THE EFFECTS OF LOCALITY ON SENTENCE COMPREHENSION IN PERSONS WITH APHASIA AND NORMAL INDIVIDUALS

By

Jee Eun Sung

B.A., Seoul National University, 2000

M.S., Yonsei University, 2002

Submitted to the Graduate Faculty of

The School of Health and Rehabilitation Sciences in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2009

UNIVERSITY OF PITTSBURGH

SCHOOL OF HEALTH AND REHABILITATION SCIENCES

This dissertation was presented

by

Jee Eun Sung

It was defended on

December 04, 2009

and approved by

Michael Walsh Dickey, Assistant Professor, Communication Science and Disorders

Connie Tompkins, Professor, Communication Science and Disorders

Tessa Warren, Assistant Professor, Psychology

Dissertation Advisor: Malcolm R. McNeil, Distinguished Service Professor and Chair,

Communication Science and Disorders

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Jee Eun Sung, Ph.D.

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The first aim of the current study was to investigate the effects of the distance manipulation on sentence comprehension in normal individuals (NI) and persons with aphasia (PWA). Consistent with Gibson's (1998; 2000) locality theory, when distance was manipulated by varying the syntactic dependency (subject-verb: SV and filler-gap: FG) and type of modifier (No, prepositional-phrase: PP, and relative-clause: RC), NI demonstrated an increase in the number of errors and response times to the yes/no questions as the distance increases. NI also exhibited a relatively systematic increase of reading times on the verb (RT-V) and response times (RT) as a function of distance manipulation except for the most complex condition (FG-RC) in which 77% of NI performed at chance-level. More than 60% of normal individuals performed at chance-level in sentences with FG-dependency. Consistent with the previous literature on syntactic comprehension in aging, older adults showed decreased performance on the filler-gap computations.

PWA generated more errors in the FG- than SV-dependency. However, their sentence comprehension was not affected by the manipulation of the modifiers. Their RT-V data were difficult to interpret due to the very limited observations for FG-dependency conditions after chance-level performers were excluded from the analyses. One can argue that the high rate of chance-level performance in PWA, especially in the FG conditions, is consistent with the specific impairments hypotheses. However, chance-level performance was observed in majority of individuals with aphasia and even in

normal individuals, which was not predicted by those hypotheses. The current results were more consistent with resource-related hypotheses which suggested that sentence comprehension deficits will manifest themselves regardless of the type of aphasia when their capacity is taxed to be exceeded.

When distance-based integration cost was held constant between the two dependencies, FG-dependency generated more errors across the groups. However, the RT-V was not significantly different between the two conditions in older adults. These results are consistent with the locality theory. Considering the longer RT-V differences between FG- and SV-dependency in older adults than younger adults, the non-significant group results might be due to the large variability of older adults' performance and the limited sample size.

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LIST OF ABBREVIATIONS

ABCD = Assessment Battery of Communication in Dementia (Bayles & Tomoeda, 1993)

ALH = Argument Linking Hypothesis

BDAE = Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983)

CMLP = cross modal lexical priming

CRTT = Computerized Revised Token Test (McNeil, Pratt, Szuminsky et al., 2008).

DLT = Dependency Locality Theory

EU = energy unit

FG = Filler-Gap

FG-No = Filler-Gap with No modifier

FG-PP = Filler-Gap with Prepositional Phrase modifier

FG-RC = Filler-Gap with Relative Clause modifier

LTM = long term memory

MLU-m = mean length of utterance for morpheme

MLU-w = mean length of utterance for word

MU = memory unit

NAVS-R = Northwestern Assessment of Verbs and Sentences-Revised (Thompson, Ballard, & Tait, 2008)

NI = normal individuals

NP = noun phrase

PALPA = Psycholinguistic Assessments of Language Processing in Aphasia (Kay, Lesser, & Coltheart, 1992)

PICA = Porch Index of Communicative Ability (Porch, 2001)

PP = prepositional phrase

PWA = persons with aphasia

RC = relative clause

RSDT = Revised Standardized Difference Test (Crawford & Garthwaite, 2005)

RSVP = rapid serial visual paradigm

RT = Response Time

RT-V = Reading Times-Verb

SALT = Systematic Analysis of Language Transcripts (Miller & Chapman, 1998)

SOA = stimulus onset asynchrony

SOAP = Subject-relative, Object-relative, Active, and Passive (Love & Oster, 2002)

STM = short term memory

SV = Subject-Verb

SV-No = Subject-Verb with No modifier

SV-PP = Subject-Verb with Prepositional Phrase modifier

SV-RC = Subject-Verb with Relative Clause modifier

TDH = Trace Deletion Hypothesis

WAB = Western Aphasia Battery (Kertesz, 1979).

WM = working memory

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1.0. INTRODUCTION

In order to account for sentence comprehension deficits in aphasia, many theories have been proposed. Some researchers have claimed that syntactic comprehension disorders in persons with aphasia (PWA) are attributed to the specific loss of syntactic knowledge, rules, or representations required for sentence comprehension (e.g., Grodzinsky, 1986; 2000). Others have argued that people with all types of aphasia might have intact syntactic knowledge in general, but they have reduced processing resources required to compute syntactic operations and use them to understand the meaning of a sentence (e.g., Caplan, Waters, DeDe, Michaud, & Reddy, 2007). Some researchers have specified processing resource by employing the notion of verbal working memory (WM) involved in sentence comprehension. The role of WM in sentence comprehension has gained increasing attention with respect to examining whether a reduced or limited WM capacity can account for sentence comprehension deficits in PWA. However, the issues surrounding the relationship between WM and sentence comprehension in aphasia are still under debate.

One group of researchers specified constraints on the availability of WM in normal sentence processing by proposing that the distance between the two linguistic elements to be integrated is one of the critical sources of demands on WM (e.g., Gibson, 1998; 2000). Gibson suggested that the notion of distance accounts for the increase in processing times as a function of WM demands in specific regions of a sentence in young normal college students. However, the effects of the distance on sentence comprehension have not been examined systematically in normal elderly or PWA as a critical source affecting their processing and syntactic comprehension challenges or impairments. The primary objectives of the current research were twofold: (1) to investigate the effects of distance on sentence comprehension in PWA and in normal individuals (NI) when the distance is systematically varied and (2) to examine the effects of different types of linguistic dependencies on sentence comprehension between PWA and non-impaired individuals when the distance is controlled. The reported work serves as a test of the generality of locality-based integration cost hypothesis, and it contributes to understanding the nature and potential sources of sentence comprehension deficits in aphasia.

Specific Aim A: **To investigate the effects of distance on sentence comprehension in persons with aphasia and normal individuals when the distance is systematically manipulated.** Gibson (1998; 2000) has reported that the distance or locality-based integration cost predicted online processing times in sentence comprehension in young college students. The integration cost is a quantified energy unit required to incorporate each new lexical item into a current syntactic structure. Gibson hypothesized that the integration cost would be heavily influenced by the distance between a linguistic element and the site to which it is attached. The distance is measured in a simplified version by the number of new discourse referents present in the sentence such as a noun phrase (NP) or a tensed verb (Grodner & Gibson, 2005; Warren & Gibson, 2002). However, how the distance-based integration cost accounts for online processing of a sentence has not been investigated in PWA or in normal elderly adults. The current study employed the distance-based sentence processing model to examine whether PWA were differentially affected by the distance manipulation compared to age-matched non-impaired individuals.

Specific Aim B: **To investigate the effects of syntactic dependency on sentence comprehension in both persons with aphasia and normal individuals when**

the distance-based integration cost is held constant between the subject-verb and filler-gap dependencies. It is a well-studied phenomenon that PWA (e.g., Caplan, Baker, & Dehaut, 1985; Caplan, Waters, & Hildebrandt, 1997; Grodzinsky, 1989; Hickok, Zurif, & Canseco-Gonzalez, 1993) as well as NI (e.g., Ford, 1983; Hakes, Evans, & Brannon, 1976; Holmes & O'Regan, 1981; King & Just, 1991; Waters & Caplan, 2004; Wanner & Maratsos, 1978) have greater difficulties processing sentences with filler-gap dependencies than sentences with subject-verb dependencies. However, previous work has confounded the two factors of linguistic dependency and distance, since the filler-gap dependencies usually involve greater distance between the two linguistic elements to be integrated than the subject-verb dependencies. Therefore, it is not clear whether the source of the difficulties in understanding sentences with the filler-gap dependencies in PWA is due to the greater distance between linguistic elements or to specific impairments in processing the filler-gap dependency. The current study compared the differential effects of the dependency manipulation on sentence comprehension in PWA to non-impaired individuals when the distance was controlled between the two linguistic dependencies.

2.0. BACKGROUND AND SIGNIFICANCE

2.1. BACKGROUND

It is a well-known phenomenon that both NI (e.g., Ford, 1983; Hakes et al., 1976; Holmes & O'Regan, 1981; King & Just, 1991; Waters & Caplan, 2004; Wanner & Maratsos, 1978) and PWA (e.g., Caplan, et al., 1985; Caplan et al., 1997; Grodzinsky, 1989; Hickok, et al., 1993) have difficulties in processing sentences with a center-embedded object-relative clause (Object-RC) such as "The nurse$_i$ who$_i$ the doctor called (t$_i$) visited the patient". According to one theory of syntax (e.g., Chomsky, 1977; 1986), in sentence (1), the relative pronoun '*who*' moves to its surface position by leaving a trace (t$_i$) in its original place following the verb '*called*', and this process results in a non-canonical word order. In order to assign proper thematic roles to the moved constituents, the trace needs to be coindexed with the moved constituent. The syntactic structure, which requires this process of resolving the movement relationship by identifying a gap or trace and coindexing it with its linguistically dependent lexical item, is called a filler-gap (FG) dependency (e.g., Frazier & Flores d'Arcais, 1989). The extra steps required for processing FG sentences compared to the other sentence types such as the ones with subject-verb association, termed a subject-verb (SV) dependency, are regarded as a source of the differences in processing difficulties between the two sentence types.

Caramazza and Zurif (1976) reported a study suggesting that people with Broca's or conduction aphasia had specific difficulties in comprehending semantically reversible sentences with a FG dependency, although they were able to match a picture to a semantically reversible sentence with subject-verb canonical order. That is, when they had to rely only on syntactic computations in order to resolve the semantically reversible argument structures, their performance substantially decreased. Based on these results, Caramazza and Zurif argued that people with Broca's or conduction aphasia were not able to use "syntactic-like algorithm processes" that characterize the rules of syntactic operations. They did, however, retain the capacity to use "heuristic procedures" to assign a semantic interpretation to an incomplete syntactic representation (Caramazza & Zurif, 1976, p. 581). Since their seminal report, many of the subsequent studies on sentence comprehension deficits in aphasia have focused on specific impairments in processing sentences with FG dependencies.

Several theories have been proposed to account for sentence comprehension deficits in aphasia which are often most evident in sentences with the FG dependencies. Some researchers have argued that syntactic comprehension deficits in people with agrammatic production are attributed to the loss of specific syntactic rules or representations (e.g., Grodzinsky, 1986). In contrast to the linguistic specific impairment hypotheses, some researchers have claimed that the major problems in syntactic comprehension are due to limited or reduced availability of processing resources (e.g., Berndt, Mitchum, & Wayland, 1997; Caplan et al., 1985; Caplan et al., 2007; Haarmann, Just, & Carpenter, 1997) or inefficiency of allocating processing resources for people with aphasia (e.g., McNeil, Odell, & Tseng, 1991) based on the assumption that PWA have intact syntactic rules and representations. Some researchers argued that limitation or reduction in WM capacity is related to sentence comprehension deficits in PWA (e.g., Caplan et al., 1999; Miyake et al., 1994).

2.1.1. Sentence Comprehension Deficits in Aphasia

As mentioned above, some researchers such as Grodzinsky, (1986; 1995; 2000); Hickok & Avrutin, (1995); Hickok, Zurif, & Canseco-Gonzalez, (1993) and Mauner, Fromkin, & Cornell, (1993) have posited that sentence comprehension deficits in PWA are due to the specific loss or impairments of syntactic representations or computational rules. More specifically, these researchers postulated that people with Broca's aphasia have specific deficits in syntactic computations of co-indexing the trace with its moved constituent.

Grodzinsky (1984; 1986) proposed the *Trace Deletion Hypothesis* (TDH) to account for agrammatic production and comprehension which suggested that people with agrammatic Broca's aphasia[1] lost their ability to assign the correct thematic role to the syntactic structure after a constituent was moved from its original position to the surface position. According to this hypothesis, there is a "trace" created as a result of the movement of a constituent, and this trace is regarded as "phonologically silent" but "syntactically active" (Grodzinsky, 2000, p. 5). In order to assign proper thematic roles

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[1] Terminology referring to people with agrammatic production and/or comprehension has not been consistently used across the studies. Furthermore, the selection criteria for agrammatic production and/or comprehension have been controversial. Theoretical and empirical issues on defining agrammatic behaviors both in production and comprehension and the selection criteria will be discussed in a later chapter.

Grodzinsky, Piñango, Zurif, and Drai (1999) have clearly stated that the subject selection criteria should meet "agrammatism associated only Broca's aphasia, that is, only with the short, telegraphic and syntactically simplified and incomplete utterances that figure importantly in the classic Broca's profile" (p. 139). Therefore, for the time being, the terminology of "agrammatic Broca's aphasia" will be used to refer to a group of individuals with aphasia to whom the TDH was applied by Grodzinsky and colleagues.

to the moved constituents, the trace needs to be 'co-indexed' with the moved constituent. However, in individuals with agrammatic Broca's aphasia, all traces of movement were assumed to be deleted from syntactic representation by Grodzinsky and colleagues. For example, in a semantically reversible passive sentence such as 'The boy was pushed by the girl', people with agrammatic Broca's aphasia incorrectly assigns the subject ('the boy') the agent role by the default strategy. However, the object of the preposition *by*, ('the girl') is correctly assigned the agent role because there is no syntactic movement involved in this part of the representation. Grodzinsky and colleagues assumed that the thematic competition between the two agents would induce chance-level performance on a sentence-picture matching task. The TDH predicts that individuals with agrammatic Broca's aphasia would perform at or below chance-levels on sentence-picture matching tasks in semantically reversible sentences with as passive, object-cleft, and object-RC sentences. However, it was argued that their performance would be significantly above chance for active, subject-cleft, and subject-RC sentences (Grodzinsky, 1986; 1989; 2000 Grodzinsky, Piñango, Zurif, & Drai, 1999; Hickok et al., 1993; Hickok & Avrutin, 1995).

