ABSTRACT

Title of Thesis:	AUTOMATIC SYNTACTIC PROCESSING IN AGRAMMATIC APHASIA: THE EFFECTS OF GRAMMATICAL VIOLATIONS
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This study aimed to examine syntactic processing in agrammatic aphasia. We hypothesized that agrammatic individuals' automatic syntactic processing would be preserved, as measured by word monitoring task, and their knowledge of syntactic constraints would be impaired, as measured by sentence judgment task, and their performance would vary by type of syntactic violation. The study found that the sentence processing in agrammatism differed based on the type of violation in both tasks: preserved for semantic and tense violations and impaired for word category violations. However, there was no correlation between the two tasks. Furthermore, single-subject analyses showed that automatic syntactic processing for word category violations does not seem to be impaired in aphasia. Based on the findings, this study supports that knowledge of syntactic constraints and automatic processing may be relatively independent abilities which are not related. Findings suggest that individuals with agrammatic aphasia may have preserved automatic syntactic processing.

AUTOMATIC SYNTACTIC PROCESSING IN AGRAMMATIC APHASIA: THE EFFECTS OF GRAMMATICAL VIOLATIONS

by

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Chapter 1: Introduction

There are two symptoms in aphasia indicating impaired syntax: agrammatic production and asyntactic comprehension. Agrammatism, a term that focuses on production in Broca's aphasia and non-fluent aphasia, is an expressive language deficit characterized by fragmented utterances and, reduced syntactic complexity, use of grammatical morphemes and verbs (Bastiaanse & Thompson, 2012; Berndt Mitchum, & Wayland, 1997; Goodglass, 1976; Kean, 1977; Saffran, Schwartz, & Marin, 1980). As the name implies, asyntactic comprehension refers to a pattern of greater difficulty in comprehending syntactically complex sentence, irrespective of sentence length (Caramazza & Zurif, 1976). While it seems intuitive that persons with agrammatic production would also have asyntactic comprehension due to a core or central syntactic impairment, agrammatic productions and asyntactic processing do not necessarily co-occur in aphasia. For example, Caramazza and Zurif (1976) found that individuals with conduction aphasia showed asyntactic comprehension but did not exhibit agrammatic production. It has also become obvious that not all Broca's aphasic persons present with asyntactic comprehension, and not all subjects with asyntactic comprehension also present with agrammatic production (Caramazza, Capasso, Capitani & Miceli, 2005).

Comprehension of sentences is a complex cognitive process: it requires successful auditory processing, rapid analysis of syntactic structures, and access to semantic representations. Further, these different subsystems interact on millisecond time scales (Friederici, 2002; Friederici & Kotz, 2003; Friederici, Pfeifer & Hahne, 1993; Hagoort, 2003; Kaan & Swaab, 2002). Evidence from studies using Event-Related

Potentials (ERP) has shown that sentence processing in neurotypical individuals is carried out through two parsing stages. The first stage operates quickly and automatically to assign an initial syntactic structure primarily based on syntactic word-category information, and the second stage includes thematic role assignment by mapping syntactic and lexical-semantic information (Friederici, 1995; Ferreira & Clifton, 1986). ERP studies suggest that sentence comprehension is achieved through these automatic processing stages, integrating syntactic and semantic information in time.

A number of studies have been conducted to understand the complex process of sentence comprehension and the nature of asyntactic comprehension in agrammatic individuals (Dickey & Thompson, 2009; Friederici et al, 1993; Grodzinsky, 1988; Wassenaar & Hagoort, 2005). It has been reported that agrammatic individuals show deficits in sentence comprehension in off-line tasks such as sentence to picture matching (Berndt et al., 1997; Goodglass, 1976; Kean, 1977; Saffran et al., 1980). However, some researchers have found that individuals with agrammatic aphasia may have preserved automatic syntactic processing using tasks such as cross-modal lexical priming and word monitoring (Prather, Zurif, Love & Brownell, 1997; Dickey & Thompson, 2009; Faroqi-Shah, Slevc, Saxena, Fisher & Pifer, 2019). They proposed that syntactic representation and automatic activation may be retained in aphasia, but the ability to operate on these activations is impaired. The evidence has been mixed on automatic syntactic processing in agrammatism; some studies have shown preserved automatic processing (Dickey & Thompson, 2009; Faroqi-Shah et al., 2019; Prather, Zurif, Love & Brownell, 1997; Wassenaar & Hagoort, 2005), while others have shown that it is impaired (Dickey, Choi

& Thompson, 2007; Prather, Zurif, Love & Brownell, 1997). Therefore, the current study aims to further investigate automatic syntactic parsing in individuals with agrammatic production. This research is important because it would clarify not only the integrity of syntactic processing in agrammatism, but also whether agrammatic production arises from a central core syntactic problem. The present study examined if automatic processing is preserved in agrammatic aphasia and if so, how different syntactic violations affect automatic processing.

In the following sections, a brief background on sentence comprehension and automatic processing in individuals with aphasia and neurotypical individuals will be provided, and possible hypotheses underlying asyntactic processing will be reviewed. Subsequently, different sentence types will be reviewed to understand their impact on sentence processing.

Automatic syntactic processing in aphasia

On-line tasks are typically used to measure automatic processing, where participants' performance is measured while they are performing tasks such as listening to or reading sentences. Event-related potentials (ERPs) and eye-tracking are frequently used as on-line measures, providing continuous records of the process. Another method used to examine automatic syntactic processing is measuring response time to sentences that do or do not have syntactic violations although the participants are not instructed to actively monitor for grammaticality. These tasks may use self-paced reading or auditory presentation of sentences. The idea is that participants respond more slowly at the point of syntactic violation because their brain is trying to resolve the ungrammaticality.

Impaired automatic processing in aphasia is indicated by diminished or delayed ERP responses or absence of response time differences between sentences with and without violations.

ERP studies in neurotypical adults show three types of ERP responses for sentence processing (Friederici & Kotz, 2003). Sentences with sematic violations (e.g., The book was despite replanted by a publisher) elicit N400 components suggesting that the semantic relations between words are processed at around this time (Holcomb & Neville, 1991; Kutas & Van Petten, 1994). Regarding syntactic processing, two ERP effects are especially relevant, which are an early left anterior negativity (ELAN) and the P600/Syntactic Positive Shift (SPS) (Friederici et al., 1993; Hagoort, Brown & Osterhout, 1999; Hahne and Friederici, 1999). ELAN effects have been observed in response to violations of word-category constraints, gender, and tense agreement (Münte, Heinze, Matzke, & Steitz, 1993), and P600/SPS effects have been elicited by a variety of syntactic violations (e.g., of phrase structure, verb subcategorization, number, and gender agreement) (Ainsworth, Darnell, Shulman & Boland, 1998; Coulson, King, & Kutas,1998; Hagoort, Brown, & Groothusen, 1993; Münte, Matzke, & Johannes, 1997). To summarize, an initial stage of local structure building is reflected by ELAN, a second stage of lexical-semantic processes is reflected by the N400, and a third stage involving processes of syntactic revision and integration is reflected by the P600 during sentence processing in neurotypical individuals (Friederici & Kotz, 2003).

To date, there are four studies that provide insights into automatic syntactic processing in agrammatic aphasia, two used ERP (Kielar, Meltzer-Asscher & Thompson,

2012; Wassenaar & Hagoort, 2005), one used eye-tracking (Dickey et al., 2007), and one used word monitoring (Faroqi-Shah et al., 2019). Wassenaar and Hagoort tested ERP responses in individuals with Broca's aphasia, non-aphasic individuals with a right hemisphere lesion, and neurotypical individuals. They presented sentences that included violations of word-category (e.g., The lumberjack dodged the vain *propelled* on Tuesday). Individuals with Broca's aphasia showed a very reduced and delayed P600/SPS effect in contrast to the two control groups who appeared sensitive to the violations. They concluded that individuals with Broca's aphasia were unable to detect on-line violations of word-category, resulting in a reduced P600 effect. The ERP study of Kielar et al. (2012) used sentences with verb argument structure violations and found that individuals with agrammatic aphasia showed a P600 but no N400 in contrast to the neurotypical group who showed a N400 followed by P600. The data from this study reported that agrammatic individuals did not demonstrate normal real-time sensitivity to verb argument structure requirements during sentence processing. The results of both ERP studies concluded that aphasic individuals with comprehension deficit presented delayed or reduced ERP responses in response to sentences with grammatical violations. However, it should be noted that Kielar et al. (2012) found that agrammatic individuals exhibited impaired N400 effect while processing sentences containing grammatical violations in contrast to the findings of Wassenaar and Hagoort's (2005) that showed limited P600 effect. Such inconsistent pattern of ERP effects between the studies may result from various factors. While Kielar et al.'s study used sentences with argument violations, Wassenaar and Hagoort used sentences with word-category violations. Additionally, the

participants in Kielar et al.'s study had Broca's aphasia and they used only a comprehension test to qualify their participants, whereas the participants in Wassenaar and Hagoort's study had agrammatic production. It is not clear that their different findings are due to the different stimuli or different participants. Therefore, further research is necessary in larger and specific group using various sentence stimuli.

