they have difficulty integrating prosodic information with lexical information, even when plausibility cues are present.

4.3 Question 3: Do individuals with aphasia show sensitivity to prosody and plausibility manipulations at the sentence-final word?

For our analyses at the sentence-final word (*customers*) we anticipated we would find a sustained sentence-final negativity that extends beyond the traditional N400 time window in the age-matched controls to both sentences with incongruent prosody (Pr−TF+, Pr−TF−). We predicted this effect would be present, but delayed, in both subgroups of individuals with aphasia. We also anticipated the effect would have a larger amplitude in the IWAAs relative to the IWBAs. Our predictions for the age-matched controls were confirmed. Additionally, in the group of all individuals with aphasia a delayed sustained negativity was revealed, with a more posterior distribution compared to the negativity in the healthy controls. This scalp distribution difference is likely due to the brain damage underlying these patterns. Furthermore, the IWAA and IWBA groups differed at the sentence-final word. The IWAAs evinced an attenuated negativity, only to Pr−TF− sentences, that was only present in the early time window. In contrast, sentence-final negativities were elicited by both sentences with incongruent prosody (Pr−TF+, Pr−TF−) in the IWBAs, but only in the later time window. Thus, while the IWBAs did not show typical N400 or P600 effects at the ambiguous NP or critical verb, they show a delayed sensitivity to prosodic violations at the sentence-final word. These findings coincide with Swaab et al. (1997) who found that a group of individuals with aphasia with a moderate-severe comprehension impairment exhibited attenuated and delayed N400 effect to lexical-semantic violations at the sentence-final word. Moreover, this delayed sensitivity to lexical-semantic and prosodic information is similar to the delayed lexical access observed during online sentence comprehension in studies examining participants with agrammatic Broca's aphasia (Ferrill et al., 2012; Love, Swinney, Walenski, & Zurif, 2008). It is possible that individuals with Broca's aphasia with a comprehension deficit may have a processing delay that impacts multiple sources of information, in this case both lexical-semantic and prosodic processing. Since sentence processing likely involves the activation (and sometimes re-activation) of different information types that must be synchronized during the unfolding of the sentence, a deficit in timing would likely result in an off-line sentence comprehension disorder of the sort sometimes observed in Broca's aphasia (see, for example, Ferrill et al., 2012; Love et al., 2008).

4.4 Summary

These patterns, taken together, suggest that our age-matched controls could repair the syntactic structure before the critical verb when thematic fit/plausibility cues were available at the ambiguous NP, indicated by the N400-P600 complex at *the beer* in Pr−TF− sentences. Furthermore, they showed evidence of engaging in syntactic reanalysis, indicated by the N400-P600 complex at the critical verb in classic garden-path sentences where thematic fit/plausibility information wasn't available to help predict upcoming syntactic structure (Pr−TF+ vs. Pr−TF−). Finally, the presence of a sustained N400 effect to the final-word in sentences with incongruent prosody (Pr−TF+, Pr−TF−) provides more evidence that the age-matched controls were sensitive to the prosody violation.

Similar to the age-matched controls, the IWAAs were able to detect a lexical-semantic violation and engage in syntactic reanalysis (N400-P600 complex) when encountering a thematic fit violation at *the beer* in Pr−TF− sentences. However, the classic garden-path comparison between Pr−TF+ and Pr+TF+, without a plausibility cue, only elicited a delayed N400 with no evidence of a P600 in the IWAAs. Hence, we assume that the IWAAs can immediately identify a thematic fit violation and engage in syntactic reanalysis, but when there is no plausibility cue to help predict upcoming syntactic structure, syntactic reanalysis is not observed. Even in the analyses of sentence-final words, only the condition with incongruent prosody and an implausible NP (Pr−TF−) elicited an N400 effect, suggesting that these participants did not detect the prosody-driven garden-path violation (Pr−TF+) even at the end of the sentence. Accordingly, IWAAs are able to use plausibility cues to predict upcoming syntactic structure, yet they are not able to detect or resolve syntactic ambiguities resulting from incongruent prosody alone. Thus, though these participants evinced a relatively minor comprehension deficit on testing with a sentence-picture matching exam (i.e., the SOAP, see Table 2), a detailed on-line analyses using ERPs suggests a nuanced disorder that affects the ability to integrate prosodic and lexical-semantic information during auditory sentence processing.

The IWBAs did not show evidence of N400 or P600 effects resulting from the thematic fit violation at *beer* in Pr−TF− sentences or from the garden path violation at the critical verb *pleased* in Pr−TF+ sentences. Even so, sustained positivities were elicited at the ambiguous noun phrase *beer* in Pr−TF− sentences and at the critical verb in both sentences with incongruent prosody (Pr−TF+, Pr−TF−). It is unlikely these positivities reflect true P600-like syntactic reanalysis as they had an earlier onset than a traditional P600 effect, although it is possible they reflect error perception but not repair processes. Moreover, the delayed sentence-final negativities in both sentences with incongruent prosody suggest that delayed processing likely accounts for a portion of the comprehension deficits in the IWBAs.