However, there are some alternative accounts for sentence comprehension deficits in individuals with agrammatic Broca's aphasia. Piñango (1998; 2000) suggested that the syntactic comprehension deficits are not attributed to the impairments in the coindexation process but to the competition of the two unmatched linking systems between semantic and syntactic representations even after the successful syntactic computations; this she termed the Argument Linking Hypothesis (ALH). The findings from Piñango (2000) suggested that four persons with Broca's agrammatic aphasia showed chance-level performance on sentences with non-canonical connections of theme-experiencer such as fear-type passive sentences (e.g., The man is feared by the boy) and frighten-type active sentences (e.g., The gun frightened the man). However, they performed better than chance in sentences following the canonical order of experiencer-theme connection such as fear-type active sentences (e.g., The boy feared the man) and frightened-type passive sentences (e.g., The man is frightened by the gun). Based on the findings, Piñango argued that chance-level performance can be obtained regardless of the presence of the movement structures, and the data are better accounted for by the canonicity of the order in the two linking systems between the semantic and syntactic roles.

Another alternative account for specific impairments in individuals with agrammatic Broca's aphasia is called the Mapping Hypothesis. This account differs from the TDH in that syntactic comprehension deficits are not attributed to the complete loss of syntactic rules or representations, but to the deficiency in using the products from syntactic analysis to determine the meaning of the sentence (e.g., Linebarger et al., 1983; Schwartz, Linebarger, & Saffran, 1985). Linebarger et al. (1983) found that four agrammatic individuals were still sensitive to the information of syntactic structures, as indicated by their performance on a grammaticality judgment task, although they performed poorly on sentence-picture matching tasks. Linebarger et al. interpreted the results as indicating that the agrammatic individuals were able to correctly construct syntactic structures, but they failed in mapping the syntactic analysis onto semantic representations.

Another possible interpretation of the Linebarger et al. (1983) data was that there could be a tradeoff between syntactic and semantic processing. In other words, agrammatic individuals sacrifice one type of processing in order to get optimal performance in the other. The authors mentioned that the second possibility arises from the limitations on "computational resources", although they did not explicitly define it. The underlying assumption with regards to computational resources was that the processing mechanisms onto which more demands are imposed do not function optimally.

The latter explanation for syntactic comprehension deficits is more in line with the resource-related hypotheses than the specific impairments hypotheses. In their subsequent works, Saffran, Schwartz, and Linebarger (1998) suggested that sentence comprehension deficits might be due to "the selectively weakening syntactic input to a dynamic system in which other components continue to operate much as they normally do" (p. 290), and this argument can be seen as a variant of resource-related hypotheses (Caplan et al., 2007). Linebarger (1990) noted that the mapping difficulties could arise from memory or resource limitations rather than from a specific loss of abilities to perform the mapping computations. However, the mapping hypothesis was not further elaborated into the subsequent experiments to specifically test the predictions based on the resource-related hypotheses.

As reviewed above, the specific impairment hypotheses on syntactic comprehension deficits have been discussed exclusively by focusing on a subtype of aphasia such as agrammatic Broca's aphasia. The terminologies of Broca's aphasia and agrammatism have been used interchangeably in several studies without specifying the definitions or differences of the two terms. Agrammatism was once regarded as a symptom within a larger syndrome of Broca's aphasia, but agrammatism has also been observed as the critical and defining feature of a redefined syndrome of Broca's aphasia (Berndt & Caramazza, 1980).

Agrammatism is typically used to describe a production disorder in aphasia characterized as simplified syntactic structures of utterances, the omission of function words such as articles, prepositions, conjunctions, auxiliary verbs, the deletion of grammatical morphemes as inflectional markers of verb tense, person, or number, and difficulties with word order (Caramazza & Berndt, 1985; Goodglass & Kaplan, 1983). The criteria for Broca's aphasia and agrammatism were at one time taken to include preserved comprehension, as Caramazza and Badecker (1989) noted. However, ample evidence suggested that people with agrammatic production exhibited asyntactic comprehension (operationally defined as impaired performance on semantically reversible sentences with non-canonical movement structures; e.g., Caramazza & Zurif, 1976; Heilman & Scholes, 1976; Schwartz, Saffran, & Marin, 1980). These observations lead to theories of asyntactic comprehension in people with agrammatic production based on the assumption that underlying mechanisms engaged in comprehension and production might be shared (e.g., Berndt & Caramazza, 1980; Caramazza & Berndt, 1978; Caramazza & Zurif, 1976; Saffran, Schwartz, & Marin, 1980). In other words, the co-occurrence of agrammatic production and comprehension in sentences requiring specific syntactic computations involved in word-order led to the formulation of the agrammatic comprehension hypotheses. These hypotheses proposed that there is a general deficit in syntactic processing that was the source of both their production and comprehension patterns (Berndt & Caramazza, 1980).

However, the validity of grouping patients to study syntactic comprehension deficits based on the presence of agrammatic production has been questioned in several ways (Caplan, 1995). First of all, the rationale behind linking a disorder in production with another disorder in sentence comprehension has not been clearly established. There are several studies which showed differential patterns of performance between agrammatic production and comprehension. That is, some researchers have argued that agrammatic production is not necessarily accompanied by impaired comprehension based on the findings that people with agrammatic production demonstrated excellent comprehension of various types of sentences (Caramazza & Hillis, 1989; Kolk, van Grunsven, & Keyser, 1985; Miceli, Mazzucchi, Menn, & Goodglass, 1983; Nespoulous et al., 1988). A summary of this literature by Berndt, Mitchum, and Haendiges (1996) also suggested that "features of agrammatic sentence production are quite commonly found in patients with little or no impairment of sentence comprehension" (p. 297).

The summary of Berndt et al. (1996) suggested that performance on the comprehension of reversible active and passive sentences was heterogeneous in people with agrammatic sentence production. The authors argued that the heterogeneity is not consistent with the hypotheses which assumed a specific and uniform performance on sentence comprehension with movement structures in people with agrammatic production (e.g., Grodzinsky, 1986; Mauner et al., 1993). Several researchers further argued that selection of particular participants on the basis of features of agrammatic sentence production does not assure a homogeneous grouping of participants (Badecker & Caramazza, 1985; Berndt et al., 1996; Martin, Wetzel, Blossom-Stach, & Feher, 1989). It appears that PWA who exhibit features of agrammatic sentence production vary widely in their ability to understand semantically reversible sentences with the movement structure.

There are a couple of studies that have focused on the selective difficulty with reversible sentences among PWA who are not agrammatic speakers (e.g., Caramazza & Zurif, 1976; Caramazza & Miceli, 1991; Martin & Blossom-Stach, 1986; Mitchum, Haendiges, & Berndt, 1995). These studies reported that patterns of comprehension deficits in people with or without agrammatic production symptoms were indistinguishable (Berndt et al., 1996). Berndt, Caramazza and colleagues have questioned the rationale for the attempt to formulate global theories to accommodate both comprehension and production impairments for any patient group (e.g., Berndt et al., 1996; Caramazza & Badecker, 1989; Caramazza & Berndt, 1985), although agrammatic production and comprehension can co-occur.

As reviewed above, there is evidence for the dissociation or differential performance of agrammatic comprehension from agrammatic production, while there is also evidence of the co-occurrence of the two behaviors. However, it is still not clear whether co-occurring impairments in language production and comprehension arise from damage to a common set of processing mechanisms or whether the two symptoms just co-occur as a result of damage to unrelated processing mechanisms (Caramazza & Badecker, 1989). Despite the controversies over the co-occurrence of agrammatic production and comprehension impairments, researchers have investigated syntactic comprehension deficits by focusing a certain group of aphasia with production disorders such as individuals with agrammatic Broca's aphasia. This was based on the argument that individuals with agrammatic Broca's aphasia who showed syntactic complexity-induced sentence comprehension deficits outnumbered those who have no such problem (Zurif & Piñango, 1999).

Another issue in studies on syntactic comprehension deficits in people with agrammatic production is the loosely defined inclusion criteria used to select a specific subtype of PWA. In several publications from Grodzinsky and colleagues, a subgroup of PWA was identified with a focal lesion to "the left cerebral hemisphere, caused in the majority of cases by occlusion of the left middle cerebral artery" (Grodzinsky, 2000, p. 4), in addition to the behavioral symptoms. However, the theoretical rationale of considering the inclusion criteria based on the specific anatomical lesions was underspecified. Furthermore, there is evidence that a lesion in Broca's area and performance on sentence comprehension are not significantly related (Caplan et al., 1985; Caplan, Hildebrandt, & Makris, 1996). Several studies have reported that selective deficits in syntactic comprehension can occur in all aphasic groups regardless of the lesion site and even in normal controls under stressful conditions (e.g., Blackwell & Bates, 1995; Dick, Bates, Wulfeck, Utman, & Dronkers, 2001; Miyake, Carpenter, & Just, 1994). These findings questioned the theoretical rationale for considering anatomical lesions as selection criteria to identify a subgroup with agrammatic production and comprehension to test their specific hypothesis. To reiterate, several cautions are warranted in interpreting data from the studies, which exclusively focused on subgroups of aphasia with agrammatic production to examine sentence comprehension deficits in aphasia.

For some researchers, the fact that deficits were not all-or-none according to a specific subtype of aphasia leads to formulating the hypothesis that all aphasic syndromes share a common deficit (e.g., Caplan et al., 1985; Caplan et al., 2007; McNeil, 1982, 1988; McNeil, Odell, & Tseng, 1991; Schuell & Jenkins, 1959). Several researchers have argued that sentence comprehension deficits in aphasia may be induced by the limitation of processing resources (e.g., Caplan & Hildebrandt, 1988; Caplan et al, 1985; Caplan et al., 2007; Dick et al., 2001; Frazier & Friederici, 1991; Friederici & Frazier, 1992; Haarmann et al., 1997; Kolk & Weits, 1996; McNeil, 1983; Miyake, Carpenter, & Just, 1995; Miyake et al., 1994; Murray et al., 1997b). Processing resources required in sentence comprehension were defined as a construct to refer to "features of mental functioning (i.e., of a "functional cognitive architecture") that allow cognitive operations to proceed and that affect their operating characteristics, but that are not themselves computational operations or a type of knowledge" (Caplan et al., 2007, p. 147). Another line of research emphasizes the temporal aspects of resources (e.g., slowed processing) which are regarded as a critical factor to account for sentence comprehension deficits (e.g., Campbell & McNeil, 1985; Friederici & Kilborn, 1989; Haarmann & Kolk, 1991; McNeil, Darley, Olson, & Rose, 1984; McNeil, Darley, Rose, & Olson, 1984; Swinney, Zurif, Prather, & Love, 1996; Zurif, Swinney, Prather, Solomon, & Bushell, 1993).

Researchers who argued for the resource-related hypotheses shared a couple of assumptions. First, it is assumed that more complex sentences require more processing resources. Sentence complexity may be manipulated in several ways such as varying word order, varying the number of verbs and arguments per verb, or padding additional linguistic elements. Second, people with aphasia are assumed to have fewer processing resources after stroke compared to unimpaired individuals. Some researchers postulated that the notion of reduced total resources is a less compelling argument in PWA. They have suggested instead that the allocation of resources to particular linguistic tasks is inefficient, given that performance is variable (e.g., Hageman, McNeil, Rucci-Zimmer, & Cariski, 1982; McNeil, Odell, & Campbell, 1982; McNeil et al., 1991). However, these two possible different sources of the deficits (reduced amount of resources in size vs. inefficient allocation of resources) have not been differentiated in studies on sentence comprehension in PWA. Furthermore, critical factors which constrained processing resources in sentence comprehension have been underspecified in the general resource-reduction explanations by most investigators.

2.1.2. Sentence Comprehension and Aging

Several studies have reported that sentence comprehension abilities are affected by aging, as measured in offline tasks. (e.g., Davis & Ball, 1989; Emery, 1985; Feier & Gertsman, 1980; Kemper, 1986; Obler, Fein, Nicholas, & Albert ,1984). Feier and Gerstman (1980) examined sentence comprehension abilities using an object-manipulation task with sentences containing center-embedded and right-branching relative clauses in adults with an age range from 18 to 80. The authors found that performance of older adults started to decline in their 60s. They also found a relatively wide variability within each age group, and this was accounted for by vocabulary, digit span scores and educational level. Consistent with their findings, Davis and Ball (1989) also found that comprehension accuracy declines after age 60.

Davis and Ball (1989) examined the effect of aging on sentence comprehension using sentences with center-embedded or right-branching subordinate clauses. For example, participants listened to sentences with a center-embedded clause (e.g., “The niece that woke the uncle called the aunt.”) and sentences with a right branching clause (e.g., “The niece visited the aunt that hurt the uncle.”) (Davis & Ball, 1989, p. 145). There were three types of questions used to test their ability to comprehend the thematic roles in each sentence: (1) asking about the recipient of the first verb (e.g., “Who was visited?”), (2) asking about the recipient of the second verb (e.g., “Who was hurt?”), and (3) asking about the agent of one of the two verbs (e.g., “Who did the visiting?”) where half of the questions were about the first verb and the other half were about the second verb.