Although the two ERP studies reported abnormalities in sentence processing in individuals with agrammatism, eye-tracking studies have found no significant impairments in sentence processing. Dickey et al. (2007) found that agrammatic individuals presented similar eye movement pattern as the neurotypical individuals in processing grammatically correct non-canonical sentences with wh- movement. They reported that the pattern differed only in the sentence's end, suggesting that agrammatic individuals may process wh- movement similarly to unimpaired individuals. Thompson et al. (2007) used sentences with verb argument structure violations which is the same grammatical conditions as Kielar et al.'s study. Again, their findings are not consistent in that while agrammatic individuals showed different ERP pattern from neurotypical's in Kielar et al.'s study (2012), Thompson et al. (2007). found that agrammatic individuals, showed similar eye movement patterns while processing sentences.

A word monitoring task can be also employed to measure on-line sentence comprehension by measuring response time to monitor for words in sentence that involve syntactic violations (Marslen-Wilson & Tyler, 1980). The critical measure in the word monitoring task is the word monitoring effect, which means difference in response time to sentences with and without syntactic violations. Faroqi-Shah et al. (2019), using a

word monitoring task, found that agrammatic individuals displayed the same pattern as neurotypical individuals, showing that agrammatic individuals demonstrated longer time to monitor for the target word in sentences with syntactic violations. Interestingly, even though all three groups' performance did not differ in the on-line word monitoring task, both non-agrammatic aphasic individuals and agrammatic individuals exhibited significantly reduced sensitivity in detecting anomalous sentences in an offline sentence judgment task. They found that agrammatic individuals showed the lowest performance among the three groups for off-line sentence judgment. Based on these findings, Faroqi-Shah et al. suggested that automatic processing in agrammatism may not be significantly impaired but preserved. The findings reported in Faroqi-shah et al.'s study are consistent with the eye-tracking studies (Dickey et al., 2007; Thompson et al., 2007) that found agrammatic individuals have spared performance on automatic sentence processing. However, this evidence contradicts the ERP studies (Kielar et al., 2012; Wassenaar & Hagoort, 2005) which found that automatic syntactic processing in agrammatism is delayed and impaired. The studies are summarized in Table 1.

It should also be noted that most of the studies cited here did not include a comparison group of non-agrammatic aphasic individuals. When an agrammatic group is compared with a neurotypical group, it is not clear if the abnormal findings are a general effect of brain injury or are specifically related to the symptom under study. In order to better understand the integrity of syntactic processes in individuals with agrammatic production, it is important to compare syntactic processing in two aphasic groups -those with and without agrammatic production. Unfortunately, out of the four studies which

examined automatic syntactic processing, only one study did this (Faroqi-Shah et al., 2019), the other three studies compared agrammatic versus neurotypical individuals.

Following up on the study of Faroqi-Shah et al. (2019) the current study proposed to examine whether automatic syntactic processing in agrammatism is preserved. Taking the discussion above, the current study compared performances on different grammatical violations to examine if the type of the violations can affect their performance.

Table 1.
Summary of sentence processing research on agrammatic aphasia automatic processing and off-line processing

	Participants	**Method**	**Stimuli**	**Results**
Dickey, Choy & Thompson (2007)	Agrammatism (12) Neurotypical (8)	Eye tracking	Wh-movement	Preserved; similar eye movement pattern other than the sentence's end)
Faroqi-Shah & Dickey (2009)	Agrammatism (10) Neurotypical (10)	On-line grammaticality judgment task	Morphosemantic & morphosyntactic tense violations	Preserved; lower performance on morphosemantic than morphosyntactic
Faroqi-Shah et al., (2019)	Agrammatic (8) non-agrammatic (10) Neurotypical (17)	Word-monitoring task Grammaticality judgment task	Verb argument, tense, word-category violations	Preserved in word monitoring task; Impaired in grammaticality judgment task
Friederici,	Broca (1)	ERP	Word category	Impaired;

Hahne, & Cramon (1998)	Wernicke (2) Neurotypical (8)		violations	Presented P600 but no ELAN effect
Kielar, Meltz & Thompson (2012)	Young adults (15) Older adults (23) Agrammatism (15)	ERP	Argument structure violations	Impaired; P600 is present but no N400
Kim & Thompson (2000)	Agrammatism (7) Neurotypical (5)	Grammaticality judgment task	Argument structure violations	Preserved; near normal level
Patel et al., (2008)	Broca (12) Neurotypical (14)	Grammaticality judgment task	Subject-verb agreement and semantic violations	Impaired; poor performance on subject-verb agreement violation
Wassenaar & Hagoort (2005)	Broca (11) Right hemisphere lesion (9) Neurotypical (15)	ERP	Word-category violations	Impaired; reduced and delayed P600
Wenzlaff and Clahsen (2004)	Agrammatism (7) Neurotypical (7)	Grammaticality judgment task	Morphosemantic tense violations	Impaired; lower performance

Sentence comprehension in aphasia

The term *sentence comprehension* is used here to refer to judgements that participants make *after* the sentence has been presented and often require processing of the sentence meaning. This contrasts with the tasks the discussed in the previous section

where measures are taken as the sentence is unfolding. Sentence comprehension in aphasiology is often measured using sentence to picture matching tasks. Performance is evaluated based on whether it is at, above, or below chance level. *Chance* level refers to the accuracy that one would expect if the patient were guessing; chance level would be 50% if there were two pictures to choose from, 25% with four pictures to choose from, and so on. While above chance performance is interpreted as unimpaired performance, below chance performance is interpreted as the use of a heuristic or syntactic strategy which consistently leads to an incorrect interpretation of the sentence. For example, if the patient adopts a "first noun is agent of the action" strategy, they will always arrive at an incorrect interpretation of passive sentences. Another task where participants make judgments after the sentence is presented is grammaticality judgment, in which participants judge sentences that sometimes contain semantic or morphosyntactic violations. Successful performance on grammaticality judgment task implicates that the patient can assign the syntactic structure of a sentence even if they cannot use it to determine sentence meaning. To account for guessing behavior, performance on grammaticality judgment task is calculated by D-prime (Macmillan & Creelman, 1991), a measure which takes into consideration both correct and incorrect responses.

Studies have been conducted on the nature of asyntactic processing in patients with Broca's aphasia using off-line tasks (Caramazza & Zurif, 1976; Grodzinsky, 1988; Hickok, Zurif, & Canseco-Gonzalez, 1993). These studies not only differ in the task they used, but also in types of sentences examined: these may include simple versus complex sentences, verb argument structure and tense morphology, subject-verb agreement, and

binding structures. For example, Hickok et al. (1993) utilized a picture matching task and found that individuals with agrammatism performed above chance level on active and subject relative sentences but performed at chance level on object-relative and passive sentences. Their research found that the performance of sentence comprehension of these individuals varies depending on different sentence types and complexity. Patel et al. (2008) found that individuals with Broca's aphasia showed poor performance on a grammaticality judgment task using sentences with subject-verb agreement violations compared to semantic violations. The findings of different sentence types will be discussed separately below. Given that the findings differ in the type of tasks, both studies using automatic processing tasks and off-line tasks will be reviewed below.

Simple versus complex sentences

Sentence-to-picture matching studies have found that individuals with agrammatic aphasia perform above chance for simple active sentences and for syntactically complex sentences where the meaning could be inferred from semantics (e.g, nonreversible sentences like "*The apple was eaten by the boy") (Caramazza & Zurif, 1976; Caplan & Futter, 1986; Grodzinsky, 1995). However, when the meaning of the sentences could only be interpreted through syntactic parsing, including non-canonical sentences (e.g., passives, object relative sentences, reflexives), the performance was at chance or below chance (Caplan & Futter, 1986, Grodzinsky, 1995; Grodzinsky, Wexler, Chien, Marakovitz & Solomon, 1993; Hickok & Zurif, 1998; Hickok, Zurif & Canseco-Gonzalez, 1993). The below-chance performance for non-canonical sentences in off-line tasks is surprising given the findings of preserved performance in an eye-tracking

study. Dickey and Thompson's (2009) eye-tracking study found that there was no difference in agrammatic and neurotypical individuals' eye movement in response to passive NP- movement. Eye movement patterns differed only during the final adverbial phrase and after sentences' end. In the following sections, different kinds of grammatical violations addressed in the current study will be discussed.

Verb argument structures

Verb argument structure refers to the lexical information in a sentence that serves to complete the meaning of the verb. Individuals with agrammatic aphasia often have deficits in verb processing; verb argument structure complexity might impact their ability of sentence processing because verbs are key components that constitute sentences (Grodzinsky, 1995; Kim & Thompson, 2000). However, verb argument processing ability in agrammatic aphasia varies in tasks and sentence types, and the results are mixed. Kim and Thompson (2000, 2004) conducted a study to test agrammatic individuals' sensitivity to grammatical violations in verb argument structures (e.g., *The boy is carrying) by using grammaticality judgment task. They found that agrammatic individuals performed near normal level. However, as mentioned earlier, this contrasts with Kielar et al.'s finding with impaired N400 in verb argument structure violations in agrammatic individuals. Given these contrasting findings, processing of verb argument structure needs to be further investigated.