Finally here, we consider some of the limitations of the present study. There was a relatively small number of subjects within the IWAA and IWBA groups. Additionally, the groups were unequal in size, which prevented us from conducting direct statistical comparisons between these two groups. Because inter-participant variability is inherent in individuals with aphasia, it is important that the questions in our study are addressed with a larger number of participants. Furthermore, our study was not designed to specifically examine brain-language relations as we did not control for or investigate the location and extent of lesions in our participants with aphasia. Future work should consider lesion data, as they are likely to contribute to both on-line and off-line sentence comprehension performance.

5 Conclusions

We manipulated both prosodic and plausibility cues in sentences containing temporary syntactic ambiguities, and examined the ERPs in a group of healthy age-matched controls and a group of individuals with aphasia. We also examined how the “type” of aphasia (anomia vs Broca aphasia) as well as severity of the comprehension deficit in individuals with aphasia would impact their sensitivity to these manipulations by examining separately ERPs in the two groups.

While the IWAAs evinced on-time semantic integration difficulty (N400) and subsequent syntactic reanalysis (P600) in the condition with incongruent prosody and a plausibility cue at the ambiguous NP, they did not show similar sensitivity at the critical verb to sentences with a prosodic violation but no plausibility cue. In contrast, there was no evidence of semantic integration difficulty (N400) or syntactic reanalysis (P600) in either comparison in the IWBAs. Yet, both of these manipulations did produce a delayed sentence-final negativity in the IWBAs. Therefore, while the IWBAs did exhibit delayed sensitivity to prosodic and thematic fit/plausibility violations, they lacked the ability to engage in immediate semantic integration and subsequent syntactic repair to resolve these violations in the same way as the age-matched controls.

Overall the results suggest that individuals with aphasia who have a less severe comprehension deficit are able to capitalize on thematic fit/plausibility cues to predict and repair syntactic structure, but when lexical-semantic information is not available they are not able to predict and repair syntactic structure. In contrast, individuals who have a Broca's aphasia with a more severe comprehension deficit reveal a delayed sensitivity to prosodic and thematic fit violations, and cannot capitalize on lexical-semantic information to aid syntactic repair and thus final comprehension. Thus, these individuals appear to have difficulty integrating both prosodic and lexical-semantic cues with syntactic structure, partially due to a processing delay. One exciting possibility is that some individuals with aphasia have a pervasive processing delay that generalizes across different types of information, yielding a sentence comprehension deficit.

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Highlights

- Sentence processing ERPs show prosodic/semantic cues interact in healthy controls
- Comprehension deficit severity in aphasia impacts prosodic/semantic cue integration
- Individuals with anomic aphasia require semantic cues for cue integration
- A processing delay was revealed in individuals with Broca's aphasia