It was hypothesized that age interacts with syntactic structure with greater difficulties founds in sentences with embedded than right-branding clauses in older groups. This was based on the assumption that center-embedded sentences would impose greater memory burden due to the longer distance between the two thematic roles to be integrated. Overall, participants showed more errors in sentences with center-embedded clauses than with right-branching clauses. However, age did not interact with the type of syntactic structure. Instead, age-group interacted with the type of question. Questions about the second verb generated more errors than questions about the first verb in the elderly group (ages 71-79). There was a longer distance between subject and verb with the second verb than with the first verb, in sentences with both center-embedded and right-branching clauses. Distance between the separated constituents seemed to have played a role in participants' success integrating the linguistic elements. However, in older adults, the center-embedded syntactic structure did not differentially increase this distance effect compared to the right-branching structure, as indicated by a nonsignificant 3-way interaction (age-group x syntactic-structure x question-type). Davis and Ball (1989) indicated that older adults became susceptible to subtle distance effects that are unrelated to embedding of subordinate clauses.

There are several studies which investigated differences in online syntactic processing abilities between older and younger adults (e.g., Baum, 1991; Kemper & Kemtes, 1999; Kemtes & Kemper, 1997; Waters & Caplan, 2001; 2005; Zurif, Swinney, Prather, Wingfield, & Brownell, 1995). Waters and Caplan (2001) found that older adults performed significantly more poorly than young adults on a sentence acceptability judgment task. However, phrase-by-phrase listening times in older adults, as measured by an auditory moving window task, were not disproportionately worse than those of young adults, under the demanding phrase with the embedded verb in syntactically complex sentences. Waters and Caplan (2005) replicated the results of their earlier study (2001), showing that in complex sentences, older adults did not perform disproportionately worse in on-line syntactic processing than young college students. Kemtes and Kemper (1997) found that older adults were slower in making online grammaticality judgments than younger adults. However, their online processing times were not differentially affected by syntactic complexity compared to young adults.

Based on these findings, this group of researchers argued that elderly adults have greater difficulties in comprehending complex sentences than younger adults, as assessed by end-of-sentence measures presumed to tax post-interpretive cognitive capacity. However, online syntactic processing was not differentially affected by aging as a function of task demands manipulated by syntactic complexity (e.g., Caplan & Waters, 1999). Based on the assumption that syntactic processing is relatively automatic and resource-free (e.g., Fodor, 1983), this group of researchers argued that older adults with limited cognitive resources (e.g., working memory) would not be differentially affected in online sentence processing as a function of syntactic complexity, when compared to younger adults.

In contrast to these non-significant findings in online sentence processing between older and younger adults as function of syntactic complexity manipulation, other studies reported different patterns of online processing performance between age groups. Kemper and Kemtes (1999) found significant differences in word-by-word reading times between young and older adults in processing ambiguous syntactic structures. Older adults with lower WM spans showed increased reading times for syntactically ambiguous regions of sentences than did older adults with higher WM spans. However, these patterns were not observed in younger adults. Stine-Morrow, Ryan and Leonard (2000) found that older adults were less accurate at comprehending object-relative sentences than younger adults, and the older group failed to show an increase in online reading times at the capacity demanding region of complex sentences. They argued that older adults were less sensitive than younger adults to online syntactic assignment in complex sentences.

Zurif, Swinney, Prather, Wingfield, and Brownell (1995) examined online processing of object- and subject-relative sentences in older adults using a cross-modal lexical priming task. In this task, participants listened to a sentence (e.g., "The tailor hemmed the cloak that the actor from the studio needed for the performance," p. 167). Concurrently, at the gap site, a word that was semantically related (e.g., *robe*) or unrelated word (e.g., *goat*) to the antecedent noun (e.g., *cloak*) was visually presented.

Zurif et al. (1995) found that older adults showed lexical priming, reflected in lexical decision times for the visually presented words, in subject-relative sentences but not in object-relative sentences. In the second experiment, the distance between the gap and its antecedent was shortened in object-relative sentences, and priming effects were observed for the older group. Based on these results, the authors argued that memory limitation is, in part, responsible for aspects of sentence processing in the elderly. When the distance between the gap and its antecedent was within their memory capacity, older adults showed the reactivation of the antecedent at the gap site like young adults did (e.g., Swinney & Fodor, 1993). However, when storage capacity was taxed due to the long antecedent-gap distance, lexical priming performance in older adults was differentiated from that in young adults.

2.1.3. Working Memory Capacity and Sentence Comprehension

Some researchers have employed the notion of WM to account for sentence comprehension difficulties in normal individuals and PWA. Since Baddeley and Hitch (1974) proposed WM as a cognitive system consisting of temporary storage and computational components responsible for various cognitive tasks, WM has received considerable attention as a possible cognitive construct underlying language processing and comprehension in both normal and clinical populations.

Baddeley and Hitch (1974) proposed that WM consists of a central executive and its two slave subsystems of the phonological loop concerned with acoustic and verbal information and the visuospatial sketchpad involved in visual and spatial information (Baddeley, 1986). Recently, Baddeley (2000) added a forth component called ‘episodic buffer’, which was assumed to be a limited-capacity temporary storage system that is capable of integrating information by interacting with long-term memory (LTM) from a crystallized system. However, the central executive component achieved relatively little attention compared to the other slave systems in his WM model (Baddeley, 1986). Baddeley (1986) described the central executive as “the area of residual ignorance within the working memory system” (p.225), and he also admitted that the underspecified system created potential confusion with using this term.

The less specified central executive component of WM in Baddeley and Hitch (1974)’s WM model was elaborated in Just and Carpenter (1992)’s WM capacity model. Just and Carpenter expressed WM capacity as “the maximum amount of activation available in working memory to support either of the two functions” (p.123) such as storage and processing. The authors suggested that the WM capacity model differs from Baddeley’s WM model in that it did not include modality-specific buffers, rather they proposed that their conceptualization of WM “corresponded approximately to the part of the central executive in Baddeley’s model of working memory” (Just & Carpenter, 1992, p.123).

Other researchers have proposed that WM consists of three systems: (a) short-term storage in which information is in an active state above a threshold from long-term memory; (b) computational components ; (c) executive attention (Cowan, 1988; 1995; Engle, 2001; 2002; Engle & Kane, 2004; Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2002, 2003; Kane, Bleckley, Conway, & Engle, 2001; Kane, Poole, Tuholski, & Engle, 2006). By executive attention they meant “an attention capability whereby memory representations are maintained in a highly active state in the face of interference and these representations may reflect action plans, goal states or task-relevant stimuli in the environment” (Kane & Engle, 2002, p. 638).

Several studies from Kane, Engle, Cowan and colleagues have reported that WM is distinguishable from short-term memory (STM) span. For example, when the shared variance between the STM and WM was statistically removed, the residual variance of the WM still significantly correlated with general fluid intelligence, as measured by the Raven's Progressive Matrices (RAVEN; Raven, Court, & Raven, 1977) or the Cattell Culture Fair Test (CATTEL; Cattell, 1973), but STM did not (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle et al., 1999). Despite a good amount of research on the role of WM as executive attention in cognitive tasks, there are very few studies investigating the relationship between the attentional component of WM and language comprehension except for some correlational studies between WM measures and sentence comprehension tasks (e.g., Engle, Cantor, & Carullo, 1992). Furthermore, there have been no attempts to disentangle the three components of short-term storage, computation, and executive attention in the sentence comprehension literature.

WM researchers have investigated the relationship between the general notion of verbal WM and sentence comprehension. However, there are discrepancies in the assumptions, predictions, and interpretations about the role of WM in sentence comprehension depending on the model under which each research group is working. Some researchers argue that the executive attentional system (WM resources) is used for all verbally mediated tasks and therefore is composed of a single pool of WM capacity (Just & Carpenter 1992; King & Just 1991; MacDonald, Just, & Carpenter, 1992; Miyake et al., 1994). On the other hand, others have claimed that language comprehension is involved in two distinctive types of processing such as automatic (or 'interpretive') and controlled (or 'post-interpretive') processing (e.g., Caplan & Waters, 1999; Waters & Caplan, 2004). These researchers suggested that WM resources are specialized depending on the nature of the processing, and therefore they assume that there is more than one WM resource that is utilized depending on the specific processing requirements.

In order to investigate the relationship between WM and sentence comprehension, WM researchers have employed on-line measures such as word-by-word or phrase-by-phrase reading or listening times. Their assumption was that on-line measures are sensitive to local increases in processing load (e.g., Waters & Caplan, 2001; 2004; Ferreira et al., 1996) and that longer processing times reflect a greater processing load. Gibson (1998; 2000) incorporated a reading time unit into a computational resource account of sentence comprehension and equated it to the notion of WM; using the terminology of computational resources interchangeably with WM.

In this formulation, Gibson (1998) hypothesized that reading times reflected "the time required to perform a linguistic integration" and reading times were quantified as "the ratio of the integration cost required at the state to the space currently available for the computation" (p. 16). The integration cost was defined as "what quantity of computational resources need to be spent on integrating new words into the structures built thus far" (p.8). Gibson assumed that the integration cost is influenced by "the distance between the elements being integrated" (p. 11) and "the complexity of the intervening integrations" (p. 21). Waters and Caplan (2004) shared similar assumptions with Gibson (1998; 2000) in their self-paced listening time measures by suggesting that "listening times to words or phrases presented one at a time reflect the time it takes to integrate lexical items into an accruing syntactic and semantic structure, and they are therefore longer when this integration is more difficult" (p. 133).

King and Just (1991) investigated individual differences in the ability of sentence processing as a function of WM capacity in young college students using self-paced word-by-word reading. Daneman and Carpenter's (1980) reading span task was administered to all participants, and they were divided into three WM groups. Only low (n=22) and high (n=24) WM groups were included into the data analysis. The results revealed that the high span group took significantly less time than the low span group especially in the object-relative sentences resulting in the significant interaction between the WM group and sentence type ($p<.05$) in overall reading times. Although King and Just did not explicitly present significance level for the three-way interaction of WM group by sentence type by region, the authors noted that "only in the main verb sector of the object relative sentences is there a significant difference in reading times between High and Low span readers" (p. 590). Sentence acceptability judgment were significantly less accurate in the low span than in the high WM span group for object-relative clauses, resulting in a significant two-way interaction between the WM group and sentence type ($p<.05$). The reading time evidence from King and Just is consistent with the hypothesis that readers with low WM capacity were less capable of sentence processing at the critical region in which the processing resource demands are increased.

Waters and Caplan (2004) investigated the relationship between the WM capacity and the performance on on-line sentence processing measured using auditory moving window. In Experiment 1, one hundred young college students were given a version of Daneman and Carpenter (1980)'s WM task, and they were divided into the three WM groups; low (lower than the span 3.0), middle (span of 3.5, 4.0, 4.5), and high (greater than the span 5.0). Four different types of sentences were included such as cleft-object (CO), cleft-subject (CS), subject-object relative (SO), and object-subject relative (OS) sentences[2]. A Three-way ANOVA was computed with the factors of WM group, phrase, and sentence types.

[2] Examples of plausible sentences used in Waters and Caplan (2004, p. 135)

In terms of phrase segmentation, phrase was divided into four or five parts such as NP1 (noun phrase; e.g., "The man"), NP2 ("that the fire"), V1 (verb; "injured"), V2 ("called") and NP3 ("the doctor) in a plausible SO sentence of "The man that the fire injured called the doctor" (Waters & Caplan, 2004, p. 135). Phrase-by-phrase listening times and the accuracy from a sentence plausibility task were measured as dependent variables. A theoretically critical comparison is the listening time of the verb as a critical region in which WM load is assumed to increase. The performance on both speed and accuracy was compared between the CS and CO and between the OS and SO, respectively.

In terms of the listening time data, a theoretically critical interaction of WM group by phrase by sentence type was significant only by items but not by subjects in CS/CO analysis. The interaction was due to the fact that the low WM group showed longer listening time than the middle and high span group on the verb of CO sentences. However, the three-way interaction was not significant in OS/SO comparisons. The low WM group was less accurate than the high and middle span groups in the more complex sentence types such as CO or SO, but the low WM group did not differ from the other two groups in the simple sentence types.

The results from Waters and Caplan (2004) suggested that listening times on the critical region of a sentence did not differ between low and high WM groups as a function of syntactic complexity, indicating that individual differences in online sentence processing were not accounted for by individual differences in WM capacity. In contrast, the low WM group performed significantly worse than the high WM group as a function

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CS: It was (Intro) / the food (NP1) / that nourished (V) / the child (NP2).

CO: It was (Intro) / the woman (NP1) / that the toy (NP2) / amazed (V).

OS: The father (NP1) / read (V1) / the book (NP2) / that terrified (V2) / the child (NP3).

SO: The man (NP1) / that the fire (NP2) / injured (V1) / called (V2) / the doctor (NP3).

of syntactic complexity on the plausibility judgment task. Based on the results, the authors argued that WM resources required for online sentence processing are separate from those used for controlled processing. In sum, there are limited data reported on the relationship between on-line syntactic processing and WM capacity in young normal individuals.

In the aphasia sentence processing literature, there are also very few studies conducted to examine the online sentence reading or listening comprehension under the theoretical framework of WM. There are, however, a couple of studies that have investigated the relationship between WM capacity and sentence comprehension measured by off-line tasks such as a sentence picture matching task. Furthermore, findings and their interpretation on the relationship between reduced WM capacity and sentence comprehension deficits in PWA are controversial. Several studies have suggested that WM measures are significantly and highly correlated with sentence comprehension performance in PWA (Caspari et al, 1998; Sung et al., 2008; Tompkins, Bloise, Timko, & Baumgaertner, 1994; Wright et al., 2007). Some researchers have argued that reduced WM capacity is related to sentence comprehension impairments in PWA (e.g., Miyake et al., 1994). Others have argued that observed reduced WM capacity does not account for sentence processing and comprehension deficits in certain groups of PWA such as individuals with Broca's aphasia (e.g., Friedmann & Gvion, 2003).