Tense morphology

Another grammatical violation that was addressed in this study is tense violations. While some studies showed preserved ability to detect tense violations

(Benedet, Christiansen & Goodglass, 1998; Friedmann and Grodzinsky, 1997), other studies demonstrated that individuals with agrammatic aphasia also demonstrate tense processing as well as production difficulties (Bos et al., 2014; Faroqi-Shah & Dickey, 2009; Burchert, Swoboda-Moll, & De Bleser, 2005; Wenzlaff & Clahsen, 2004). In the Wenzlaff and Clahsen (2004) study of seven German individuals with agrammatism, agrammatic individuals performed significantly worse on detecting ungrammatical sentences (e.g., *Tomorrow many topics were discussed) than the neurotypical group. However, it should be noted that it may be influenced by individuals' semantic processing ability given that temporal information was provided by an adverb. Taking this into consideration, Faroqi-Shah and Dickey (2009) separated morphosemantic and morphosyntactic tense violations in an on-line grammaticality judgment task. They found that these individuals are impaired for tense comprehension, and their deficit is more pronounced for morphosemantic (e.g., Tomorrow he *walked) rather than morphosyntactic (e.g., He will *walked) aspects of tense processing. In the current study, the processing of morphosyntactic violations was examined.

Word-category substitutions

The word-category substitutions refer to sentences in which a noun replaces the main verb or vice versa. Word-category violations generate an early left anterior negativity (ELAN) (Friederici, 1995, 1998; Münte et al., 1993). Two studies using ERP investigated the processing of the sentences with word-category violations (Friederici et al., 1998; Wassenaar & Hagoort, 2005). Both studies found that Broca's aphasic individuals showed a considerably reduced and delayed P600 to the word-category

violations. Further Friederici et al. (1988) found that ELAN was absent.

In their study, Faroqi-Shah et al. (2019) presented aggregate data of three types of syntactic violations (thematic, tense, word-category) and did not analyze performance by type of violation. Hence we conducted a post-hoc analysis comparing the word monitoring effect across three violations and participant groups (agrammatic individuals (N=8), non-agrammatic aphasic individuals (N=10), non-aphasic individuals (N=17)) using independent samples Kruskal-Wallis test. To address type 2 error, *p*-value of .016 (.05/3) was used to determine statistical significance. The three groups did not significantly differ in word monitoring effect for sentences with violations of tense morphology (p = .88), verb argument (thematic violation) expectations (p = .86), and word-category (p =.034). These findings are inconsistent with some studies reviewed in literature review that concluded agrammatic individuals have impaired ability in processing sentences with tense (Wenzlaff & Clahsen, 2004) and verb argument violations (Kielar et al., 2012) and are consistent with studies that showed spared sentence processing (Kim & Thompson, 2000, 2004). Given that the findings have been mixed and non-agrammatic individuals were not included as a comparison group in many prior studies (see Table 1), it is worth investigating further to understand sentence processing of agrammatic individuals and their performances of different violation types.

Gaps in Knowledge

In summary, research on syntactic processing in individuals with agrammatic production has yielded mixed findings: studies not only vary in what kind of processing was examined (online vs offline) but also in the types of syntactic violations that were

examined. Further, most of the previous research did not include a non-agrammatic control group, making it hard to distinguish between core symptoms of agrammatism and general effects of aphasia (see Table 1). To improve current understanding of syntactic processing in agrammatism, this study proposed two changes from prior research: first, it examined online (automatic) and offline processing of the same syntactic violations to determine whether persons with agrammatic aphasia show a dissociation between preserved online processing and impaired offline performance. The second improvement is that it compared agrammatic with non-agrammatic aphasic groups to better delineate if any comprehension deficit is unique to agrammatism. The study enabled better understanding of agrammatic production by understanding if agrammatic production arises from a central core syntactic problem. To our knowledge, not many studies have systematically manipulated both task and type of sentence in a well-defined group of agrammatic individuals. Thus, the current study focused on the performance on syntactic processing in agrammatism, considering different violations including off-line sentence judgment and online automatic processing and sentence types. The current study used word monitoring data from Faroqi-Shah et al.'s (2019) study as a starting point and aimed to further analyze the processing of three violations: semantic, tense, word-category.

The Present Study

The broad aim of the present study is to investigate the integrity of syntactic processing in individuals with agrammatic aphasia. The study manipulated type of processing (online, offline) and type of syntactic violation (tense, word category) to better understand the nature of syntactic processing and how this relates to agrammatic

production patterns. Semantic violations were used as a control comparison (Kierlar et al., 2012; Patel et al., 2008). Three research questions were examined in this study.

Research Question 1: Are individuals with agrammatic aphasia able to implement knowledge of syntactic constraints, as measured by off-line sentence judgment? Does this vary by type of syntactic violation?

It is predicted that consistent with prior research (Faroqi-Shah et al., 2019; Patel et al., 2008; Wenzlaff & Clahsen, 2004), individuals with agrammatic and non-agrammatic aphasia would show impaired sensitivity to syntactic violations relative to neurotypical adults.

Research Question 2: Is automatic syntactic processing preserved in persons with agrammatic aphasia, as measured by a word-monitoring effect? Does this vary by type of syntactic violation?

If automatic syntactic processing is preserved, a positive word monitoring effect, which refers to the difference in word-monitoring response times between ungrammatical and grammatical sentences, would be observed. The results of the post-hoc analysis of the data from Faroqi-Shah et al.'s study (2019) showed that agrammatic, non-agrammatic, and neurotypical groups did not significantly differ in word monitoring effect for sentences with tense morphology, thematic, and word-category violations. Based on this prior study, it is hypothesized that both agrammatic and non-agrammatic individuals would display a positive word monitoring effect, indicating that the automatic syntactic processing ability is preserved in both groups.

Research Question 3: What influences sentence judgment in aphasia?

In order to understand interrelationships between sentence processing and other language abilities of individuals with aphasia, the extent to which sentence judgment performance is predicted by automatic processing performance, aphasia severity, percentage of grammatical utterances, and overall comprehension was examined. Based on one prior study that found a correlation between production and judgment of tense violation in agrammatism (Faroqi-Shah & Dickey, 2009) and poorer sentence judgment in agrammatic and non-agrammatic individuals compared to the neurotypical individuals (Faroqi-Shah et al., 2019), it is predicted that sentence production abilities would be significant predictors of sentence judgment performances.

Chapter 2: Methods

Participants

The initial plan to recruit 10 each of neurotypical, agrammatic, and non-agrammatic aphasic participants could not be achieved because of University of Maryland's closure of active participant testing in response to COVID-19 pandemic. Hence data collection for this study had to be discontinued. This study presents data from five individuals with agrammatic aphasia (Mean (SD) = 60.6 (10.0) years, 3 M, 4 F), seven non-agrammatic aphasic adults (Mean (SD) = 61.1 (9.7) years, 3 M, 2 F), and nine neurotypical adults (Mean (SD) = 66.9 (6.4) years, 5 M, 4 F) in the same approximate age range. Participants were recruited from the aphasia laboratory and hearing and speech clinic at University of Maryland College Park. All participants were native English speakers, and neurologically and physically stable with no psychiatric and cognitive issues, speech-language diagnoses, or substance abuse prior to their stroke. All participants passed the screening for hearing (40dB at 500, 1k, 2k Hz) and vision (20/40 on a Snellen chart). Informed consent was obtained from all participants prior to the study. All participants with aphasia had sustained a single left hemisphere stroke of the middle cerebral artery territory at least six months prior to testing.

Aphasia type and severity were assessed using the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2006). Cognitive abilities of persons with aphasia were tested using Raven's colored progressive matrices (Raven, 1938) and a memory span test which has been standardized for aphasic people (De Renzi & Nichelli, 1975). Narrative language

samples were elicited using a wordless Cinderella story book and Cookie Theft picture description from the Boston Diagnostic Aphasia Examination (BDAE-3; Goodglass, Kaplan & Barresi, 2000). Individuals with agrammatic aphasia were identified based on the result of WAB-R, and agrammatic features in narrative samples (Hsu & Thompson, 2018). The features include short and grammatically ill-formed utterances with reduced morphological elements. All agrammatic participants demonstrated a spontaneous speech score of 3-6 out of 10 and a composite comprehension score above 5 out of 10 in WAB-R. Participants details are provided in Table 2.

Table 2.
Information of aphasic participants

Participant	Age (yr), Gender, Handedness	Edu (yr)	TPO (Yr)	WAB-AQ	Aphasia Classification
AP66	62, F, R	17	1	52.2	*Broca's
AP93**	69, M, R	18	6	71.3	*Conduction
AP95	60, M, R	19	6	42.4	*Broca's
AP114**	44, M, R	19	7	65	*Broca
AP117	69, F, R	17	8	98	Anomic
AP120	72, F, R	17	3	97	Anomic
AP127	68, F, R	15	2	79.1	*Anomic
AP128	66, M, A	17	2	92.8	Anomic
AP129	60, M, R	23	2	95.8	Anomic
AP132	62, M, R	17	1	93.1	Anomic
AP134	43, F, R	15	0.7	99.2	Anomic
AP135	56, F, R	15	3	88.6	Anomic

* - Agrammatism, **Participants who had received morphosemantic treatment for verb morphology (Faroqi-Shah, 2013) within one year prior to participating in this study.