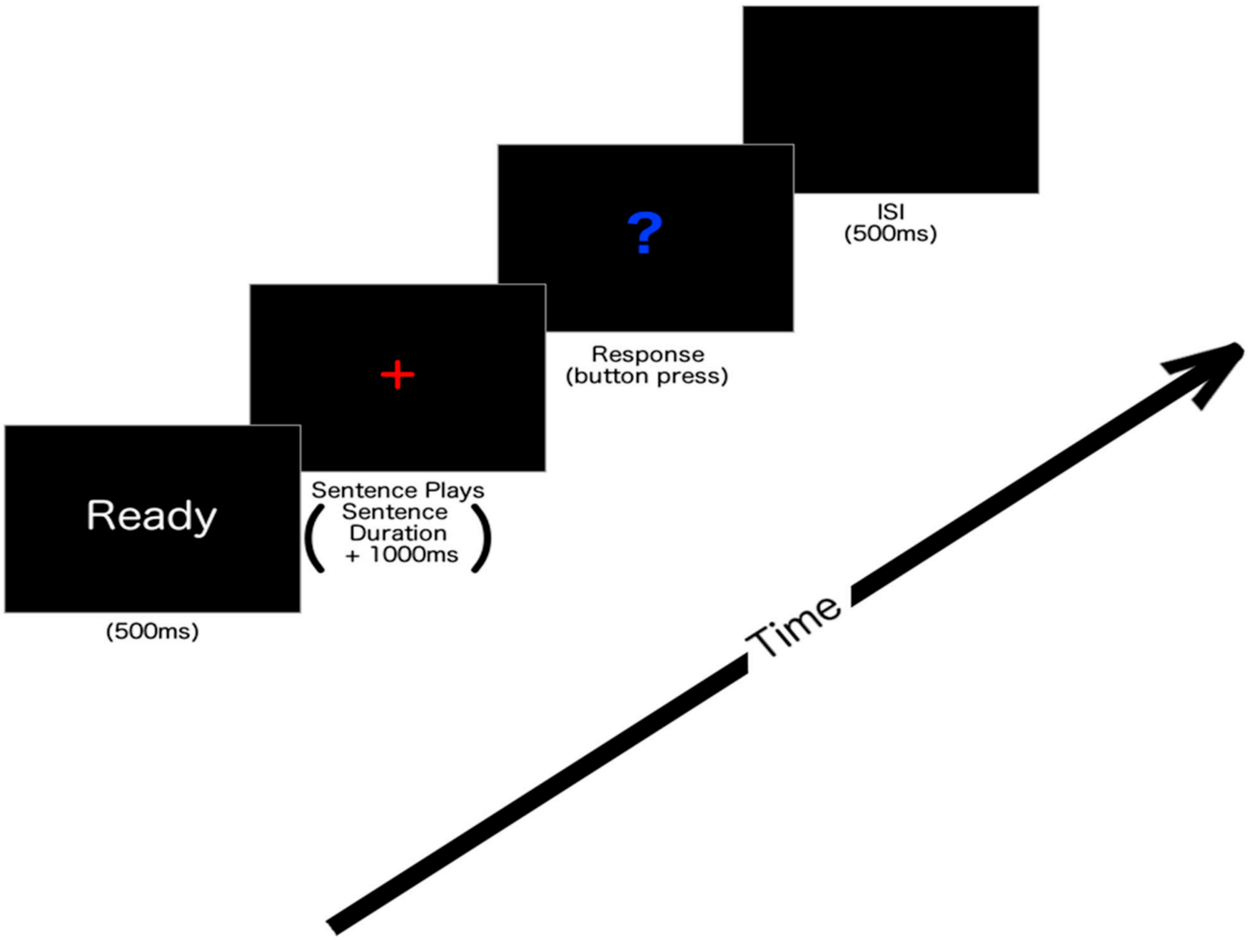

Figure 1.
Schematic of one trial. Participants were presented with the word "Ready" in the center of the screen to signal the beginning of a new trial. Next, a red cross was presented in the center of the screen, which corresponded with the sentence playing. The red cross remained on the screen throughout the sentence duration up to 1000ms after the sentence ended. A blue question mark was presented to signal that the participant could make their acceptability

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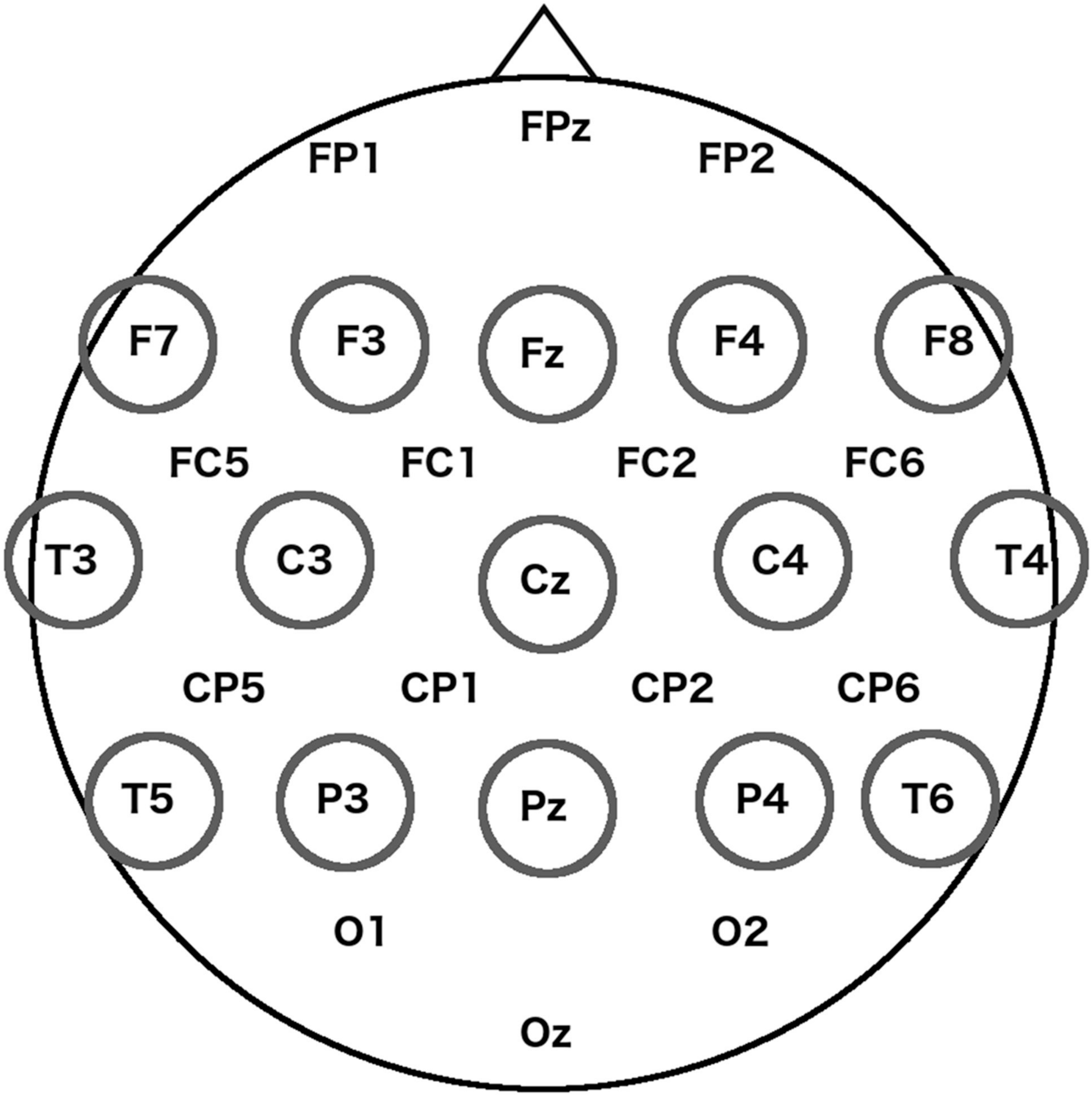

Figure 2.

Electrode montage. The circled electrodes indicate the 15 electrodes used in data analysis.