Miyake et al. (1994) hypothesized that normal individuals with reduced WM capacity would show patterns of performance similar to those of PWA on a sentence comprehension task under demanding conditions manipulated by syntactic complexity and presentation rates, using the rapid serial visual presentation paradigm (RSVP). Results revealed that the low WM span group performed significantly more poorly than the high WM group on more complex sentences and at the fast presentation rate. However, the combination of the two factors (syntactic complexity and presentation rate) did not interact with WM capacity. Miyake et al. argued that the pattern of performance on sentence comprehension tasks in the normal low WM span group was qualitatively similar to that of the performance of individuals with aphasia from Caplan et al. (1985). Based on these findings, Miyake et al. (1994) suggested that sentence comprehension disorders in PWA can be attributed, in part, to the reduction of general WM for language.

In contrast to the claim that WM capacity reduction is related to sentence comprehension deficits in PWA, several studies have suggested that there was no impairment in sentence comprehension even in the presence of limited WM (e.g., Friedmann & Gvion, 2003) or short-term memory capacity (e.g., Martin, Blossom-Stach, Yaffee, & Wetzel, 1995; Waters, Caplan, & Hildebrandt, 1991). Friedmann and Gvion (2003) investigated the relationship between WM capacity and sentence comprehension in three individuals with agrammatic production, three persons with conduction aphasia, and six control participants who were all Hebrew speakers. The authors manipulated the filler-gap distance by adding adjectives and prepositional phrases in both subject- and object-relative sentences. The group with conduction aphasia showed very limited digit-, word-, and non-word spans in both recognition and recall tasks, whereas a modified WM listening span given in a recognition task was limited in one individual, but reached ceiling values in the other two. Three individuals with agrammatic production showed limited digit, word, and non-word spans only in recall, but not in recognition tasks, while listening span reached ceiling values in two individuals with agrammatic production.

Friedmann and Gvion (2003) found that individuals with agrammatic production showed greater difficulties in the object-relative sentences than the subject-relative sentences. Despite the presence of very limited WM span in individuals with conduction aphasia, they performed well on both the subject-relative sentences with above 90% of accuracy and the object-relative sentences with better than 80% of accuracy. Both agrammatic and conduction aphasic groups were not affected by the distance between the filler and gap. Based on these findings, the authors argued that the results are not consistent with a single WM resource hypothesis given that persons with conduction aphasia who had “limited verbal WM capacity” did not show discrepancies between subject- and object relatives (Friedmann & Gvion, 2003, p. 35).

However, their interpretation of the results is not convincing enough to argue against the single WM resource capacity. Some members of both groups with agrammatic production and conduction aphasia showed relatively well-preserved WM capacity reflected in a listening and recognition version of the WM span task. Therefore, their interpretation that individuals with conduction aphasia showed good performance on sentence comprehension in the presence of the limited WM capacity is not entirely consistent with the data. The fact that the authors used the terms of WM and short-term memory (STM)[3] interchangeably makes their arguments on the relationship between WM and sentence comprehension in aphasia even more difficult to interpret.

[3] The STM construct is theoretically distinguished from WM. STM has been conceptualized as a capacity-limited storage or space in which small amounts of information is able to be held over brief intervals (e.g., Atkinson & Shiffrin, 1968). Baddeley and Hitch (1974) added “processing” or “working” component into a passive short-term storage buffer, and this processing component is a critical factor which differentiates WM from STM. Furthermore, Engle, Kane and colleagues considered STM a subset of WM by conceptualizing WM as STM plus executive attention (e.g., Engle & Kane, 2004). Although WM and STM have been theoretically differentially conceptualized, the terms have sometimes been used interchangeably by some researchers.

There appears to be little coherent evidence on the relation between WM and sentence comprehension deficits in aphasia. Furthermore, there are limits in interpreting the results of WM capacity in PWA tested by the traditional WM span measures. WM span measures were originally developed for assessing normal individuals' WM capacity, and participants are typically required to verbally recall the final words of each sentence while they make plausibility or accuracy judgments of each sentence. Verbal requirements of the WM span tasks make them very difficult to interpret especially for PWA who frequently have concurrent impairments in linguistic and motoric production processes. In this case, it is difficult to tell whether the limited span in individuals with aphasia is really due to problems in the processing or maintenance components involved in the verbal WM tasks or whether impaired performance is attributed to failure at production levels.

In sum, there are very few studies, which investigated both online and offline sentence processing under the theoretical framework of WM by systematically manipulating the WM loads in aphasia sentence comprehension literature. Furthermore, a critical factor that constrains WM is underspecified, and little attempt has been made to disentangle subcomponents of WM systems such as short-term storage buffer, the computational, or the executive attentional components in the previous literature.

2.1.4. The Effects of Locality on Sentence Comprehension as a Constraint on Working Memory Capacity

Demands on WM capacity have been manipulated in several ways, using syntactic complexity and fast presentation methods (e.g., Miyake et al., 1994; Waters & Caplan, 1996), or by using concurrent memory load with digit- or word-recall tasks (e.g., Fedorenko, Gibson, & Rohde, 2006; Gordon, Hendrick, & Levine, 2002; King & Just, 1991; Waters, Caplan, & Yampolsky, 2003). Among many factors which constrain WM capacity, Gibson (1998; 2000) suggested that the *distance* or the *locality* between the two linguistic elements to be integrated is a critical factor.

2.1.4.1. The Effects of Locality on Sentence Comprehension in Normal Individuals

Gibson (1998; 2000) proposed the *Dependency Locality Theory* (DLT) which suggested that the maintaining and processing components of WM are heavily influenced by the 'locality' between the two linguistic elements to be integrated. The theory assumes that there are two critical costs to WM. One of them is a 'storage cost' which is involved in "keeping track of incomplete dependencies" and the other component has been termed the 'integration cost' which is involved in "connecting a word into the structure for the input" (Gibson, 2000, p. 95). In terms of the storage cost, Gibson assumed that one *memory unit* (MU) is associated with each syntactic head required to complete the current input as a grammatical sentence. For example, the sentence-initial determiner *the*, needs to have the two syntactic heads of a noun and a verb; thus a cost of 2 MUs is expected to be charged to or consumed by the WM resource.

The integration cost involves two processes: One is discourse processing and the other is structural integration. Based on the established discourse processing literature, it has been suggested that the difficulty in processing a discourse referent depends on the accessibility of the referent in the current discourse. Gibson (2000) proposed a simplified version of discourse-processing cost derived from the binary distinction between 'old' and 'new' discourse referents, based on the assumption that only the processing of new discourse referents consumes resources. A discourse referent is defined as "an entity that has a spatiotemporal location so that it can later be referred to with an anaphoric expression, such as a pronoun for NP's or tense on a verb for events (Webber, 1988) (Gibson, 2000, p. 103). In other words, processing a noun phrase (NP) or a verb that refers to a new discourse event is assumed to consume substantial resources. In contrast, processing other referents which are not new or that are already present in the discourse is assumed not to consume substantive WM resources.

The other factor incorporated into theorizing the integration cost is the structural integration component. Gibson (2000) suggested that structural integration is a process associated with connecting the syntactic structure for a new linguistic input to its syntactic dependent. It is assumed that the structural integration cost depends upon the number of new discourse referents intervened between the new input and the site to which it is syntactically projected. For simplicity, a linear relationship is assumed between structural integration cost and the number of intervened new discourse referents. That is, Gibson (2000) proposed that one *energy unit* (EU) is consumed for each new discourse referent in the intervening region.

In sum, the DLT quantified the local increase of sentence processing difficulties at each word in a sentence by developing the EU metric for the integration cost or MU for the storage cost. However, Gibson (2000) noted that he initially considered the integration cost alone, ignoring the storage cost in terms of accounting for the complexity contrast between subject- and object-RC since the predicted patterns would be similar when storage cost is also taken into consideration. Examples that describe how the integration cost accounts for syntactic processing difficulties between the subject- and object-RC sentences are provided below.

(1) Subject-RC: *The nurse who called the doctor visited the patient.*

(2) Object-RC: *The nurse who the doctor called visited the patient.*

To estimate the integration cost imposed on each word, the new discourse-referential processing is considered first. One EU is assigned to the nouns such as *nurse*, *doctor*, and *patient* as well as to the tensed verbs such as *called* and *visited* in both sentence (1) and (2), since those words are the ones that count as new discourse referents. However, the structural integration is dissociated between sentence (1) and (2), and this difference occurs in the embedded verbs. For example, there is no structural integration cost assigned to the embedded verb '*called*' in sentence (1) because the attachment of the verb to the subject (*nurse*) is local, meaning that there is no new discourse referent intervened between the subject and the verb.

In contrast, structural integration for the embedded verb (*called*) in sentence (2) involves two steps. The first step is to attach the verb to the embedded subject (*doctor*), and there is no structural integration cost introduced at this stage because the attachment is local. The second step is related to the co-indexing procedure of the trace created as a result of moving the object (*the nurse*) from its original place to the surface place. The coindexation of the trace with the moved object (*the nurse*) occurs at the empty trace created right after the embedded verb (*called*). Two new discourse referents (*doctor, called*) were introduced between the empty trace and the moved object, resulting in 2 EUs of structural integration cost at the site of the trace.

When the discourse processing and structural integration cost are considered together at the embedded verb, *called,* in sentence (2), the total integration cost imposed at the verb is therefore 3 EUs with 1 EU from the new discourse-referential processing as a tensed verb and 2 EUs from the structural integration processing. In contrast, only 1 EU is assigned to the embedded verb in the sentence (1) as a total integration cost. Gibson and colleagues claimed that the different integration cost imposed in the embedded verbs account for the different processing difficulties between the subject- and object-extracted RCs.

Based on the metric for estimating the distance-based integration cost, the same integration cost is assigned for the main verb *visited* for both sentence (1) and (2), since the number of new discourse referents between the subject NP (*the nurse*) and the main verb (*visited*) is the same (*doctor, called*) for both sentence types. Therefore, the DLT proposed that the significant differences between object- and subject- RCs emerged at the embedded verb rather than at the main verb. The summary of the total integration cost from the discourse processing and structural integration processing is provided per each sentence type in Tables 1 and 2, respectively.

Table 1. Word-by-word predictions of the integration cost from the Dependency Locality Theory in the subject-relative clause structure

	Input word								
Cost Type	The	Nurse	who	**called**	the	doctor	visited	the	patient
New discourse referent	0	1	0	**1**	0	1	1	0	1
Structural integration	0	0	0	**0**	0	0	2	0	0
Total integration cost	0	1	0	**1**	0	1	3	0	1

Table 2. Word-by-word predictions of the integration cost from the Dependency Locality Theory in the object-relative clause structure

	Input word								
Cost Type	The	Nurse	who	the	doctor	**called**	visited	the	patient
New discourse referent	0	1	0	1	0	**1**	1	0	1
Structural integration	0	0	0	0	0	**2***	2	0	0
Total integration cost	0	1	0	1	0	**3***	3	0	1

* indicates the location where the differences occur between the two sentence types.

There is evidence that is consistent with online syntactic storage costs (e.g., Chen, Gibson, & Wolf, 2005; Warren, McConnell, & Grodner, 2008) and distance-based integration costs (e.g., Grodner & Gibson, 2005; Warren & Gibson, 2002; Warren et al., 2008). In the DLT, the storage cost is not assumed to be locality-sensitive since some of the evidence suggested that syntactic storage cost did not increase over distance, depending on the manipulation of the syntactic structures (e.g., Gibson, 2006). The storage cost hypothesis was supported in an on-line reading time study using a self-paced word-by-word moving window. Chen et al. (2005) demonstrated that reading time was associated with the number of predicted verbs and also with keeping track of a filler-gap dependency. The storage cost account was also corroborated in an eye-tracking experiment in which the number of syntactic predictions was manipulated via the number of arguments that a verb requires (Warren et al., 2008). The results from that study demonstrated that obligatorily ditransitive verbs required the longest processing times with the most regressive eye movements, and optionally ditransitive verbs induced intermediate processing difficulty. As predicted, transitive verbs generated the least processing difficulty, indicating that the syntactic storage cost was associated with the processing times reflected in the eye movements.

Another line of evidence is also consistent with the integration cost account for the local increase of sentence processing difficulties. As mentioned above, it is assumed that integration cost is determined by the distance between the newly encountered discourse referent and its antecedent to which the new input is linked. Among other sources (e.g., Gibson & Warren, 2004; Warren & Gibson, 2002), the most direct evidence regarding the long-distance dependency effects was provided by Grodner and Gibson (2005) who systematically manipulated the distance in two ways. They employed three different types of post-nominal modifiers; 1) no modifier, 2) prepositional phrases (PP), and 3) relative clause (RC). The other way of affecting the distance varied the syntactic dependency by manipulating subject-verb and filler-gap sentences. The matrix subject was modified in sentences with the subject-verb dependency, whereas the embedded subject was modified in sentences with the filler-gap dependency. The examples of sentence stimuli are given below (a) – (f) from Grodner and Gibson (2005, p. 273).

(a) Matrix-unmodified subject: The nurse supervised the administrator while…

(b) Matrix-PP modified subject: The nurse from the clinic supervised the administrator while…

(c) Matrix-RC modified subject: The nurse who was from the clinic supervised the administrator while…

(d) Embedded-unmodified subject: The administrator who the nurse supervised scolded the medic while…

(e) Embedded- PP modified subject: The administrator who the nurse from the clinic supervised scolded the medic while…

(f) Embedded-RC modified subject: The administrator who the nurse who was from the clinic supervised scolded the medic while…

Grodner and Gibson (2005) found that there were significant main effects for the type of modifiers with longer reading time presented in the RC modifier condition than the other two types of the modifiers and for the dependency with longer reading time observed in the filler-gap dependency than the subject-verb dependency. However, the interaction between the type of modifier and dependency was not significant, although the data followed the predicted pattern. The data indicated that reading times at the critical regions systematically increased in the filler-gap dependency compared to the subject-verb dependency as a function of the distance manipulation with the type of modifier. According to the regression analysis, the distance-based integration costs accounted for 88.9% of the variance in reading times at the verbs. The findings from Grodner and Gibson (2005) were also replicated by Warren et al. (2008). Results from experiment 2 of this study, in which eye-movement measures were used, indicated that the distance-based integration cost effects were not an artifact of the self-paced reading method.