Materials and Design

Two computer-based tasks were developed for this study to test on-line and off-line syntactic processing. These tasks were modeled after Faroqi-Shah et al., (2019). A *Sentence judgment task* was used for an off-line measure and, a *Word Monitoring task*

was used for an on-line measure. Each task contained grammatically correct and incorrect sentences with two types of violations: tense and word-category as illustrated in Table 3. Semantic violations were also included as control comparisons as has been done in prior studies of sentence processing in agrammatic aphasia (Kierlar et al., 2012; Patel et al., 2008). All tasks were programmed in PsychoPy version 3.0 experiment builder (Pierce, Gray, Simpson, MacAskill, Höchenberger, Sogo, Kastman & Lindeløv, 2019). The order of administration of these three tasks was counter-balanced across participants. Within each task, sentences were presented in a random sequence.

Table 3.
Details of the experimental tasks

Task	Stimuli	Example
Sentence judgment task (audio)	30 incorrect sentences (morphosyntactic violations: tense and word-category)	The woman will removing her shoes on the front porch The chef is hamster the milk before he buy it
	15 incorrect sentences (semantic violations)	Ray spoke to the refrigerator on the phone
	45 correct sentences	The family will visit their relatives in Barcelona
Sentence judgment task (reading)	10 incorrect sentences (morphosyntactic violations: tense and word-category)	They will studied together at the library on Wednesday morning He paper the lusty singing of the church choir
	5 incorrect sentences (semantic violations)	Many changes have walked at the time of the revolution
	15 correct sentences	These areas had been devastated during the world war
Word -monitoring task	30 incorrect sentences (morphosyntactic violations: tense and word-category)	The woman will removing her shoe on the front porch The bear watermelon a large jar of super sweet honey
	15 incorrect sentences (semantic violations)	Maria left her suitcase in the refrigerator
	45 correct sentences	Tomorrow the mechanic will fix the broken and leaky faucet.

Sentence Judgment

There were two versions of the sentence judgment task: auditory and reading. The auditory task was the primary task, which matched the auditory presentation of the word monitoring task. An additional reading version was used to account for the possibility that auditory short-term memory limitations might affect auditory sentence judgment. Stimuli for the sentence judgment task were adapted from Faroqi-Shah and Dickey (2009) and Faroqi- Shah et al. (2019). The sentences were audio-recorded by a native English speaker. The reading version of the sentence judgment task included 15 correct sentences and 15 incorrect sentences including 5 sentences with tense violation, 5 sentences with word category violations and 5 sentences with semantic violations.

Participants were presented with auditory sentences and asked to make a quick and accurate judgment of the goodness of a sentence. Five practice trials were presented for participants to understand the task. Participants pressed a key on the keyboard to progress to the next trial. The dependent variable was the accuracy of judgment. The reading sentence judgment task were implemented in the same way as the auditory sentence judgment task, but the sentence stimuli were presented on the computer screen.

Word-monitoring task

The word monitoring task consisted of 90 sentences, as shown in Table 3. Word-monitoring stimuli were from Faroqi-Shah et al. (2019). Participants were first auditorily presented with the target words auditorily to be monitored and were instructed to press a button as quickly as possible when the target word is heard in a following sentence. Participants listened to a word followed by a beep, and there was 1000 ms between the

beep and sentence stimuli. They were not informed that some of the sentences may have an error. When they pressed the button, the sentence was interrupted, and the next item was presented after 1500 ms. Five practice trials were presented for participants to understand the task. Reaction times were recorded as the time between the presentation of the target word in the sentences and the participant's response.

Data analysis and interpretation

A two-tailed *p*-value of .05 was used to determine statistical significance for all analyses. Performance on each task and sentence type was compared between three groups (neurotypical, non-agrammatic and agrammatic) using the non-parametric Kruskal-Wallis Test. Significant results were followed up with Mann-Whitney U test for pairwise comparisons. Although the thesis proposal had initially planned to analyze between-group performance, additional single-subject analyses were included because of the small number of participants in the aphasic groups (five with agrammatism and seven with non-agrammatic aphasia). Single subject data analysis was performed using Crawford and Garthwaite's (2002) proposed methods where the scores of each individual participant are compared with the average scores obtained from the normative sample. The software program made available by the authors was used (Singlims-ES.exe, retrieved from https://homepages.abdn.ac.uk/j.crawford/pages/dept/psychom.htm).

To address the first research question, accuracy of performance from the sentence judgement tasks was used to calculate a D prime for each participant for each of the three sentence types (Macmillan & Creelman, 1991). D' is a measure of sensitivity that accounts for both correct responses and false alarms.

To address the second research question that examines automatic syntactic processing, the word monitoring effect was computed for each of the three sentence types (Table 3) by calculating the RT difference between incorrect and correct sentences. Given that PWA (persons with aphasia) have generally longer RT and this could give them a larger magnitude of word monitoring effect, we calculated a ratio by dividing the word monitoring effect by the mean RT of grammatically correct sentences. Only data from valid responses were used to calculate the word monitoring effect. Responses were considered invalid when 1) the participants responded before target words appeared in the sentence, so the RT value was measured as negative, or 2) the RT value was an outlier, and was longer than 2 SD of each participant's RT.

To address the third question that examines the effect of individual factors on grammatically judgment, participant data were analyzed via linear regression analysis. Independent variables included individual characteristics (e.g., aphasia severity, percentage of grammatical utterances), and performance on the word monitoring task. The dependent variable was grammatically judgment performance (D').

Chapter 3: Results

The performance of each participant group for each experimental task and sentence type is summarized in Table 4. Table 4 also shows the number of PWA who showed a deficit, as determined with single subject statistics (two-tailed $p < .05$, Crawford & Garthwaite, 2002). The results are detailed in the following sections.

Table 4.
Performance of neurotypical and aphasic groups on the sentence judgment and word monitoring tasks.

	Types of violations	Neurotypical group, M (SD)	Non-Agrammatic aphasia, M (SD), N	Agrammatic Aphasia, M (SD), N	Kruskal-Wallis χ^2, p
Auditory Sentence Judgment Task (D')	Semantic	4.23 (2.06)	2.94 (1.74), 0	2.13 (1.23), 0	5.33, .07
	Tense	3.88 (1.67)	3.15 (2.23), 0	1.75 (1.83), 0	3.64, .16
	Word Category	4.73 (1.38)	2.82 (1.48), 2	1.36 (1.05), 2	10.70, .005**
	Overall	4.28 (1.06)	2.97 (1.61), 2	1.75 (1.14), 4	
Reading Sentence Judgment Task (D')	Semantic	6.09 (1.60)	4.80 (2.02), 1	2.84 (2.14), 2	6.16, .046*
	Tense	4.43 (2.15)	4.80 (1.11), 0	1.03 (2.85), 1	6.92, .043*
	Word Category	6.41 (1.55)	7.03 (1.33), 0	2.48 (1.66), 3	12.01, .002**
	Overall	5.65 (0.94)	5.54 (0.82), 0	2.12 (1.59), 4	
Word Monitoring Task (Ratio of RT)	Semantic	19 (154)	24 (115), 0	-103 (133), 0	3.03, .22
	Tense	56 (103)	-20 (163), 2	-35 (196), 0	2.04, .36
	Word Category	290 (130)	279 (223), 0	15 (134), 1	7.70, .021*
	Overall	468 (92)	439 (110), 0	276 (54), 1	

M=Mean, N= number of participants showing a deficit (Crawford & Garthwaite, 2002), RT=Response Time, SD = Standard Deviation,*$p < .05$, **$p < .01$