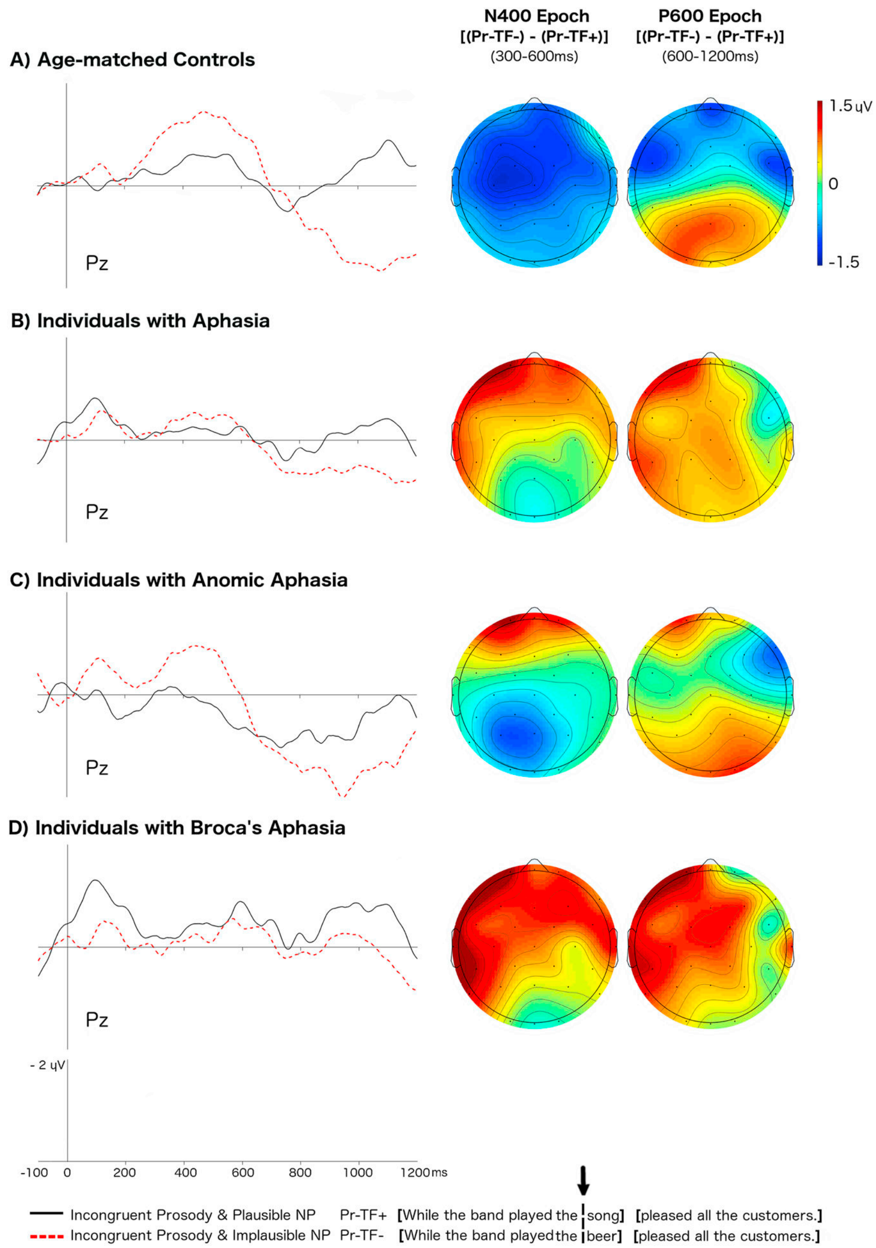

Figure 3.

Grand average ERPs and voltage maps of the N400 epoch (300–600ms) and P600 epoch (600–1200ms) at the onset of the ambiguous NP (*song/beer*) in conditions with incongruent prosody (Pr−TF+, Pr−TF−) in A) age-matched controls, B) all of the individuals with aphasia, C) IWAA, and D) IWBA. Voltage maps depict the scalp distribution of the difference waves (incongruent – congruent prosody) in each epoch. The plausibility cue present in the implausible NP (*beer*) in Pr−TF− vs. Pr−TF+ sentences elicited a significant N400-P600 complex in age-matched controls. A small N400 effect, but no P600 effect, was found in the overall group of individuals with aphasia. Although, analyses of the subgroups of individuals with aphasia revealed significant N400 and P600 effects in the IWAA group, but no evidence of either N400 or P600 effects in the IWBA group.