While the results presented above supported the distance-based integration cost, as Grodner and Gibson (2005) noted, it is not clear whether the distance-based locality effects emerged in the same manner across all types of structural integrations. As Grodner and Gibson suggested, the representations and computations required for resolving the filler-gap dependencies can be different from those for the subject-verb dependencies, and thus it is possible that the distance or locality factor might differentially affect the two types of dependency resolutions. Although untested, the numerical trends of their results implied that there are possible differences in resolving the dependencies between the filler-gap and the subject-verb manipulations even when the distance-based integration cost is the same between the two types of the dependency manipulations. Figure 3 in the Grodner and Gibson's study (2005, p. 276) shows the reading times for each condition with longer reading times for the embedded verb in which the filler-gap dependency was manipulated without a modifier (e.g., *The administrator who the nurse* <u>*supervised*</u> *scolded the medic while*…) than in the main verb in which the subject-verb dependency was manipulation with a RC modifier padded into the embedded subject (e.g., *The nurse who was from the clinic* <u>*supervised*</u> *the administrator while*…). This occurred with the same integration cost of 3 EUs imposed for the two verbs.

More research is required to investigate the possibilities that WM capacity incorporated into the distance-based integration cost would differ depending on the nature of the dependency manipulation. That is, it needs to be determined whether the locality effect calculated by the distance metric can be linearly applied to all types of structural integration. Although the assumption for the linear integration cost might hold for normal individuals, it might not be the case for those who are assumed to have specific difficulties in processing sentences with movement structures such as in PWA.

2.1.4.2. The Effects of Locality on Sentence Comprehension in Persons with Aphasia

Several studies have investigated the effects of the distance on the accuracy of sentence comprehension using sentence-picture matching tasks (Berndt et al., 1997; Friedmann & Gvion, 2003), semantic anomaly judgments (Kolk & Weijts, 1996; Schwartz, Linebarger, Saffran & Pate, 1987), or computational modeling (Haarmann et al., 1997). Distance was manipulated by adding prepositional phrases in the subject- and object-RC sentence types (Berndt et al., 1997; Friedmann & Gvion, 2003) or by padding adjectives or adverbs either in active and passive sentence types (Berndt et al., 1997; Haarmann et al., 1997) or in subject- and object-RC sentences (Kolk & Weijts, 1996; Schwartz et al., 1987).

Berndt et al. (1997) examined the effects of the sentence length in four different sentence types such as active, passive, subject-RC, and object-RC by padding adjectives in the active and passive sentences (e.g., The *stubborn* woman is *gently* pushed by the *friendly* man: padding materials are italicized), whereas prepositional phrases were added in the subject- and object-RC sentence types (e.g., The man that the woman *with the black umbrella* pushes is old). In ten PWA including five individuals with conduction and five with Broca's type of aphasia, Berndt et al. found a significant main effect for sentence length with lower accuracy observed in the long sentences than the short sentences and a significant main effect for the sentence type with greater difficulties observed in the object-RC than the other sentences. The two-way interaction between the sentence length and sentence type was also significant, showing that lower accuracy was observed in the object-RC than in the subject-RC sentences especially under the condition with modifiers. Berndt et al. argued that the results were consistent with resource-reduction hypotheses, based on the ordinal pattern of sentence complexity which indicated that performance was degraded as a function of the sentence length especially under the difficult syntactic structure such as the object-RC sentence, when both groups were included.

Berndt et al. (1997) further analyzed the data by including only the five individuals with Broca's aphasia and found a significant main effect for the sentence length with lower accuracy in the longer sentences than the shorter sentences. There was also a significant main effect for sentence type with the object-RC exhibiting the lowest accuracy with no significant difference between the passive and active sentences, with both significantly more accurate than the subject-RC sentences. There was no significant two-way interaction. Only one individual with Broca's aphasia showed chance-level performance on passive sentences and above-chance performance on active sentences. One of the five persons with Broca's aphasia who showed most severely impaired sentence production performed well on all four sentence-types with approximately 80-90% accuracy. These results are not consistent with the TDH hypothesis and also suggest that sentence production and comprehension deficits don't necessarily co-occur.

One caveat from the Berndt et al. (1997) study is that the linguistic padding was not consistent across the sentence types, given that adjectives were padded in active and passive sentences, whereas a prepositional phrase was padded in the relative clauses.

Thus, it is not clear whether the results of the over-additive difficulties in the object-relative clause but not in the passive sentences were due to the nature of difference in the manipulation of padded materials between adjectives and prepositional phrases or due to the differential difficulties of the sentences. More systematic examination of the padding effects on the syntactic complexity is needed in order to understand which factors contribute most to the taxation of processing resources sufficiently to reveal a resource-induced effect on sentence comprehension in aphasia.

In contrast to the Berndt et al (1997) findings, Friedmann and Gvion (2003) did not find significant length effects on sentence comprehension, also tested using the binary sentence-picture matching task. Friedmann and Gvion employed subject- and object-RC sentences and manipulated the distance between the antecedent and the gap with; 2, 5, 7, and 9 words. The distance was manipulated by adding adjectives into the main subject or into the NPs in a prepositional phrase or having one or two prepositional phrases. A translated example from Hebrew into English with the longest distance of 9 words was provided as: "*This is the nice grandpa with the pleasant brown eyes and the white beard that the boy hugs*" (Friedmann & Gvion, 2003, p. 30). As the adjectives follow the noun in Hebrew rather than precede it as in English, adjective 'nice' padded into the noun 'grandpa' contributes to the distance manipulation between the antecedent ('grandpa') and the gap. Three persons with agrammatic aphasia, classified using the Hebrew version of the Western Aphasia Battery (Soroker, 1997), showed above chance performance on the subject-RC, but performance of two individuals with agrammatic aphasia on the object-RC sentences were not significantly different from chance. One individual with agrammatic aphasia performed significantly better than chance on object-RC sentences. In contrast, three persons with conduction aphasia performed significantly above chance on all sentence types, and there was no difference between the two sentence types for each individual. However, performance for both groups with aphasia was not influenced as a function of the distance between the antecedent and the gap in either of the sentence types.

In Friedmann and Gvion's (2003) experiment 2, performance on the lexical disambiguity resolution was examined by manipulating the distance between the ambiguous word and the place at which the lexical ambiguity is resolved. They found that the three persons with conduction aphasia were negatively affected by the distance in a sentence-plausibility task with poorer performance observed in the long sentences than the short sentences, whereas persons with agrammatic aphasia did not perform differently between the short and long distance disambiguation. Based on the combined results from both experiments 1 and 2, the authors argued that syntactic-movement is impaired in individuals with agrammatic aphasia, whereas a phonological reactivation process is impaired in individuals with conduction aphasia.

Friedmann and Gvion (2003) argued that the null effects of the distance were comparable to the findings from Schwartz et al. (1987), given that Schwartz et al. also did not find significant padding effects. In the Schwartz et al. study, six individuals with agrammatic aphasia showed significantly poorer performance on a sentence plausibility task in a condition with the passive movement structure (e.g., "The woman was seen by the man") than in the active sentence (e.g., "The man saw the woman") and in the condition with padding (e.g., "As the concert began, the well-dressed man looked across the room and saw the woman who worked in his office"). However, individuals with agrammatic aphasia did not demonstrate a significant padding effect, although all of them showed a numerical trend of generating more errors in the padded condition than the non-padded active sentence. In contrast to the performance from those individuals with agrammatic aphasia, six persons with "fluent" aphasia demonstrated significantly greater difficulties in the padded condition than the non-padded active sentences and no significant differences between the condition with the movement structure and the padded sentence. The only significant differences between the two groups were found in the padded condition with greater distance effects observed in the group with fluent aphasia than the group with agrammatic aphasia.

Kolk and Weijts (1996) performed a partial replication of the Schwartz et al. (1987) study and found that there was a significant padding effect, which negatively affected performance on the sentence plausibility task in fifteen individuals with agrammatic aphasia. They reported that 12 out of 15 participants showed more errors in the padded condition than the other conditions. The authors argued that the combined results from their study and Schwartz et al.'s study suggested that there was a reliable effect of lexical padding on the sentence plausibility judgment in individuals with agrammatic aphasia, although the effect of the movement structure was greater than the lexical padding effect.

One of the caveats in the three studies reviewed above (Friedmann & Gvion, 2003; Kolk & Weijts, 1996; Schwartz et al., 1987) is that they did not examine the padding effect as a function of syntactic structures. Friedmann and Gvion demonstrated the distance effect by combining the subject- and object-RC sentences in a single graph. It is therefore difficult to examine a numerical trend of the distance effects for each type of sentence, although the authors noted that the separate analysis of the distance effects for each type of sentence was not statistically significant. In the other two studies, the interaction between the padding and movement was not tested statistically, and the padding was not systematically manipulated between the active sentences and sentences with movement structure. Due to this limitation, it is hard to compare the results from the three studies with the results from Berndt et al. (1997) who reported a significant distance effect and a significant interaction between the distance and syntactic structure in ten individuals with agrammatism and anomia.

In the aphasia literature, there are few studies that have examined the distance effects both in online and offline sentence processing and comprehension measured by reading or listening times and end-of-sentence tasks. Furthermore, there is no study that has systematically varied the distance using different types of modifiers depending on the syntactic dependencies. Therefore, it is necessary to examine the distance effects in both on-line and end-of-sentence performance for both people with aphasia and normal elderly controls using a systematic distance metric, such as that established by Gibson's (1998; 2000) locality theory. While Friedmann and Gvion (2003) calculated the distance based on the number of words intervened between the antecedent and the gap including the adjectives, prepositions, and conjunctions, all word types are not assumed to require substantial resources according to the locality-based metric proposed by Gibson and colleagues. Further studies need to investigate whether sentence comprehension in PWA is affected when the distance is systematically manipulated using a theoretically established distance metric under the framework of WM capacity.

2.2. SUMMARY AND STATEMENT OF PURPOSE

Many theories have been proposed in order to account for sentence comprehension deficits in aphasia. One of them is based on the assumption that people with agrammatic Broca's aphasia have lost syntactic representations, rules, or computations (e.g., Grodzinsky, 1986; 1995; 2000; Hickok & Avrutin, 1995; Hickok, Zurif, & Canseco-Gonzalez, 1993; Mauner, Fromkin, & Cornell, 1993). This line of research shared a common assumption that people with agrammatic Broca's aphasia have specific deficits in certain syntactic computations such as coindexing the gap with the filler. However, this approach, termed the specific impairment hypotheses, has been questioned in several ways. First, there is little theoretically and empirically substantiated evidence for the assumption that the specific impairments in computing the filler-gap dependency hold only for a particular type of aphasia (so-called "agrammatic Broca's aphasia"). Some researchers have found that individuals with agrammatic Broca's aphasia showed little impairments of sentence comprehension (e.g., Berndt et al. 1996). Others have found impaired syntactic comprehension in people with aphasia who did not present with agrammatic production (e.g., Caramazza & Zurif, 1976; Caramazza & Miceli, 1991; Mitchum et al., 1995). These inconsistent findings between agrammatic production and comprehension raise questions about the underlying principle for linking sentence production deficits to the syntactic comprehension deficits.

In contrast, another approach to account for sentence comprehension deficits in aphasia does not assume a specific loss of linguistic knowledge; rather, it argues that reduced processing resources contribute to syntactic comprehension deficits regardless of the specific types of aphasia (e.g., Caplan & Hildebrandt, 1988; Caplan et al., 2007; Dick et al., 2001; Haarmann et al., 1997). These researchers found that more severely impaired PWA on sentence comprehension showed differentially greater difficulties as a function of syntactic complexity compared to less severely impaired PWA (e.g., Caplan et al., 1985; Miyake et al., 1994). These findings were interpreted as indicating that individuals with less processing resources had greater impairments than individuals with more processing resources especially in the sentence types which required more processing resources. However, critical factors which constrained processing resources in sentence comprehension have been underspecified in the general resource-reduction explanations by most investigators.

Some researchers have, however, specified the processing resources that are required specifically for sentence comprehension as verbal WM. Under these verbal WM accounts, some researchers have argued that there is a domain-general WM system applied to all types of sentence processing (e.g., Just & Carpenter, 1992; Miyake et al., 1994). Others claimed that there are at least two separate WM systems: One engaged in automatic, unconscious, obligatory and interpretive syntactic processing and the other involved in controlled, conscious and post-interpretive sentence processing (e.g., Caplan & Waters, 1999). However, these two WM hypotheses (single vs. multiple WM systems) have not been explicitly examined in the clinical population with aphasia, and the questions surrounding their precise nature in PWA remain unresolved.

There has been an attempt to examine WM requirements for sentence processing in young normal adults by specifying the primary factors that affect WM. Gibson and colleagues (1998; 2000) proposed that among other factors, distance between the two linguistic elements to be integrated is one of the critical factors that impose the greatest demands on WM. However, there are few studies which have examined the effects of distance on sentence processing in PWA compared to older adults by systematically manipulating the distance using a theoretically well motivated distance metric.

The purposes of the current research were twofold: The first purpose was to investigate the effects of systematically manipulating distance on sentence comprehension in PWA and in an age-matched normal control group. The second purpose of the study was to investigate the effects of syntactic dependency on sentence comprehension in both PWA and normal adults, when the distance is held constant between the subject-verb and filler-gap dependencies.