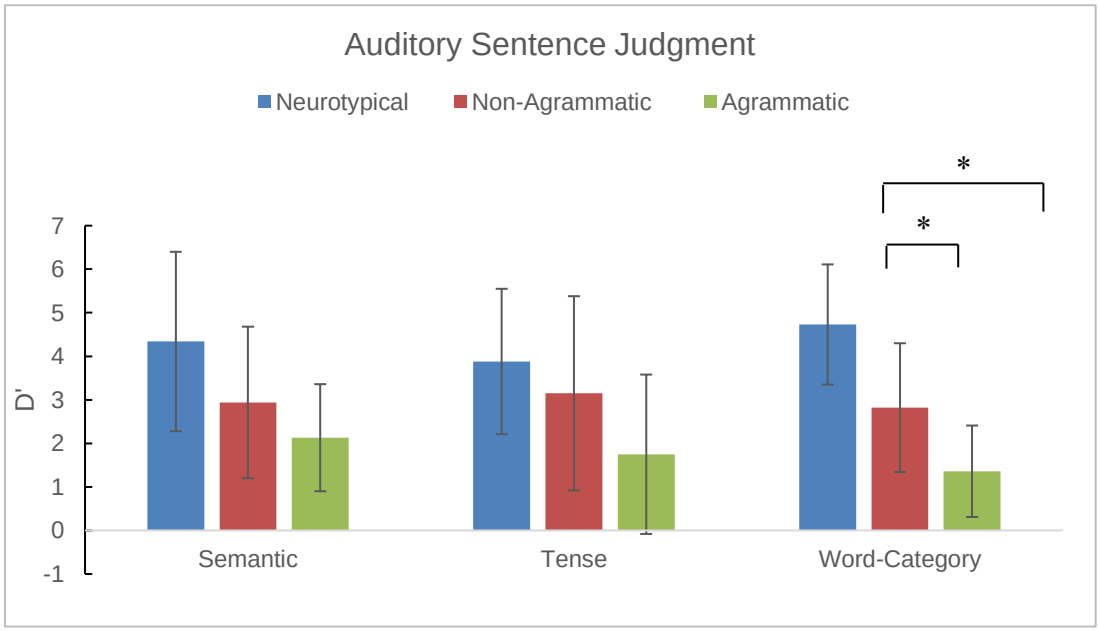
Sentence Judgment

Auditory Sentence Judgment

Individuals with aphasia exhibited numerically poor performance on the auditory

sentence judgment task for semantic and tense violations, but there was no difference in D' scores between groups (See Figure 1 and Table 4, Kruskal-Wallis χ^2, p >.05). But the groups differed for word-class violations (Kruskal-Wallis χ^2, p <.01). Follow up pair-wise comparisons using Mann-Whitney U test showed that both the non-agrammatic (Mann-Whitney U =12.5 , p =.04) and agrammatic (Mann-Whitney U =1.0 , p =.004) groups scored significantly below the neurotypical group. Non-agrammatic and agrammatic groups did not differ from each other (Mann-Whitney U =6.0, p =.07)

Figure 1.
Performance on the sentence judgment task with auditory presentation. Error bars indicate standard deviations



*p<.05

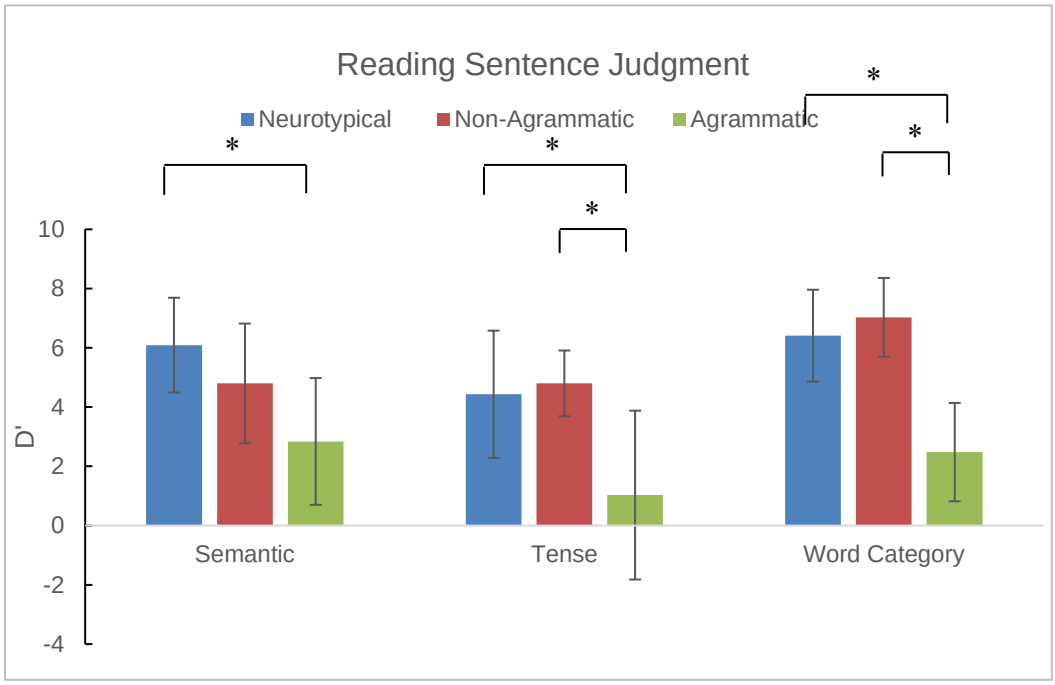
In line with the results of the group comparisons, single subject data analysis (Crawford & Garthwaite, 2002) showed that no participants showed significant difference for semantic and tense violations. However, similar to the result of the group comparisons, 2 agrammatic and 2 non-agrammatic individuals differed in D' score for

word-category violation. The Table I in appendix includes the D' values and *p*-values of individual aphasic participants.

Reading Sentence Judgment

While the results of auditory sentence judgment showed that the word class violation is the only condition in which aphasic individual appears to show significant difference, in the reading task, there was significant difference between groups for all three syntactic violations (See Figure 2 and Table 4, Kruskal-Wallis χ^2, $p<.05$). Pair-wise comparisons using Mann-Whitney U test showed that non-agrammatic group did not differ from the neurotypical group in all three syntactic violations. However, agrammatic group performed significantly below the neurotypical group in all semantic, tense, and word category violations (Mann-Whitney U =5.5, p =.017, Mann-Whitney U =7.0, p =.034, Mann-Whitney U =2.5, p =.005 respectively). Additionally, the non-agrammatic and agrammatic groups differed in tense and word category violations (Mann-Whitney U =4.0, p =.023, Mann-Whitney U =5, p =.003) but not in semantic violations (Mann-Whitney U =9.0, p =.150). It should be noted that this task had very few stimuli (N=5 of each sentence type) and was only meant as a back-up in case PWA had difficulties with the auditory sentence judgment task.

Figure 2.
Performance on the sentence judgment task with reading presentation. Error bars indicate standard deviations

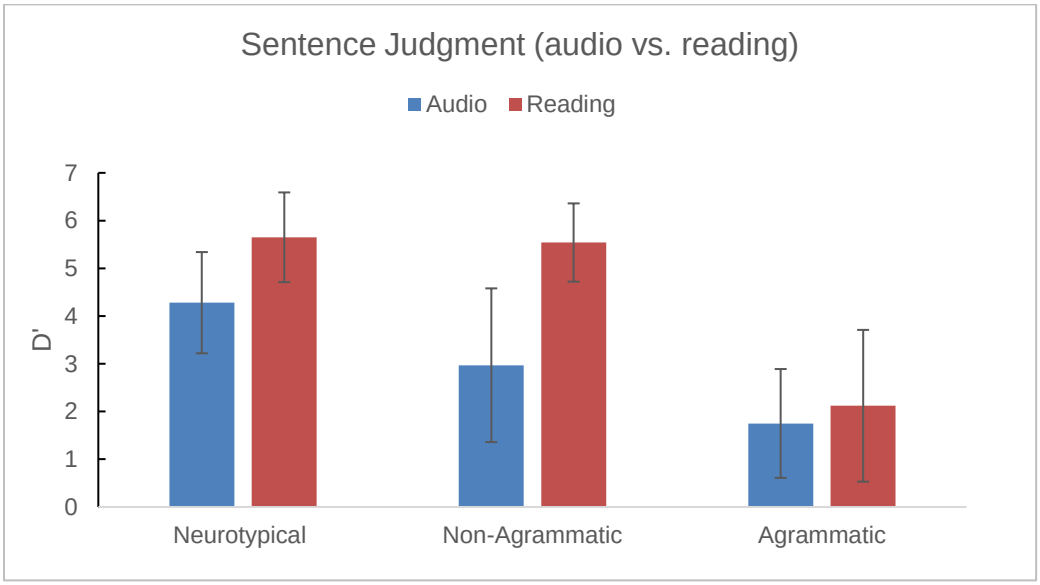


*p <.05

As shown in Table 4, of all PWA, four out of five agrammatic participants were impaired in overall D' scores. Among the sentence types, three out of five agrammatic participants showed deficits in word category violations. The results for the other conditions did not show any consistent pattern.

Neurotypical group and aphasic groups performed less accurately for the auditory task compared to the reading task (Table 4, Figure 3), indicating that the auditory sentence judgment task is more challenging than reading sentence judgment task. However, the difference in D' between groups is more significant in the reading task.

Figure 3.
Comparison of performance on the auditory and reading sentence judgement tasks



Spearman's rank correlations were computed to see the correlations between auditory and reading sentence judgment (see Table 5). The aphasic individuals' performance on auditory sentence judgment was significantly correlated with reading sentence judgment for word category violations ($r_s(10) = .64$, $p = .02$), but not correlated for other two violations ($r_s(10) = -.11$, $p = .73$, $r_s(10) = .39$, $p = .21$ for semantic and tense).

Table 5.
Correlations between auditory and reading sentence judgment performance of aphasic participants. The numbers in parentheses are *p*-values.