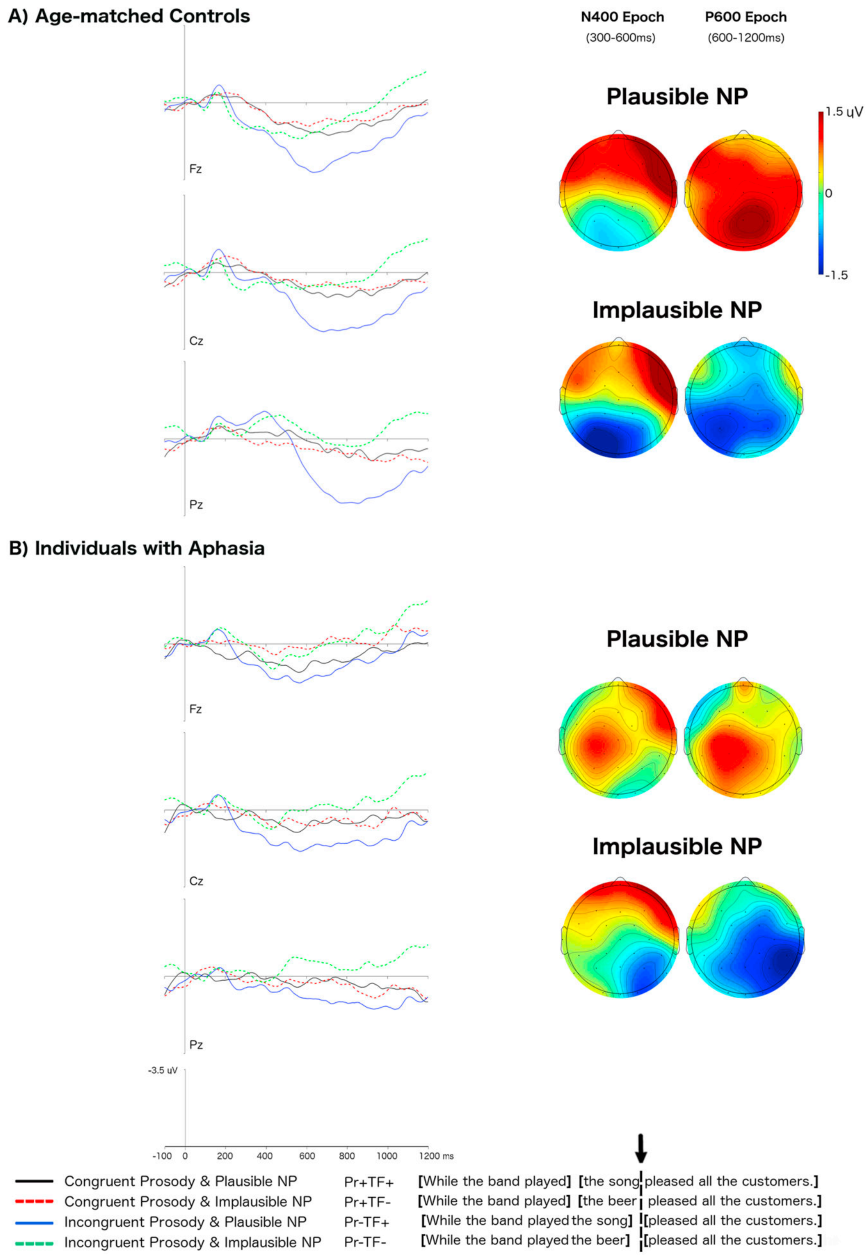

Figure 4.

Grand average ERPs and voltage maps of the N400 epoch (300–600ms) and P600 epoch (600–1200ms) at the onset of the critical verb (*pleased*) in A) age-matched controls, and B) individuals with aphasia. Voltage maps demonstrate the scalp distribution of the difference waves (incongruent – congruent prosody) in conditions with a plausible NP (*song* in Pr−TF+ vs. Pr+TF+) and an implausible NP (*beer* in Pr−TF− vs. Pr+TF−) in each epoch. In the age-matched controls and individuals with aphasia, both sentences with incongruent prosody (Pr−TF+ and Pr−TF−) elicited an N400 effect, while a P600 effect was only revealed in Pr−TF+ sentences.