In order to accomplish the first purpose of the study, the following hypotheses were examined by systematically manipulating the distance using three different post-nominal modifier conditions (no modifier, prepositional phrase, and relative clause) and two types of linguistic dependencies (subject-verb and filler-gap): 1) there are significant differences in the reading times at the first verb as a critical region and accuracies to yes/no sentence comprehension questions across the groups, as the distance is increased and 2) there are significant differences between the normal group and the group with aphasia in the reading times and accuracies as a function of the distance manipulations. Gibson (1998) quantified the reading times as "the ratio of the integration cost required at the state to the space currently available for the computation" (p. 16). If PWA have a limited STM span, impaired syntactic computations, or reduced executive attentional resources, or problems in all or any combination of the three WM components underlying their sentence comprehension impairments compared to the normal group, it would be predicted that PWA would show over-additive processing difficulties compared to the normal group as the distance increases. This would result in significant interactions among the group, modifiers, and dependency types in both reading times and accuracy measures. This prediction is consistent with the resource-related WM hypotheses (e.g., Caplan et al., 1985; Caplan et al., 2007; Miyake et al., 1994), but not with the specific impairment hypotheses; specifically the Trace Deletion Hypothesis. While the effects of distance or sentence length were not explicitly considered in the TDH, it does not predict an effect of the sentence length manipulation on comprehension, given that the addition of modifiers do not affect the trace (Berndt et al., 1997). Thus, the TDH would not predict over-additive degradation of performance on the filler-gap sentences as a function of modifiers in PWA compared to NI.

However, if distance manipulation overtaxes normal elderly adults' WM capacity, due to the high WM demands imposed especially by the filler-gap computations, over-additive degradation in PWA compared to normal older adults would not be expected, given that abilities to compute filler-gap dependency declines in older age groups (e.g., Davis & Ball, 1989; Emery, 1985; Feier & Gertsman, 1980; Zurif et al., 1995).

In order to assess the second purpose of the study, the following hypothesis was investigated: There will be significant differences between the filler-gap dependencies and subject-verb dependencies in PWA compared to the normal individuals, when the distance is controlled between the two types of linguistic dependencies. The Dependency Locality Theory (Gibson, 1998; 2000) does not predict significant differences in the local processing times between the two linguistic dependencies, once the distance for each type of sentence is equated based on the assumption that the distance affects equally all types of syntactic computations. However, it was predicted that there would be greater difficulties in processing sentences with the filler-gap dependency than with subject-verb dependency even when the distance is held constant, resulting in a significant main effect for the dependency. Although the number of new discourse referents is same between the two linguistic dependencies according to Gibson's (1998; 2000) model, it is derived from the two different structural integration processes for the subject-verb versus filler-gap dependencies. If the structural integration cost from the co-indexation process poses differentially greater computational loads on WM for sentence comprehension than that from the subject-verb association, greater processing difficulties in the filler-gap than subject-verb association will be reflected in the accuracy and reading times at the verb.

It was also assumed that there would be over-additive difficulties in sentences with the filler-gap dependency than with the subject-verb dependency especially for PWA, resulting in a significant two-way interaction between the group and dependency. Greater difficulties in processing filler-gap dependencies than the subject-verb dependencies for PWA compared to NI could be accounted for by both the specific impairment hypotheses and the resource-related WM hypotheses. Resource-related WM hypotheses would assume that there are insufficient WM resources required to compute the filler-gap dependencies with greater computational WM loads than the subject-verb dependencies for PWA compared to NI. Based on the assumption, it was predicted that PWA would generate more errors and longer reading times at the verb in the filler-gap than subject-verb dependency conditions. If PWA have impaired abilities to resolve the filler-gap associations, they also would show greater difficulties in processing the filler-gap than subject-verb associations compared to normal individuals. However, the specific impairment hypotheses have been applied only to a specific type of aphasia such as agrammatic Broca's aphasia, and thus these hypotheses would not predict an over-additive performance degradation in filler-gap dependency in a group of PWA with other aphasia types.

2.3. SIGNIFICANCE

This research was designed to contribute to understanding the nature of the sentence processing difficulties by examining how distance affects sentence processing as a critical factor in both PWA and non-impaired normal individuals. Although there are several studies which have manipulated the distance between linguistic elements to be integrated in PWA (Berndt et al., 1996; Friedman & Gvion, 2003; Kolk & Weijts, 1996; Schwartz et al., 1987), the distance has not been systematically controlled depending on the linguistic dependencies. This study was designed to investigate 1) whether processing difficulties vary as a function of the distance and 2) whether greater processing difficulties are imposed in the filler-gap than the subject-verb dependencies when the distance is controlled between the two linguistic dependencies.

3.0. RESEARCH DESIGN AND METHODS

3.1. PARTICIPANTS

Thirty NI (14 female; 16 male) and 20 PWA (8 female; 12 male) participated in the study. They were all native English speakers. Both groups completed the following screening procedures: (a) vision screening with the reduced Snellen chart with 20/40 or better visual acuity (with correction if necessary) and (b) performance on the immediate/delayed story retell task of the *Assessment Battery of Communication in Dementia* (ABCD) (Bayles & Tomoeda, 1993) yielding a ratio (the delayed recall/immediate recall x 100) greater than 0.70 on the delayed recall compared to the immediate recall. All normal participants had a self-reported negative history for neurologic, limb motor, psychiatric, visual, speech/language, and reading impairments. Mean of age for the NI group was 66 (SD=12) with the range of 41 to 87, and their mean education was 14 years (SD=2) with the range of 12 to 20.

3.2. SCREENING AND DESCRIPTIVE MEASURES

All twenty PWA demonstrated language deficits caused by focal damage to cortical and/or subcortical structures of the hemisphere(s) dominant for language, consistent with the McNeil and Pratt (2001)'s definition of aphasia as determined by performance on the *Porch Index of Communicative Ability* (PICA) (Porch, 2001) and the *Computerized Revised Token Test* (CRTT) (McNeil, Pratt, Szuminsky et al., 2008). PWA presented with no history of degenerative central nervous system disease and psychiatric problems. Mean age for the PWA was 60 (SD=14) with a range of 40 to 91, their mean education was 16 (SD=3) with the range of 12 to 24.

Both groups were administered the following descriptive and screening measures: a) PICA as a test of general language performance, b) CRTT as a test of auditory sentence comprehension, c) a reading version of the CRTT presented using a self-paced word-by-word presentation (CRTT-R-$_{WF}$) (McNeil, Pratt et al., 2008) as a test of reading sentence comprehension, d) Written Word-Picture Matching subtest from the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA) (Kay, Lesser, & Coltheart, 1992) and the Verb Comprehension Test from the Northwestern Assessment of Verbs and Sentence-Revised (NAVS-R) (Thompson et al., 2008) as tests of single-word reading comprehension, e) forward word/digits pointing span task as a short-term memory span measure and backward word/digits pointing span task as a working memory span measure, f) the Raven Coloured Progressive Matrices (Raven, 1956) as a non-verbal cognitive skill test, g) the Edinburgh Handedness Inventory (Oldfield, 1971) as a test of handedness, h) the *Subject-relative, Object-relative, Active, and Passive* (SOAP) test (Love & Oster, 2002) as a test of syntactic complexity comprehension, and i) a single form of story retelling procedure (McNeil et al., 2007) as a measure of connected speech. Specific information of individuals' performance on the measures from a) through f) was summarized in Table 3 for NI and Table 4 for PWA.

One-way ANOVAs revealed that there were also not significant differences between the groups in age, $F(1, 49)=2.76$, $p>.10$, and years of education, $F(1, 49)=2.76$, $p>.05$. PWA performed significantly worse than NI in all of the screening and descriptive measures (all *p*s<.05) except for the PALPA in which the two groups were not significantly different ($p>.10$).

The handedness survey revealed that 27 NI were right-handed, and three participants were ambidextrous. Eighteen PWA were pre-morbidly right-handed, and one was ambidextrous, and one was left-handed.

Table 3. Performance on descriptive and screening measures in normal individuals

ID	PICA		CRTT-A	CRTT-R-$_{WF}$	PALPA	NAVS-R	F-D	F-W	B-D	B-W	RAVEN
	OA	%ile									
101	14.43	40	14.68	13.12	40	22	6.6	4.4	5.8	2.8	34
102	14.55	55	13.04	11.42	40	22	7	6	6.8	4.8	33
103	14.67	70	14.04	12.82	39	22	5	4.2	4.6	3.6	32
104	14.26	25	14.35	12.75	39	21	5.6	3.4	5	3.4	30
105	14.11	22	14.25	12.63	40	22	7	5	5	4.2	30
106	14.26	25	14.85	12.88	40	22	6	5.4	4.4	3.2	31
107	14.17	20	14.51	12.58	39	22	7	6.6	7	4.2	31
108	14.01	16	14.74	12.91	39	22	6	5.2	6	5	34
109	14.39	35	14.48	13.07	38	22	5.2	4	4	2.6	25
110	13.97	10	14.57	12.81	39	22	6.4	5.2	5	2.6	33
111	13.89	7	14.69	12.51	40	22	6.6	6	5.6	4.8	33
112	14.4	37	14.86	12.67	40	22	6.6	5.2	5.6	4.8	35
113	14.14	20	14.85	12.92	39	22	5.8	4.8	4.6	3.4	26
114	14.01	17	14.68	12.74	39	22	6.8	5	4.4	3.8	29
115	14.38	35	14.58	12.93	40	22	6.8	5.8	5.4	5.4	32
116	13.99	10	14.43	13.39	39	22	7	5	6.2	5	33
117	14.52	50	14.44	12.92	39	22	7	5.6	4.6	3.8	35
118	14.34	37	14.21	12.88	39	22	7	6	6.6	5	31
119	14.56	55	14.57	13.58	40	22	7	5.6	7	5	36
120	14.15	20	14.67	13.37	37	22	7	6	7	5.4	33
121	14.16	20	14.63	12.8	38	22	7	5.6	6	5	28
122	14.08	15	14.67	12.73	40	22	6.8	5	5.4	4.4	30
123	14.2	23	12.77	13.87	40	22	6.4	5.4	6	4.8	32

124	13.87	5	14.63	12.77	39	22	5	3.6	4.4	3	36
125	14.79	85	14.12	12.71	40	22	6	5.4	4.4	3.8	32
126	14.26	25	14.64	12.94	40	22	6	4.8	5.8	4	33
127	14.1	20	14.07	12.76	39	22	5.8	4.6	4	4	33
128	14.33	33	14.41	12.95	40	22	7	6.8	7	6.8	36
129	14.37	35	13.58	12.95	40	22	7	7	7	6.4	36
130	14.39	35	14.84	12.75	40	22	6.8	5.8	5.8	4.2	31
Mean	14.26	30.07	14.4	12.87	39.37	21.97	6.44	5.28	5.55	4.31	32.1
SD	0.23	18.4	0.5	0.4	0.76	0.18	0.64	0.85	0.99	1.03	2.77

SD = Standard Deviation
PICA = Porch Index of Communicative Ability (PICA) (Porch, 2001)
PICA %ile: Norms for the PICA percentile are from Porch (2001) for PWA and from Duffy and Keith (1980) for NI
CRTT-A = Auditory version of the Computerized Revised Token Test (CRTT) (McNeil, Pratt, Szuminsky et al., 2008)
CRTT-R-WF = A reading version of the CRTT
PALPA = Written Word-Picture Matching subtest from the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA) (Kay, Lesser, & Coltheart, 1992)
NAVS-R = Northwestern Assessment of Verbs and Sentences-Revised (Thompson et al., 2008)
F-D = Forward digit pointing span task (Martin, Kohen, & Kalinyak-Fliszar, 2008)
F-W = Forward word pointing span task (Martin, Kohen, & Kalinyak-Fliszar, 2008)
B-D = Backward digit pointing span task
B-W= Backward word pointing span task
RAVEN = The Raven Coloured Progressive Matrices (Raven, 1956)

Table 4 Performance on descriptive and screening measures in individuals with aphasia

Participant ID	PICA		CRTT-A	CRTT-R-$_{WF}$	PALPA	NAVS-R	F-D	F-W	B-D	B-W	RAVEN
	OA	%ile									
201	11.21	54	11.27	10.67	36	19	3	2.4	2.2	2	30
202	13.14	78	14.38	10.85	40	22	5.8	5.2	3.8	3.8	20
203	11.22	54	12.21	12.28	37	19	2.8	1.8	1.6	1.6	33
204	12.48	69	12.4	10.45	37	21	3.2	2.4	3	2.2	14
205	12.27	66	11.93	12.75	37	22	4.4	3.4	5	3	32
206	14.04	89	13.43	11.72	39	22	6	4.8	3	2.8	33
207	13.21	79	12.99	11.00	40	21	5.6	5	4	4.6	25
208	13.06	77	12.37	12.05	35	21	4.6	2.2	3.8	2.2	33
209	12.73	72	10.93	12.53	39	22	3.4	2.8	4.2	3.4	35
210	13.58	84	14.37	12.6	39	22	5	3.6	3.2	3	23
211	12.85	74	12.44	12.31	40	22	4.4	3.6	4	3	32
212	13.46	82	13.53	12.68	39	22	5.8	5	5	3	32
213	12.52	69	14.31	11.93	40	20	3.6	2.2	2.6	2	12
214	13.86	88	11.6	12.81	37	22	4.8	3.8	3.8	3	34
215	12.77	73	13.02	11.62	40	22	3.8	2.4	2.4	2.4	27
216	14.09	90	14.44	12.71	40	22	4.8	3.2	3.4	2.4	23
217	14.21	92	14.43	13.03	40	22	7	5.6	5	4	34
218	13.04	76	12.91	11.37	40	22	6.2	4.2	4	4	27
219	13.56	84	13.12	12.00	40	22	5	3.8	4.8	3	35
220	13.36	10.07	14.1	12.77	40	22	5	4	3	2.4	34
Mean	13.03	73.00	13.01	12.01	38.75	21.45	4.71	3.57	3.59	2.89	28.40
SD	0.83	18.22	1.11	0.79	1.62	1.00	1.16	1.14	0.97	0.78	6.91

3.2.1. Performance on a Test of Syntactic Complexity

The percent correct for the SOAP was calculated for each of the four syntactic structures (active, passive, subject-relative, and object-relative) for each participant in both groups. The mean of the percent correct for each condition was described in Table 5 for both groups.