	Auditory Sentence Judgment (D')		
Reading Sentence Judgment	Semantic	Tense	Word Category
Semantic	-.11 (.73)		
Tense		.39 (.21)	
Word Category			.64 (.02*)

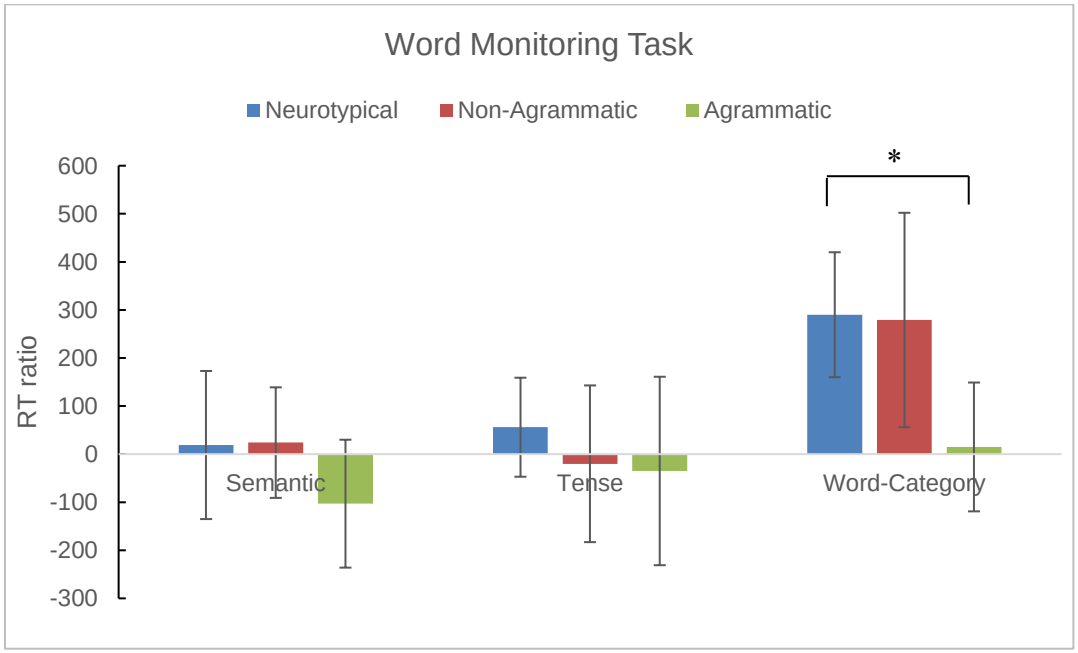
*= statistically significant, $p < .05$.

Word Monitoring

There was no difference in word monitoring effect between groups for semantic

and tense violations (See Figure 5 and Table 4, Kruskal-Wallis χ^2, p >.05). But the groups differed for word-category violations (Kruskal-Wallis χ^2, p <.05). Pair-wise comparisons using Mann-Whitney U test revealed that the agrammatic (Mann-Whitney U =1.0 , p =.004) group performed below the neurotypical group in word category violation. The neurotypical group and non-agrammatic groups did not present difference in word monitoring effect (Mann-Whitney U =28.0, p =.71). Non-agrammatic and agrammatic groups also did not differ from each other (Mann-Whitney U =6.0, p =.06) although this difference approached significance. It is noted that even the neurotypical group did not show a word monitoring effect for semantic and tense violations, presenting with no significant RT difference between correct and incorrect sentences.

Figure 4.
Performance on the word monitoring task. Error bars indicate standard deviations.



RT =response time, RT ratio
$=word\ monitoring\ effect/average\ RT\ of\ correct\ sentences$

Single subject data analysis (Crawford & Garthwaite, 2002) showed that two non-agrammatic aphasic participants in tense violation and one agrammatic participant in word-category violation differed significantly from the neurotypical group. Though the group comparison analysis revealed that the agrammatic group showed significant difficulties for word category violation in the word monitoring task, only one out of five agrammatic participants significantly differed from the neurotypical group. There was no difference in word monitoring effect for semantic violation.

Association between sentence judgment and other language abilities

In order to understand interrelationships between sentence processing and other language abilities of individuals with aphasia, the extent to which sentence judgment performance is predicted by automatic processing performance, aphasia severity, percentage of grammatical utterances, and overall comprehension was examined using a separate linear regression analysis for each violation type. Although the initial plan was to include presence or absence of agrammatism as a "binary" variable, this was not done because of the small number of participants in each aphasic group. Further, as the previous sections show, agrammatic and non-agrammatic PWA did not differ significantly in sentence processing performance. None of the regression models was a significant predictor of performance on the sentence judgment task, showing that all R^2 values < .5, F values < 1.1, and all *p*-values > .05 (Table 6). None of the correlation coefficients among the variables and each violation condition were significant.

Table 6.
Results of the three linear regression analyses predicting performance on offline sentence judgment for each type of violation in PWA.

Predictor variables	Model summary for each type of sentence judgment violation		
	Semantic	Tense	Word Category
Model 1: WM semantic, % grammatical sentence production, AQ, STM	F =.70, *p* =.62, R^2 =.32		
Model 2: WM tense, % grammatical sentence production, AQ, STM		F =.58, *p* =.69, R^2 =.28	
Model 3: WM word category, % grammatical sentence production, AQ, STM			F =1.04, *p* =.459, R^2 =.41

AQ= aphasia quotient, STM = short-term memory, WM = word monitoring.

Additional exploratory analyses

Given that agrammatism is a production symptom, another set of analyses was performed to examine the factors that possibly impact sentence production by examining interrelationships between sentence production and other language abilities. The independent/predictor variables were online and offline sentence processing performance, WAB-R AQ and short-term memory, and the dependent variable was the percentage of grammatical utterances in the narrative sample. Three regression models were examined, one with each type of sentence violation data – semantic, tense and word category. That is, the sentence judgement and word monitoring data were included from either semantic (Model 1), tense (Model 2) or word category (Model 3) violations (See Table 7). However, the standardized coefficients (β) of any of the individual predictor variables failed to reach statistical significance, as shown in Table 8. The only exception was short

term memory (digit span), a significant predictor of grammatical sentence production in Model 3, which had sentence processing data from word category violations.

Table 7.
Results of the three linear regression analyses predicting percent grammatical sentence production in PWA

Models with Predictor Variables	Model Summary
Model 1: Sentence judgment semantic, WM semantic, AQ, STM	$F = 7.73$, $p = .015$*, $R^2 = .84$
Model 2: Sentence judgment tense, WM tense, AQ, STM	$F = 5.53$, $p = .033$*, $R^2 = .79$
Model 3: Sentence judgment word category, WM word category, AQ, STM	$F = 10.50$, $p = .007$*, $R^2 = .88$

*= statistically significant, $p < .05$.

Table 8.
Significance values of individual predictors for each of the linear regression models predicting percent grammatical sentence production.

Model	Controlled variable	*p*-values
Model 1 Semantic	Sentence judgment semantic	.88
	WM semantic	.23
	AQ	.42
	STM	.21
Model 2 Tense	Sentence judgment tense	.72
	WM tense	.58
	AQ	.48
	STM	.14
Model 3 Word category	Sentence judgment word category	.24
	WM word category	.08
	AQ	.22
	STM	.04*

*= statistically significant, $p < .05$.

Additional Spearman's rank correlations were computed to explore the relationships between variables. In line with linear regression analysis, the aphasic individuals' performance on sentence judgment was not correlated with word monitoring

task performance ($r_s(10) = -.14$, $p = .66$, $r_s(10) = .21$, $p = .51$, and $r_s(10) = .49$, $p = .11$ for semantic, tense, and word category violations respectively). Also, there was no significant correlation between sentence judgment and other measures for any sentence type (Table 9).

Table 9.
Correlations between sentence judgment and other language measures for aphasic participants. The numbers in parentheses are *p*-values.

	Sentence Judgment (D')		
	Semantic	Tense	Word Category
Word monitoring (WM effect) Semantic	-.14 (.66)		
Tense		.21 (.51)	
Word Category			.49 (.11)
Short Term Memory (digit)	.27 (.40)	.23 (.48)	.42 (.17)
WAB-R Aphasia Quotient	.42 (.17)	.40 (.20)	.54 (.07)
% Grammatical Sentence Production	.09 (.79)	.09 (.80)	.16 (.64)

Chapter 4: Discussion

This study aimed to investigate sentence processing ability in individuals with agrammatic and non-agrammatic aphasia. The current study examines what aspects of sentence processing are preserved and impaired in agrammatism. The three specific questions were: 1) whether individuals with agrammatism implement knowledge of syntactic constraints and if this differs from neurotypicals, non-agrammatic PWA and by type of violation, 2) whether automatic syntactic processing preserved in agrammatism across different sentence violations, and 3) whether there are any factors that may influence sentence judgment performance in aphasia. It was hypothesized that agrammatic individuals would show impaired sensitivity in the sentence judgment task and preserved automatic syntactic processing in the word monitoring task compared to neurotypicals. For the sentence judgment task, this study found that the aphasic groups and the neurotypical group did not differ for tense and semantic violations, but for word category, both aphasic groups were impaired relative to the neurotypicals. Second, automatic syntactic processing of the agrammatic group, as measured by word monitoring task, also varied by type of violations. The agrammatic individuals did not differ from the non-agrammatic individuals in all three violations, but they differed from the neurotypicals for word category violations. Third, there was no association between sentence judgment performance and automatic processing. The implications for these findings are discussed in the following sections.