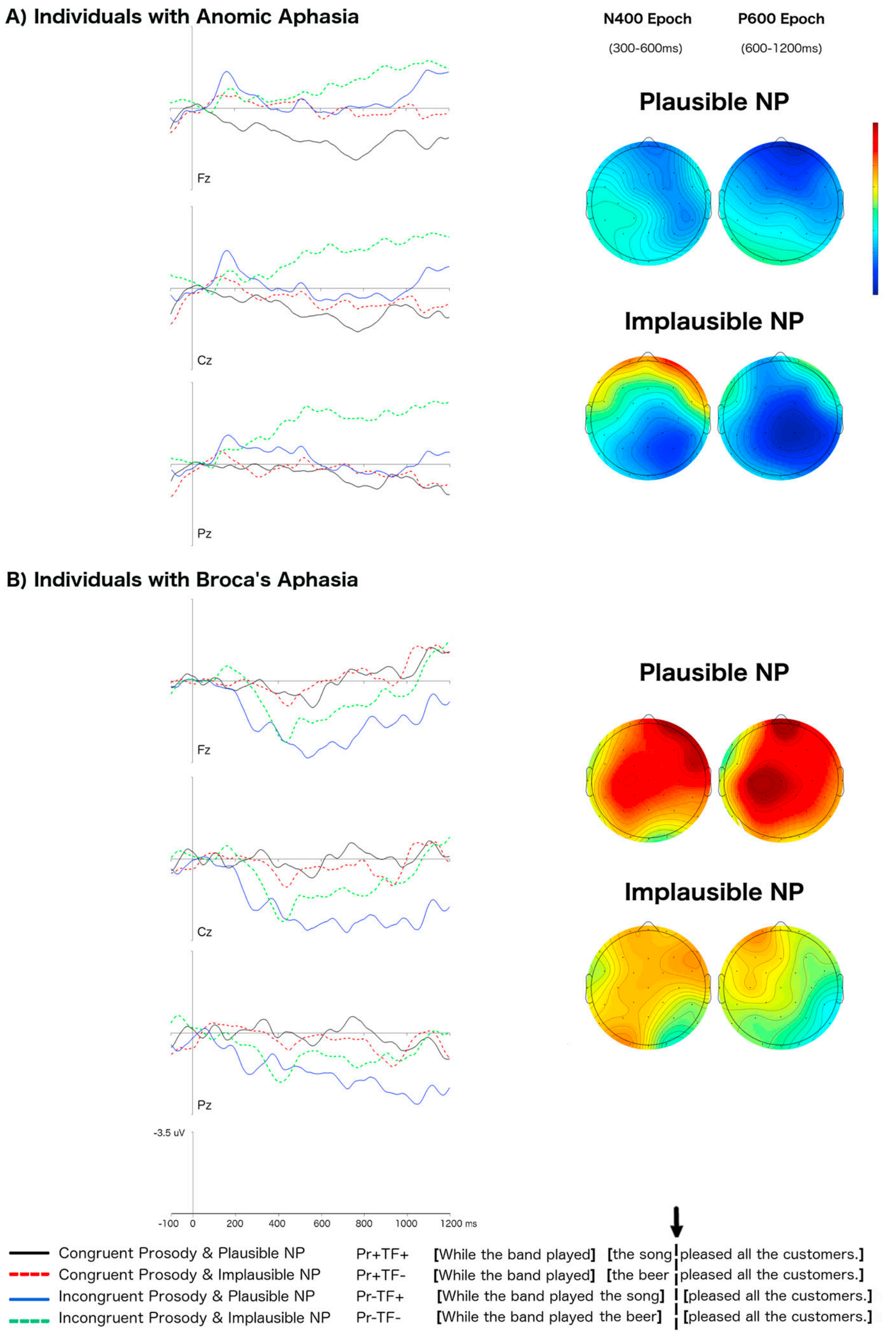

Figure 5.

Grand average ERPs and voltage maps of the N400 epoch (300–600ms) and P600 epoch (600–1200ms) at the onset of the critical verb (*pleased*) in the A) IWAA group, and the B) IWBA group. Voltage maps demonstrate the scalp distribution of the difference waves (incongruent – congruent prosody) in conditions with a plausible NP (*song* in Pr−TF+ vs. Pr+TF+) and an implausible NP (*beer* in Pr−TF− vs. Pr+TF−) in each epoch. In IWAAs, the implausible NP *beer* elicited a right-lateralized N400 effect in both the 300–600 and 600–1200ms time windows, whereas incongruent prosody (Pr−TF+ and Pr−TF−) evoked a negativity in the 600–1200ms window. Both types of sentences with incongruent prosody (Pr−TF+, Pr−TF−) elicited a sustained positivity across both time windows in the IWBAs.