Table 5. The mean of the percent correct (standard deviation) for each condition from the SOAP in both groups

	Active	Passive	Subj-R	Obj-R	Canonical	Non-canonical
NI	99 (3)	97 (7)	100 (2)	86 (14)	100 (2)	92 (8)
PWA	96 (7)	86 (14)	88 (13)	59 (19)	92 (9)	73 (14)

Note: NI=Normal Individuals; PWA=Persons With Aphasia; Subj-R=Subject-Relative sentence; Obj-R=Object-Relative sentence; Canonical= Canonical sentences (averaged performance from Active and Subj-R sentences); Non-canonical= Non-canonical sentences (averaged performance from Passive and Obj-R sentences)

Results of a one-way ANOVA revealed that PWA performed significantly more poorly than NI in all of the four syntactic structures: Active, $F(1, 49)=4.24$, $p<.05$, passive, $F(1, 49)=14.48$, $p<.000$, subject-relative, $F(1, 49)=24.37$, $p<.000$, and object-relative sentences, $F(1, 49)=34.67$, $p<.000$.

In order to examine whether participants' performance on each syntactic structure was significantly different from chance, a two-tailed unpaired *t*-test was computed for each group with the test value of 33, given that 33% accuracy is considered chance-level performance in a three-choice picture-matching task. Both NI and PWA group showed significantly better than chance performance in all four types of sentences: 1) Active, $t_{29}=143.21$, $p<.000$ for NI and $t_{19}=19.62$, $p<.000$ for PWA, 2) Passive, $t_{29}=53.84$, $p<.000$ for NI and $t_{19}=15.11$, $p<.000$ for PWA, 3) Subject-Relative, $t_{29}=200.00$, $p<.000$ for NI and $t_{19}=19.20$, $p<.000$ for PWA and 4) Object-Relative, $t_{29}=21.04$, $p<.000$ for NI and $t_{19}=5.35$, $p<.000$ for PWA.

In order to examine the patterns of performance depending on canonicity, the four syntactic structures were categorized into the two categories as Love and Oster (2001) had done: Canonical sentence type (averaged performance of active and subject-relative constructions) vs. Non-canonical sentence type (averaged performance of passive and object-relative constructions). Each group was examined using the two-tailed paired *t*-test to determine significant differences between canonical and non-canonical sentence types. Performance on the canonical sentences was significantly better than the non-canonical sentences in both NI, $t_{29}=5.52$, $p<.000$, and PWA, $t_{19}=9.02$, $p<.000$.

Chance-level differences between canonical and non-canonical sentence types were also examined by computing a two-tailed unpaired *t*-test for each group. Both NI and PWA performed significantly better than chance in both canonical and non-canonical sentences (NI: $t_{29}=238.74$, $p<.000$ for canonical and $t_{29}=38.04$, $p<.000$ for non-canonical sentences and PWA: $t_{19}=22.48$, $p<.000$ for canonical and $t_{19}=10.65$, $p<.000$ for non-canonical sentences).

Finally, in order to identify each individual who performed at chance-level (i.e., not significantly difference from chance-level), the 95% confidence interval (CI) was calculated using the binomial probabilities with reference to the table which gives critical values for testing the null hypotheses that the population proportion is equal to .50 (Marascuilo & Serlin, 1988; p. 756). The 95% CI was between 4 and 62% accuracy. In other words, performance on each syntactic construction which falls between 4 and 62 percent correct was not significantly different from chance. Those who performed below 4% or above 62% accurate were significantly worse or better than chance-level performance. All NI performed significantly better than chance on active (M=99.33, SD=2.54), passive (M=97, SD=6.51), and subject-relative (M=99.67, SD=6.51) sentences. Two normal participants performed at chance-level on the object-relative sentence type, and both individuals showed 60% accuracy. On average, 86% accuracy (*SD*=13.80) was observed in object-relative sentences for NI. None of the NI showed chance-level performance either on the aggregated canonical (*M*=99.5, *SD*=1.53) or non-canonical (*M*=91.5, *SD*=8.42) sentence types.

All of twenty PWA showed significantly better than chance performance on active (*M*=96, *SD*=6.81) and subject-relative (*M*=88, *SD*=12.81) sentences. There was only one PWA who showed chance-level performance on passive sentences with 50% accuracy. However, 13 of 20 (65%) PWA showed chance-level performance on object-relative sentences. The average performance of the chance-level PWA performers (*n*=13) was 48.46 (*SD*=12.81; *Range*=20-60), and the average of the remaining participants (*n*=7) who performed significantly better than chance was 78.57 (*SD*=9; *Range*=70-90). In sum, there was only one individual with aphasia (Participant ID=209) who showed chance-level performance in both passive (50% of accuracy) and object-relative (20% of accuracy) sentence types.

None of the PWA performed at chance-level on canonical sentences. There were three individuals with aphasia (Participant ID=209, 213, and 219) who performed at chance-level on non-canonical sentences (35%, 60%, and 60%, respectively). The remaining participants (*n*=17) performed significantly better than chance on non-canonical sentences (*M*=76.18, *SD*=10.54, *Range*=65-95).

3.2.2. Connected Speech Sample

Connected speech samples were obtained for both NI and PWA groups from a randomly selected single form of the story retelling procedure (McNeil et al., 2007). The obtained data was used as a descriptive measure of sentence production. The speech sample was digitally recorded and orthographically transcribed. One of the participants with aphasia (Participant ID=203) was not able to provide any intelligible speech from the sampling procedure. Thirty normal individuals and 19 individuals with aphasia were included for the data analysis.

Lexical and morphosyntactic patterns of the speech sample were analyzed by examining (a) number of utterances (#U), (b) number of words (#W), (c) mean length utterance-word (MLU-w), (d) mean length utterance-morpheme (MLU-m), (e) number of open class word (#O), (f) number of closed class word (#C), (g) ratio of open to closed class word (open/closed ratio), (h) number of nouns (#N), (i) number of verbs (#V), (j) ratio of noun to verb (noun/verb ratio), and (k) percent of grammatically well-formed utterance (%GWU).

These measures were obtained using a method developed by Thompson, Shapiro, Tait, Jacobs, Schneider, and Ballard (1995) in conjunction with using a computer package for the analysis of language samples, the *Systematic Analysis of Language Transcripts* (SALT) (Miller & Chapman, 1998).

One-way ANOVAs were performed to test whether there were significant differences between NI and PWA groups in any of the linguistic measures. There were significant differences between the groups on all of the linguistic measures except for the open/closed ratio and noun/verb ratio. Descriptive and statistical information from the one-way ANOVAs is summarized in Table 6.

Table 6 Means (standard deviation) and F-statistics for each linguistic measure obtained from a story retelling procedure in both groups

	NI	PWA	F-statistics
#U	13.79 (2.92)	11.86 (3.75)	$F(1, 47) = 4.06$, $p<.05$
#W	155.34 (35.51)	143.25 (46.40)	$F(1, 47) = 4.12$, $p<.05$
MLU-w	10.91 (1.94)	8.50 (2.27)	$F(1, 47) = 15.67$, $p<.000$
MLU-m	11.95 (2.14)	9.39 (2.45)	$F(1, 47) = 13.87$, $p<.005$
#O	68.46 (16.05)	48.82 (19.72)	$F(1, 47) = 14.55$, $p<.000$
#C	90.62 (22.31)	62.25 (26.89)	$F(1, 47) = 16.04$, $p<.000$
open/closed ratio	0.78 (0.10)	0.82 (0.21)	$F(1, 47) = 0.96$, $p=.33$
#N	27.77 (5.33)	19.51 (7.99)	$F(1, 47) = 18.91$, $p<.000$
#V	27.24 (6.15)	19.60 (7.90)	$F(1, 47) = 14.39$, $p<.000$
noun/verb ratio	1.07 (0.22)	1.04 (0.25)	$F(1, 47) = 0.18$, $p=.67$
%GWU	91.50 (9.58)	66.43 (21.58)	$F(1, 47) = 31.12$, $p<.000$

Note: NI=normal individuals; PWA= persons with aphasia
#U= number of utterances; #U= number of words; MLU-w= mean length utterance-word; MLU-m= mean length utterance-morpheme; #O= number of open class word; #C= number of closed class word; open/closed ratio= ratio of open to closed class word; #N= number of nouns; #V= number of verbs; noun/verb ratio= ratio of noun to verb; %GWU= percent of grammatically well-formed utterance.

It was further examined as to whether individuals with aphasia performed significantly lower than the group with aphasia using a modified *t*-test, using the formula provided from Crawford and Howell (1998, p. 483).

$$t = \frac{X_1 - \overline{X}_2}{S_2\sqrt{\frac{N_2 + 1}{N_2}}}$$

Note: X_1 = the individual's score; $\overline{X}_2$ =the mean of the normative sample; S_2= the standard deviation of the normative sample; N_2= the sample size

There was no individual with aphasia who differed significantly from the group on the number of utterances, words, open class words, closed class words, nouns, verbs or noun to verb ratio.

Participant 201 generated a significantly higher ratio of open class to closed class (1.55) words compared to the rest of the group (mean=0.82), t_{17}=6.16, p<.05. Participant 209 exhibited a significantly smaller MLU-w (4.12), t_{17}=-2.19, p<.05, and MLU-m (4.33), t_{17}=2.66, p<.05, than the group mean (MLU-w=8.75 and for MLU-m=9.71). Participant 214 presented significantly lower %GWU (12.7), t_{17}=-3.12, p<.05, than the group (mean= 65.87).

3.3. EXPERIMENTAL DESIGN AND STIMULI

The locality-based integration cost was manipulated in two ways following the same procedures as Grodner and Gibson (2005). One way of manipulating the distance between the two linguistic elements employed subject-verb and filler-gap dependencies in which filler-gap dependencies result in longer distance than the subject-verb dependencies due to their structural differences. The other manipulation of the distance varied the types of post-nominal modifiers with no modifier, a prepositional phrase and a relative-clause. It was hypothesized that reading times for the first verb would be the longest and accuracy to yes/no question would be the lowest in sentences with filler-gap dependencies with RC modifiers compared to the other sentences.

The current experiment consisted of six conditions with two levels of linguistic dependency (subject-verb vs. filler-gap) and three levels of post-nominal modifiers (bare, prepositional phrase, relative clause). Specific examples of each sentence for each condition are illustrated below. The numbers in parenthesis indicate the computed integration cost (EU) imposed for each word.

a) SV dependency – No modifier (SV-No)

The (0) nurse (1) called (1) the (0) doctor (1) in (0) the (0) morning (1).

b) SV dependency – Prepositional Phrase (PP) modifier (SV-PP)

The (0) nurse (1) from (0) the (0) clinic (1) called (2) the (0) doctor (1) in (0) the (0) morning (1).

c) SV dependency – Relative Clause (RC) modifier (SV-RC)

The (0) nurse (1) who (0) was (1) from (0) the (0) clinic (1) called (3) the (0) doctor (1) in (0) the (0) morning (1).

d) FG dependency – No modifier (FG-No)

The (0) doctor (1) who (0) the (0) nurse (1) called (3) visited (3) the (0) patient (1) in (0) the (0) morning (0).

e) FG dependency – PP modifier (FG-PP)

The (0) doctor (1) who (0) the (0) nurse (1) from (0) the (0) clinic (1) called (5) visited (4) the (0) patient (1) in (0) the (0) morning (0).

f) FG dependency – RC modifier (FG-RC)

The (0) doctor (1) who (0) the (0) nurse (1) who (0) was (1) from (0) the (0) clinic (1) called (7) visited (5) the (0) patient (1) in (0) the (0) morning (0).

The construction of the stimuli was based on the form of initial clause in the sentences from both Grodner and Gibson (2005) and Warren et al. (2008). As outlined above, this created six different conditions by manipulating the distance in two ways: (1) by having the SV and FG linguistic dependency and (2) by varying the types of post-nominal modifiers that were padded into either the matrix subjects in the sentences with the SV dependency or the embedded subjects in the sentences with the FG dependency.

Sentence stimuli consisted of a transitive verb with animate NP arguments in which either the matrix subject or the embedded subject is unmodified, PP-modified or RC-modified. The RC-modifier conditions were constructed from the PP-modifier conditions by inserting the relative pronoun (who) and a tensed verb (was), and thus created minimal semantic differences between the PP- and RC-modifier conditions. Sentences with the FG dependencies were created as a variant of the sentences with the SV dependencies by having the object NP of the sentences with the SV dependencies as the subject of the sentences with the FG dependencies. There were thirty sets of sentences per condition (Grodner & Gibson, 2005).

The original sentence stimuli from the two previous studies were adjusted in two ways in order to make them as appropriate as possible for PWA. First, the original sentence stimuli ended with an adjunct clause that is related to the main clause (e.g., *The nurse supervised the administrator while a patient was brought into the emergency room*). However, for the current study, the adjunct clause was truncated to the adverbial phrase in order to reduce the memory load (e.g., *The nurse called the doctor in the morning*).

Second, the log-normalized frequency (log-frequency) of the written words in the original stimuli from Grodner and Gibson (2005) was obtained from E-lexicon website (Balota et al., 2004) and compared with that in the descriptive measures of single-word comprehension from the stimuli used in the screening. This procedure helped to determine whether the word-frequency effects were equivalent between the experimental and the screening stimuli. The nouns used in the experimental stimuli were obtained from the NPs and PPs in the main clauses, resulting in four nouns for each set of sentences and 120 items total. The verbs in the experimental stimuli were obtained from the main verb and the embedded verb in the main clause, yielding a total of 60 verbs. Screening stimuli were obtained for the nouns (*n*=40) from subtest 48 (Written Word – Picture Matching) of the *Psycholinguistic Assessments of Language Processing in Aphasia* (PALPA) (Kay, Lesser, & Coltheart, 1992) and for the verbs (*n*=22) from the Verb Comprehension Test of the *Northwestern Assessment of Verbs and Sentences-Revised* (NAVS-R) (Thompson, Ballard, & Tait, 2008).