This study aimed to improve prior gaps in research in two ways: comparing off-line and online processing in the same group of participants with the same type of

syntactic violations, and including a non-agrammatic aphasic group to determine if any sentence processing deficits are unique to agrammatism. While the first goal was met, the second goal of delineating agrammatic from non-agrammatic sentence processing was only partially met because data collection had to be discontinued. Thus, it is important to note that because of the small sample size, the ability to draw firm conclusions from the data is limited. For instance, Figures 1, 2, and 4 illustrate that agrammatic PWA's performance tended to be lower than nonagrammatic PWA although this difference reached statistical significance only for the reading sentence judgement task. This latter task was a secondary verification task for the auditory sentence judgement task and had very few stimuli. Given the trend of lower agrammatic performance, it is unclear if there is no processing difference between agrammatic and non-agrammatic groups (as per statistics) or that there is a difference which would have emerged if we had collected more data.

Off-line Syntactic Processing in Aphasia

Before discussing the findings of the experimental task, it is important to discuss the diagnosis of agrammatism and solidify the definition in this study. As mentioned earlier, agrammatism is a term that focuses on production in Broca's aphasia and non-fluent aphasia (Bastiaanse & Thompson, 2012; Berndt Mitchum, & Wayland, 1997; Goodglass, 1976; Kean, 1977; Saffran, Schwartz, & Marin, 1980). All agrammatic participated in this study should meet the diagnostic criteria; a spontaneous speech score of 3-6 out of 10 and a composite comprehension score above 5 out of 10 in WAB-R. To test reliability and accuracy of categorization between non-agrammatic and agrammatic

aphasia, we computed single subject data analysis (Crawford & Garthwaite, 2002) using the data of aphasia quotients, spontaneous speech score in WAB-R, and percentage of grammatical utterances to examine if there is a significant difference between groups. The results showed that each of all five agrammatic participants significantly differed from the non-agrammatic group in all three variables ($p < .01$). Such results implied that the diagnostic criteria functioned successfully to differentiate two aphasic groups.

We hypothesized that individuals with agrammatic aphasia were likely to have impaired sensitivity to syntactic violations (Faroqi-Shah et al., 2019; Patel et al., 2008; Wenzlaff & Clahsen, 2004). Results of knowledge of syntactic constraints in this study are mixed, showing different tendency based on the type of violation. The results of word category violations are supported by the previous studies reporting off-line processing is impaired in agrammatism. These studies include Patel et al. (2008), who found impaired judgment of subject-verb agreement violations in individuals with Broca's aphasia and two ERP studies of word category violations (Friederici et al., 1998; Kierlar et al., 2012). These two studies will be discussed under word monitoring as ERP can be considered to be a measure of automatic syntactic processing.

In contrast to the results in word category violations, the current study found that neither agrammatic group nor non-agrammatic aphasic group showed significant difference from the neurotypical group for the tense violation. Such results are supported by the findings reporting that off-line processing is preserved in agrammatism. However, these results are inconsistent with the previous studies that showed sentence processing for tense violation is impaired (Faroqi-Shah & Dickey, 2009; Faroqi-Shah et al., 2019;

Wenzlaff & Clahsen, 2004). Furthermore, there was no single participant who showed impairments for tense violation in the single subject analysis. These results are surprising given that the experimental task used in this study is very similar to that used by Faroqi-Shah & Dickey (2009) and Faroqi-Shah et al. (2019). There are three possible reasons for this. One is small sample size. The other is because two out of five agrammatic participants also participated in a treatment study that focused on morphosemantic treatments for verb morphology within one year prior to participating in this study. The key aspect of this treatment was comprehension and production of verb tense, and it included a sentence judgment step. It should be noted that the treatment effects from the morphology treatment study may mediate the performance on the current study because that study focused on treatment of tense errors.

A third reason for the inconsistent findings could be the difference in the sentence stimuli and grammatical violations. Wenzlaff and Clahsen (2004) used sentences with morphosemantic violations whereas the current study used morphosyntactic violations. Morphosemantic feature is a feature that there is a adverb-verb morphology mismatch (e.g., Tomorrow he *walked), and morphosyntactic features mean a feature that there is a local syntactic violation such as auxiliary-verb inflection mismatch (e.g., He will *walked). Wenzlaff and Clashen tested eleven German-speaking individuals with Broca's aphasia, whereas the current study included five agrammatic and seven non-agrammatic English-speaking individuals. Thus, it is not clear if their data differ from our results. Faroqi-Shah and Dickey (2009), using both morphosemantic violations and morphosyntactic violations, found that agrammatic individuals had more difficulty in

judging sentences with morphosemantic violations than morphosyntactic violations on the on-line sentence judgment task. Given these results, it is possible that the different results across the studies may be due to the different violation type used in the study.

The results of the reading sentence judgment task showed that the agrammatic group significantly differed between groups for all violations, though D' values for all three groups were higher than the auditory task. These findings indicate that both aphasic and neurotypical individuals found it more difficult to detect grammatical violations in the auditory sentence judgment task compared to the reading sentence judgment. Given that the agrammatic group showed significant difference in all three violations, whereas there was no difficulty in the tense and semantic violations for the auditory presentation, it can be assumed that agrammatic individuals may have had difficulties in reading sentence stimuli.

Additional correlation analysis between reading and auditory sentence judgment showed that aphasic groups showed significant correlation for word category violations. However, they are not correlated for tense and semantic violations. There are possible reasons to explain the different results between violations. First, the small sample size and sentence stimuli could yield this outcome. We used five sentence stimuli for each violation for the reading task since it was not a primary task to measure sentence judgment. Additionally, it was found that non-agrammatic group showed better reading sentence judgment performance on word category and tense violations than the neurotypicals. Such results may be also due to the limited sample and stimuli, explaining why the reading and auditory tasks were not correlated. A second reason of for this is

because of the different modalities used in the task. We used the aphasic group's sample to compute correlation analysis. Considering that aphasic individuals may have more difficulty with one modality than others, their ability in different modalities may not be related. Hence it is possible that good performance on auditory task may not lead to good reading performance and vice versa.

To summarize, the current study found that individuals with both non-agrammatic and agrammatic aphasia showed preserved off-line processing for semantic and tense violations but impaired for word category violation. The findings indicate that the type of violations does impact the performance of detecting ungrammatical sentences. In addition, it should be noted that performance of agrammatic and non-agrammatic individuals did not differ in all three violations. This may imply that asyntactic off-line processing is not a unique deficit of agrammatism but one of the characteristics of aphasia.

Automatic syntactic processing

The prediction of the current study was that the agrammatic individuals would have preserved automatic processing (Dickey et al., 2007; Faroqi-Shah et al., 2019) despite poor off-line processing (Faroqi-Shah et al., 2019; Patel et al., 2008; Wenzalff & Clahsen, 2004). We hypothesized that both agrammatic and non-agrammatic individuals were more likely to present a positive word monitoring effect, indicating that automatic syntactic processing is preserved in both groups.

The current study found that automatic processing in agrammatism differed based on the type of violations used in the task. Only for word category violations, the

agrammatic group differed from the non-agrammatic and neurotypical groups, and the latter two groups did not differ each other. This pattern is similar to that found for word category violations for the sentence judgement task: agrammatic PWA performed worse than both groups for reading and worse than neurotypicals for auditory judgement. However, for semantic and tense violations, it is noteworthy that even the neurotypicals did not observe significant positive word monitoring effect (see Figure 5, this will be also discussed later under *Limitations*). This could mean that the stimuli used in this study were not salient enough to elicit a word monitoring effect for semantic and tense violations. Also, even neurotypicals tended to have difficulty with false alarm compared to hit rate in sentence judgment. They particularly presented with low performance on false alarm for tense violations, showing that almost half of neurotypicals (4/9) responded poorly for more than five out of 15 sentence stimuli with tense violations. Therefore, it is possible that their ability to detect tense violations may affect the results of word monitoring effect. Audibility of tense morpheme could also impact non-significant word monitoring effect. The past tense morpheme 'ed' is less audible since it is not stressed in sentences and located at the end of words. Half of this study's sentence stimuli (7/15) used 'ed' to decide the incorrectness of sentences (e.g., the chef does not baked a cake). Such less audibility of tense morpheme may result in poor word monitoring effect for tense violations. Hence, the following section is focused on the findings of the word category violations.