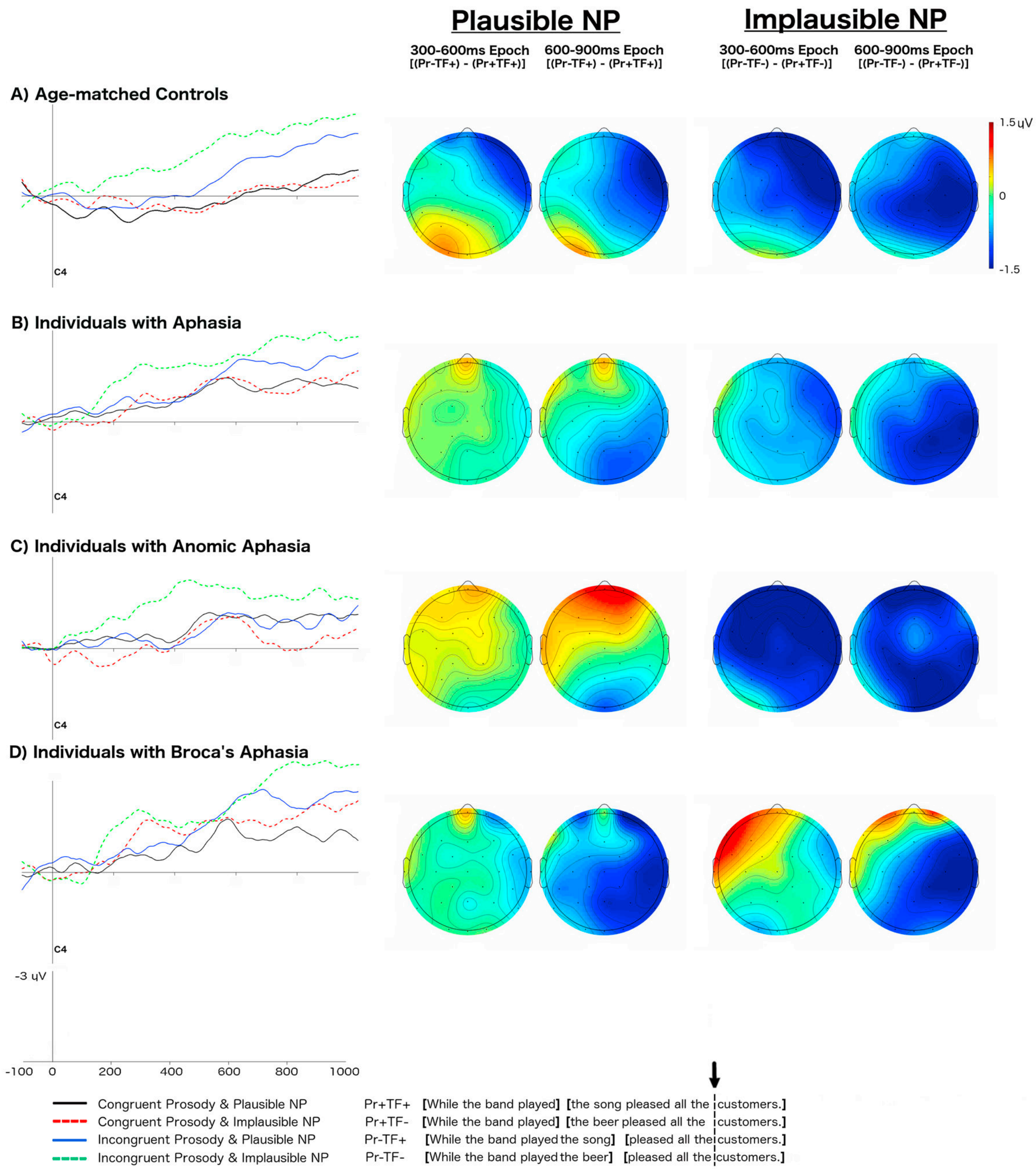

Figure 6.

Grand average ERPs and voltage maps time locked to the onset of the final word across all four conditions. Two epochs are shown (300–600ms and 600–900ms) in A) age-matched controls, B) all of the individuals with aphasia, C) IWAAs, and D) IWBAs. The voltage maps depict the scalp distribution of the difference waves (incongruent – congruent prosody) in conditions with a plausible NP [*song* in (Pr−TF+) – (Pr+TF+)] and an implausible NP [*beer* in (Pr−TF−) – (Pr+TF−)] in each epoch. Sentences with incongruent prosody elicited a sustained negativity effect at the final word in both the 300–600ms and 600–900ms epochs in the age-matched controls, while delayed negativities were revealed in these sentences in the individuals with aphasia in the 600–900ms epoch. Only sentences with incongruent prosody and an implausible NP (Pr−TF−) elicited a significant sustained negativity effect in the 300–600ms epoch in IWAAs. Sentences with incongruent prosody (Pr−TF+, Pr−TF−) elicited a delayed negativity in the 600–900ms epoch in the IWBAs.

Table 1.

Example sentences.

Sentence	**Prosody (Pr)**	**Plausibility / Thematic Fit (TF)**	**Condition**
9a. **[**While the band played**] [**the song pleased all the customers.**]**	Congruent (+)	Plausible (+)	Pr+TF+
9b. **[**While the band played**] [**the beer pleased all the customers.**]**	Congruent (+)	Implausible (−)	Pr+TF−
9c. **[**While the band played the song**] [**pleased all the customers.**]**	Incongruent (−)	Plausible (+)	Pr−TF+
9d. **[**While the band played the beer**] [**pleased all the customers.**]**	Incongruent (−)	Implausible (−)	Pr−TF−

Table 2.

Aphasia Participant Information.

Participant	Group	Sex	BDAE	Years Post-Stroke	Lesion Location	Age at Testing (Years)	Education Level	SOAP: Overall Score
LHD017	Anomia (IWAA)	M	4	17.5	Large lesion involving frontal cortical region & deeper BG structures	58	2 years of college	100%
LHD139	Anomia (IWAA)	M	3	16.5	L MCA infarct	40.5	Some college	67.5%
LHD142	Anomia (IWAA)	M	4	6	L MCA infarct	76.5	8th grade	72.5%
LHD151	Anomia (IWAA)	F	4	6.5	L caudate nucleus, putamen, ventrolateral thalamus & posterior limb of L internal capsule	63.5	4 years college	95%
LHD159	Anomia (IWAA)	F	3	5.5	Large L parietal lobe & L frontoparietal lobe	62	College	95%
LHD191	Anomia (IWAA)	M	4.5	1.5	L MCA infarct	56	Master’s degree	90%
LHD009	Broca’s Aphasia (IWBA)	M	3	15	Large L lesion involving IFG (BA 44, 45)	54	1 yr. grad school	55%
LHD101	Broca’s Aphasia (IWBA)	M	2	9	Large L lesion involving posterior IFG (BA44) with posterior extension	65	Ph.D.	57.5%
LHD130	Broca’s Aphasia (IWBA)	M	4	8	L IPL with posterior extension sparing STG	62	4 years college	65%
LHD138	Broca’s Aphasia (IWBA)	M	2	17.5	L MCA infarct	37	Some college	52.5%
LHD140	Broca’s Aphasia (IWBA)	F	2	15.5	L MCA infarct Secondary to occlusion of L proximal CA	39.5	4 years college	42.5%
LHD169	Broca’s Aphasia (IWBA)	M	1	4	L MCA infarct with small areas of acute infarction at margins of encephalo-malacia	58	High School	60%
LHD175	Broca’s Aphasia (IWBA)	F	3.5	7.5	L MCA infarct	60	Some college	47.5%
LHD176	Broca’s Aphasia (IWBA)	F	3	2	L IFG & L BG	50	College	45%
LHD189	Broca’s Aphasia (IWBA)	M	2	7.5	L MCA infarct	57	Master’s degree	25%

Note. BDAE = Boston Diagnostic Aphasia Examination (0 = no usable speech or auditory comprehension, 5 = minimal discernable speech handicap); SOAP (Subject-relative Object-relative Active and Passive Test of Auditory Sentence Comprehension)

L = left; BA = Brodmann area; IPL = inferior parietal lobule; STG = superior temporal gyrus; MCA = middle cerebral artery; CA = cerebral artery; CVA = cerebrovascular accident; IFG = inferior frontal gyrus.

Table 3.

Statistically significant results of analyses performed on the mean amplitude of ERP waveforms in all between-group analyses at the ambiguous NP (*song/beer*), the critical verb (*pleased*), and the final word (*customers*) of age-matched controls (n = 20) vs. individuals with aphasia (n = 15). *p* values in parentheses.

While the band played	the song / the beer	pleased	all the	customers.
	(Ambiguous NP)	***(Critical Verb)***		***(Final Word)***
N400 (300–600ms):	G × TF (**.002** **) G × TF × A (**.014** *)	G × Pr × A (**.038** *) G × Pr × L (**.038** *) G × Pr × A × L (**.013** *)		N/A
P600 (600–1200ms):	G × TF × A (**.003** **)	G × Pr × A × L (**.008** **)		N/A
Early Negativity (300–600ms):	N/A	N/A		---
Late Negativity (600–900ms):	N/A	N/A		G × Pr × A (**.014** *)

Note.

* ≤ .050,

** ≤.010,

*** ≤.001

G = Group; Pr = Prosody; TF = Thematic Fit; A = Anteriority; L = Laterality

Table 4.

Statistically significant results of within-group analyses performed on the mean amplitude of ERP waveforms between experimental sentences at the temporarily ambiguous NP (*song/beer*) in all experimental groups. *p* values in parentheses.

		Age-Matched Controls (N = 20)		**Individuals with Aphasia (N = 15)**
Ambiguous NP				
N400 (300–600ms		TF (**.003** **)		TF × A (**.005** *)
P600 (600–1200ms)		TF × A (< **.001** ***)		---
		Individuals with Aphasia (IWA) (N = 15)		
		Individuals with Anomic Aphasia (IWAA) (n = 6)		Individuals with Broca's Aphasia (IWBA) (n = 9)
Ambiguous NP				
N400 (300–600ms)		TF × A (**.026** *)		TF (**.050** *)†
P600 (600–1200ms)		TF × A (**.049** *)		---

Note.

* < .050,

** ≤ .010,

*** ≤.001

TF = Thematic Fit; A = Anteriority

† effect is in opposite direction (i.e., waveforms in Pr−TF− sentences were significantly more positive)

Table 5.

Statistically significant results of within-group analyses performed on the mean amplitude of ERP waveforms between experimental sentences at the critical verb (*pleased*) in all experimental groups. *p* values in parentheses.

	Age-Matched Controls (N = 20)	**Individuals with Aphasia (N = 15)**
Critical Verb		
N400 (300–600ms)	Pr × L (**< .001*****) Pr × A (**< .001*****)	Pr × A × L (**.001*****)
P600 (600–1200ms)	Pr × TF (**.006****) Pr × TF × A (**.005****) Pr × A × L (**.008****) TF (**.020***) TF × L (**< .001*****)	Pr × TF × L (**.026***) Pr × TF × A (**.008***) TF × L (**.014***)
	Individuals with Aphasia (N = 15)	
	Individuals with Anomic Aphasia (IWAA) (n = 6)	Individuals with Broca's Aphasia (IWBA) (n = 9)
Critical Verb		
N400 (300–600ms)	TF × L (**.003****)	Pr × A × L (**.005****)†
P600 (600–1200ms)	Pr (**.034***) Pr × L (**.043***) TF (**.010****) TF × L (**.021***)	Pr × TF × L (**.019***)

Note.

* < .050,

** ≤ .010,

*** ≤.001

Pr = Prosody; TF = Thematic Fit; A = Anteriority; L = Laterality

†effect is in opposite direction (i.e., waveforms in Pr−TF+ and Pr−TF− sentences were significantly more positive)

Table 6.

Statistically significant results of within-group analyses performed on the mean amplitude of ERP waveforms between experimental sentences at the final word (*customers*) in all experimental groups. *p* values in parentheses.

		Age-Matched Controls (N = 20)		**Individuals with Aphasia (N = 15)**
Final Word				
Early Sustained Negativity (300–600ms)		Pr (**.005** **) Pr × A (**.003** **) Pr × L (**< .001** ***) TF (**.017** *)		---
Late Sustained Negativity (600–900ms)		Pr (**< .001** ***) Pr × L (**.001** ***)		Pr × L (**.050** *)
		Individuals with Aphasia (N = 15)		
		Individuals with Anomic Aphasia (IWAA) (n = 6)		Individuals with Broca's Aphasia (IWBA) (n = 9)
Final Word				
Early Sustained Negativity (300–600ms)		Pr × TF (**.031** *)		---
Late Sustained Negativity (600–900ms)		---		Pr × A (**.027** *)

Note.

* < .050,

** ≤ .010,

*** ≤.001

Pr = Prosody; TF = Thematic Fit; A = Anteriority; L = Laterality