The results of this study are supported by the previous ERP studies of word category violations reporting automatic processing is impaired in agrammatism

(Friederici et al., 1998, Kierlar et al., 2012, Wassenar & Hagoort, 2005). The results are not supported by the previous findings reporting that automatic processing is preserved in agrammatism for wh-movement sentences using eye-tracking (Dickey et al., 2007) and a set of mixed stimuli that included tense, thematic and word category violations using word monitoring (Faroqi-Shah et al., 2019). However, prior to discussing the possible explanations for the different findings, it must be noted that in the single subject analysis, there was only one out of five agrammatic participants who significantly differed in word category violations from the neurotypical group (AP66, see Appendix 1B). Therefore, it is possible that the limited number of participants may have caused the different findings between this study and Faroqi-Shah et al. (2019), who also used a word-monitoring task. The inconsistent results between the present study and Dickey et al (2007) could be also due to the different stimuli used or due to different experimental task.

To summarize, although the group analysis implied impaired processing in agrammatic aphasia, this single subject analysis showed that this effect was driven by a single participant. We followed up with a post-hoc analysis that combined agrammatic and non-agrammatic participants into a single aphasia group and compared with the neurotypical word monitoring performance for word category violations (Mann-Whitney $U = 29$, $p=.08$) and there was no significant word monitoring deficit in aphasia as a group. So, the general conclusion of this study is that automatic syntactic processing, as measured by a word monitoring task, does not seem to be impaired in aphasia. ERP data are more fine-grained and could reveal different results.

Comparison across tasks

One of the main goals of this study was to compare off-line and online processing of the same syntactic violations in the same group of participants. The discussion focuses on word category violations as tense and semantic violations yielded no differences from neurotypical participants. The non-agrammatic group showed a mismatch between tasks, with impaired auditory sentence judgement performance and spared automatic syntactic processing. This may imply that their automatic syntactic processing is preserved though their off-line processing in the same syntactic conditions is impaired, especially in the auditory modality (reading sentence judgment was impaired). Similar to non-agrammatic individuals, agrammatic individuals also showed poor performance in sentence judgment. But their automatic processing results were inconclusive because the group level impairment seems to be driven by a single participant. Given that four out of five agrammatic individuals demonstrated good word monitoring ability in the single subject analysis, this is consistent with Faroqi-Shah et al.'s (2019) finding of preserved automatic processing in agrammatic aphasia.

However, these results should be cautiously interpreted because the number of agrammatic individuals participated in this study is limited, and the group comparison presents that the agrammatic group showed poor performance compared to the neurotypicals. We need more data before we can make conclusions.

Association between the sentence judgment and other language abilities in PWA

The current study aimed to find any possible factors that could influence aphasic individuals' sentence judgment. We hypothesized that sentence judgment may be affected

by other abilities such as automatic processing ability, aphasia severity, % grammatical sentence production, and short-term memory. Specifically, based on the previous finding of Faroqi-Shah and Dickey's study (2009), we predicted sentence production abilities as measured by % grammatical sentence production would be a significant predictor of sentence judgment performance. The results of the current study reported that sentence judgment was not predicted by any other language measure. It is surprising that the performance on sentence judgment task and word monitoring task were not associated in both linear regression and correlation analysis.

The results of the current study also do not support the findings of Faroqi-Shah and Dickey's study (2009). Faroqi-Shah and Dickey found that there is a correlation between production of verb tense in an elicited task and judgment of tense violation in a sentence judgment task. One possible reason of different results across the studies is that they focused on the use of tense morphology in PWA whereas the current study included other grammatical elements as well as tense. Hence, it is likely that the difference in measuring grammatical sentence production may yield the disparity. Future research utilizing the same conditions and methodology is needed to solidify this conclusion to find factors that possibly impact their sentence processing.

The results of the regression analysis in this study had several limitations. One limitation is, most importantly, that this study utilized a relatively large number of predictor variables with the small number of participants. Hence, the limited numbers of participants may influence the accuracy of the analysis results. Second, the association between sentence production and other variables could be mediated by other variables

such as education years, socioeconomic status, and their cognition. Therefore, it is important to consider these limitations to interpret the results of the regression analysis in the current study study.

Limitations and Future Directions

One limitation of this study is that we could not prevent mediation effect from other language interventions that may have influenced results. Two out of five agrammatic participants received treatments focused on tense errors within one year of this study. The treatment effect is likely to mediate the performance of sentence comprehension since tense violations is one of three grammatical conditions that this study aimed to examine. In addition, education and years post onset of aphasia were not matched between aphasic groups in this study. Given these limitations, this possibility should be considered during interpretation. We recommend that future researchers should control their treatment history and background to minimize possible errors. Also, this study includes small number of participants including five agrammatic and seven non-agrammatic aphasic individuals due to COVID-19 pandemic. For future researchers to get large number of data would allow them to get accurate data.

Another recommendation to explore sentence processing in this population is to utilize various methodologies for the. same syntactic conditions For example, there are various methods to measure automatic sentence processing including ERP, eye tracking, and word monitoring, and one measure may show different aspects that the other may not be able to present even for the same syntactic conditions (Kielar et al., 2012; Kim & Thompson, 2000). Integrating findings from various methodologies will elucidate the

characteristics of agrammatic individuals and understand underlying source of agrammatic production.

Conclusions

In this study, agrammatic, non-agrammatic, and neurotypical individuals completed sentence judgment and word monitoring task to examine agrammatic individuals' performance on off-line and automatic syntactic processing. The current study found that the sentence processing of persons with agrammatic aphasia differed based on the type of violation. While the agrammatic and non-agrammatic individuals did not perform differently in sentence judgment, both of them showing impaired off-line processing only with word-category violations, they probably had an impairment in word monitoring (as per between group analyses). There was no correlation between the performance of off-line and automatic syntactic processing. These findings suggested that off-line processing and automatic processing may be relatively independent abilities. This study adds suggestive evidence that the two symptoms of aphasia, agrammatic production and asyntactic comprehension, are not necessarily involved in each other.

Appendices

Appendix IA – D' scores of aphasic participants and significance values for the single subject analyses. Agrammatic participants are indicated by *. The numbers in parentheses are *p*-values, ***p* <.05

Participant	**Auditory Sentence Judgment (D')**			**Reading Sentence Judgment (D')**		
	Semantic	Tense	Word Class	Semantic	Tense	Word Class
AP66*	1.58 (.26)	0.18 (.07)	2.34 (.14)	0 (.01**)	0.59 (.13)	1.09 (.01**)
AP93*	2.12 (.36)	0.59 (.10)	0.19 (.01**)	3.97 (.25)	0 (.09)	3.97 (.17)
AP95*	1.95 (.32)	1.42 (.20)	0.33 (.02**)	1.09 (.02**)	2.88 (.51)	1.68 (.02**)
AP114*	0.86 (.16)	1.75 (.26)	1.58 (.06)	4.56 (.39)	-2.88 (.01**)	1.09 (.01**)
AP117	0.92 (.17)	0.90 (.13)	0.98 (.03**)	7.44 (.50)	4.56 (.96)	7.44 (.55)
AP120	5.22 (.66)	1.73 (.26)	2.61 (.18)	4.56 (.39)	4.56 (.96)	7.44 (.55)
AP127*	4.145 (.97)	4.83 (.61)	2.34 (.14)	4.56 (.39)	4.56 (.96)	4.56 (.29)
AP128	0.96 (.17)	0.85 (.12)	0.95 (.03**)	7.44 (.50)	4.56 (.96)	4.56 (.29)
AP129	4.56 (.88)	7.44 (.08**)	5.22 (.75)	3.97 (.25)	3.97 (.96)	7.44 (.55)
AP132	2.61 (.48)	3.97 (.96)	4.34 (.79)	4.56 (.39)	4.56 (.96)	7.44 (.55)
AP134	4.56 (.88)	4.15 (.88)	3.00 (.27)	4.56 (.39)	7.44 (.22)	7.44 (.55)
AP135	1.73 (.28)	3.00 (.63)	2.61 (.18)	1.09 (.02**)	3.97 (.85)	7.44 (.55)

Appendix IB – Word monitoring effects of aphasic participants and significance values for the single subject analyses. Agrammatic participants are indicated by *. The numbers in parentheses are *p*-values, ***p* <.05

Participant	**Word monitoring effect (ms)**		
	Semantic	Tense	Word Class
AP66*	27.57 (.96)	118.80 (.58)	-198.48 (.01**)
AP93*	-168.9 (.28)	-152.35 (.09)	33.50 (.10)
AP95*	38.24 (.91)	-187.14 (.06)	-9.48 (.06)
AP114*	-141.69 (.35)	-184.2 (.06)	150.34 (.34)
AP117	32.25 (.93)	-197.31 (.05**)	94.28 (.19)
AP120	14.99 (.98)	128.35 (.53)	579.61 (.07)
AP127*	-270.22 (.11)	229.68 (.15)	100.10 (.20)
AP128	62.53 (.80)	92.80 (.75)	168.28 (.40)
AP129	-75.94 (.57)	4.54 (.65)	613.42 (.05**)

AP132	-5.86 (.88)	139.48 (.47)	92.97 (.19)
AP134	84.12 (.70)	-109.62 (.16)	310.08 (.89)
AP135	53.06 (.84)	-199.15 (.05**)	91.64 (.19)

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