In order to determine significant differences in the nouns and verbs between the experimental and the screening stimuli, a one-way ANOVA was computed. There was no significant difference in the frequency for the nouns between the experimental stimuli (M=1.37, SD=.63) and screening stimuli (M =1.22, SD =.63), $F(1, 160)=1.81$, $p>.05$. However, the nouns in the experimental stimuli were one standard deviation below the mean of the nouns in the screening measures. They were therefore replaced with higher frequency nouns in order to minimize the lexical frequency effects on sentence comprehension. This procedure results in a significant difference in the noun frequency, $F(1, 167)=23.99$, $p<.001$, with a significantly higher frequency in the experimental stimuli (M=1.73, SD=.59) than in the screening stimuli (M =1.22, SD =.63).

The same procedure was applied to control the lexical frequency of the verbs. A one-way ANOVA revealed that there was a significant difference in frequency of the verbs between the experimental (M=1.46, SD=.61) and screening (M=1.83, SD=.67) stimuli, $F(1, 80)=5.56$, $p<0.05$. A total of 43 verbs (out of 60) were replaced with higher frequency ones. A follow-up ANOVA revealed no significant difference in the frequency of the verbs ($F(1, 80)=.82$, $p>.05$) between in the experimental (M=1.70, SD=.55) and screening (M=1.83, SD=.67) stimuli. Fifty-eight of the 60 verbs used in the experiment were past-tensed and regularly inflected. The two exceptions were *find* and *hit*.

Fifty-five filler sentences were obtained from Warren et al. (2008), and five additional sentences were created. The sixty filler sentences contained a wide variety of embedded and unembedded structures. Thirty additional filler sentences with subject-RC were created from the experimental stimuli. One of the six conditions with filler-gap dependency without modifier (e.g., The nurse who the doctor called visited the patient) was converted to the subject-RC (e.g., The nurse who called the doctor visited the patient). These filler sentences were added because the comparisons between the object- and subject-RC are the most frequently studied phenomenon in sentence processing literature. Given that the experimental stimuli do not contain these syntactic comparisons, the subject-RC structures were collected as filler sentences. However, these structures were not separately analyzed in the current study. A total of 90 filler sentences were generated.

Yes/no questions, with a fifty percent chance of accuracy, for the experimental sentences stimuli were constructed to assess the thematic assignments between the subjects and objects in relation to the verbs (e.g., Did the doctor call the nurse?). In order to minimize the possibility that participants would pay attention only to the thematic relations of the sentence, yes/no questions for the 60 filler sentences obtained from Warren et al. (2008) were created by assessing other elements of a sentence than the thematic relationship. All of the experimental sentence stimuli and filler sentences stimuli are provided in Appendix A and B, respectively.

Stimuli were divided into six lists with thirty experimental items and thirty filler sentences for each list according to a 3 x 2 Latin-square design crossing the types of modifiers (No, PP, RC) with the types of linguistic dependencies (SV vs. FG). The six lists of the conditions were pseudo-randomized with intervening filler sentences.

3.4. DATA COLLECTION PROCEDURES

Sentences were presented using a non-cumulative, self-paced, word-by-word display on a PC computer monitor running purpose-built software (LINGER). Each trial began with dashes representing all non-white-space characters in a sentence. Participants pressed a button on a key pad to replace each succeeding dash. After the display of the first word, the bar press caused the previous word to disappear. A yes/no comprehension question followed each sentence, asking participants to press the buttons with Y or N labeled on the key pad. There was no feedback for the responses. Participants were instructed to read at a normal rate in a manner that would enable them to answer the comprehension questions as accurately as possible.

Prior to the experimental stimuli, participants were familiarized with the task using 10 practice trials. The experiment began following the practice session. Each participant was given four lists with the six conditions included for each list. Each list consists of 30 experimental stimuli (five observations for each condition) and 30 filler sentences. Four lists of sentence stimuli provided 20 observations for each condition. A total of 240 sentence stimuli were read. After participants completed the entire experiment, a survey on the plausibility rating of each experimental sentence stimulus was administered to each participant. In the survey, an initial clause of each sentence was extracted with only verbs and the two arguments included. Sentences in the survey consisted of the target sentences from the experimental stimuli (e.g., "The nurse called the doctor") and the reversed sentences (e.g., "The doctor called the nurse"). Participants were asked to rate the plausibility of the initial clauses from the experimental stimuli based on a scale of 1 (implausible) to 7 (plausible).

4.0. RESULTS

4.1. SPECIFIC AIM I.

The first specific aim was to investigate the effects of distance on online sentence processing times and sentence comprehension accuracies in both NI and PWA groups when the distance was systematically manipulated.

4.1.1. Number of Errors

4.1.1.1. Analysis of Variance (ANOVA)

In order to examine whether there are any significant changes in number of errors as a function of distance manipulation in both normal and aphasic group, a three-way mixed ANOVA was computed with Dependency (SV vs. FG) and Modifier (No, PP, RC) as within-subject factors and Group (NI vs. PWA) as a between-subject factor for the number of errors in yes/no questions. According to Mauchly's test of sphericity, data were normally distributed for within-subject factors: Modifier, p=.207 and Dependency x Modifier, p=.322.

There were significant main effects for Dependency, $F(1, 48)$=195.97, p<.000, with more errors found in the FG than the SV sentence type and for Group, $F(1, 48)$=25.03, p<.000, with PWA generating more errors than NI. There was a significant two-way interaction between the Modifier and the Group, $F(2, 96)$=2.97, p=.05. Post-hoc analyses were performed using the interaction contrasts to examine the significant two-way interaction. Results revealed that NI showed significantly more errors in the RC-modifier than No-modifier, $F(1, 29)$=8.66, p<.01, and PP-modifier, $F(1, 29)$=7.37, p<.05. However, there were no significant differences among the types of modifiers for the PWA.

There was a significant three-way interaction, $F(2, 96)=3.45$, $p<.05$. In order to identify the source of this significant interaction (Dependency x Modifier x Group), two separate repeated two-way ANOVAs were computed with Dependency and Modifier as factors for each group. In NI group, there were significant main effects for Dependency, $F(1, 29)=139.33$, $p<.000$, with more errors in FG than SV, and Modifier, $F(2, 58)=6.31$, $p<.005$. Pairwise comparisons with the Bonferroni correction revealed that there were significantly more errors in RC-modifier than No-, $p<.05$, and PP-modifier, $p<.05$; but no significant difference between No- and PP-modifier. A two-way interaction between Dependency and Modifier was also significant, $F(2, 58)=195.97$, $p<.05$, and the interaction was due to the fact that there were significantly ($p<.05$) more errors in the RC-modifier than No-modifier in FG-dependency and no significant differences in errors among the types of modifiers in SV-dependency. In PWA, there was a significant main effect for Dependency, $F(1, 19)=69.63$, $p<.000$, with more errors in FG- than SV-dependency. No other effects were significant in the two-way ANOVA, indicating that PWA did not show significant differences in errors as a function of modifier and that there were no differences between the two dependencies by type of modifier.

In sum, the significant three-way interaction was attributable to the fact that 1) NI generated significantly more errors in RC-modifier than the No- modifier condition in the FG-dependency sentences, without significant differences in the SV-dependency as a function of modifier, and 2) PWA did not show a significant difference in errors as a function of modifier in either SV- or FG-dependency forms (Figure 1.). No other effects were statistically significant.

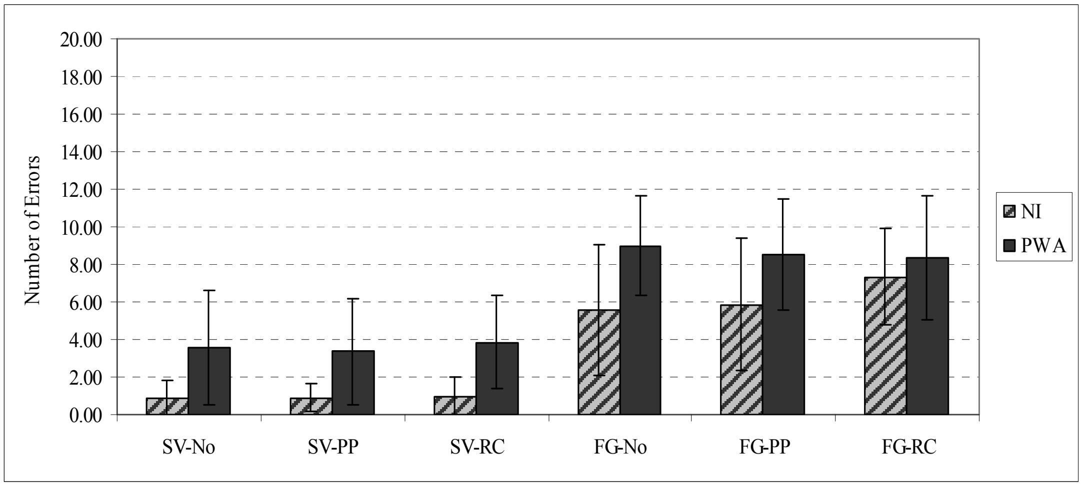

Figure 1. Number of errors for each condition in both groups
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier.

4.1.1.2. Analysis of chance-level performance

Given that sentence comprehension was measured using the yes/no questions, it was examined whether individuals' performance was significantly better or worse than chance-level or not different from chance-level. The 95% CI was calculated for chance-level performance for the number of errors using the binomial probabilities (Marascuilo & Serlin, 1988). 95% CI was between 5 and 15 errors. In other words, if the number of errors was either 5 or less, or 15 or more, performance on yes/no questions was significantly different from 50% chance at .05 level of confidence. Number of errors ranging from 6 through 14 was not significantly different from chance-level performance.

No NI performed at or below chance-level in the SV-dependency conditions, indicating that they all performed significantly better than chance on the yes/no questions. However, 50% (n=15) of the NI performed at chance-level in the FG-No and FG-PP conditions. 77% (*n*=23) performed at chance in the FG-RC condition with the rest of participants (*n*=7) performing significantly better than chance. Twenty-five percent (*n*=5) of the PWA performed at chance-level in SV-No, SV-PP, and SV-RC conditions. . However, 95% (*n*=19), 80% (*n*=16), and 85% (*n*=17) of the PWA performed at chance-level in FG-No, FG-PP, and FG-RC conditions, respectively. There was one PWA (Participant ID=209) who performed significantly below chance in the FG-RC condition.

There were only three normal individuals (105, 112, and 115) who performed significantly better than chance in all of the six conditions. There were only one individual with aphasia (218) who showed significantly better than chance performance in all of the six conditions.

4.1.1.3. D-prime Analysis

Given that about 60% of normal individuals and 87% of individuals with aphasia performed at chance in the FG-dependency conditions, response biases were taken into account by calculating d-prime for each participant in each condition. D-prime is the most commonly used measure in signal detection theory to increase sensitivity by taking the response bias into account (Robin & McNeil, 1994).

D-prime is the standardized difference between the means of HIT (when participants said YES in YES response trials) and FALSE ALARM (or false positive) (when participants said YES in No response trials). The formula for d-prime is as follows: d-prime = z (H) – z (F). H indicates HIT rate which is a probability (p-value) of YES responses in YES trials. F indicates false alarm rate which is a probability (p-value) of YES responses in NO trials. D-prime is the difference between the z-transforms of these two rates (Macmillan & Creelman, 2005).

D-prime was calculated for each condition for each participant. In SV-dependency condition, majority of participants in both NI and PWA group performed near perfectly. In other words, participants responded YES to the most YES trials with very few false alarm rate, giving a hit rate close to 1.00 and false alarm rate close to zero. In this case, z-score for p-value of 1.00 corresponds to negative infinity, and z-score for p-value of zero corresponds to positive infinity. A conventional way of adjusting these values is to set the minimum value for p=1/N (N=number of trials) and the maximum value for p= (N-1)/N. Z-score for maximum p-value of hit rate (19/20=0.95) was 1.6, and z-score for minimum p-value of false alarm rate (1/20=0.05) was -1.6. Thus, the substituted d-prime value for those incidences was 3.2. In terms of interpreting the d-prime value, d-prime value will be greater to the extent that participants identified the trials differently. In other words, when participants were not sensitive to detect the signal between YES and NO trials, smaller d-prime values will be observed. When the d-prime value is equal to zero, it indicates that participants selected responses completely by chance (Macmillan & Creelman, 2005).

Using the d-prime scores, a three-way ANOVA was computed with Modifier and Dependency as within-subject factors and Group as a between-subject factor. Descriptive information for d-prime values in each condition and group was illustrated in Table 7.

The main effect for Dependency was significant, $F(1, 48)=148.76$, $p<.000$ with a smaller d-prime value in the FG- (d-prime=0.95) than the SV-condition (d-prime=2.85). The main effect for Group was significant, $F(1, 48)=402.47$, $p<.005$ with smaller d-prime value for PWA (1.60) than NI (2.19). However, the main effect for Modifier was not significant, $F(2, 90)=1.55$, $p=.22$.

The three-way interaction was significant, $F(1, 48)=5.16$, $p<.05$. In order to identify the source of interaction, two separate 2-way ANOVAs were computed with

Modifier and Dependency as within-subject factors in each group. In NI, there were significant main effects for Dependency, $F(1, 29)=108.26$, $p<.000$, with a smaller d-prime value for FG-dependency (1.24) than SV-dependency (3.19) and for Modifier, $F(2, 54)=148.76$, $p<.000$. Multiple comparisons with Bonferroni correction indicated that a smaller d-prime value was observed in the RC-modifier (2.03) than the No- (2.33) and PP- (2.28) modifier conditions. The two-way interaction between Modifier and Dependency was significant, $F(2, 54)=3.97$, $p<.05$, reflected in the significantly smaller d-prime in the RC-modifier than No- and PP-modifier conditions, only for the FG-dependency. In PWA, the main effect for Dependency was significant, $F(1, 19)=48.71$, $p<.000$ with a smaller d-prime value for FG-dependency (0.71) than SV-dependency (2.50). None of the other effects were significant.

The other way the three-way interaction was examined was to assess group differences in each condition with multiple one-way ANOVAs. Due to the multiple comparisons, alpha level was adjusted to 0.01 (0.05/6=0.01). There were significant differences between the groups in the SV-dependency conditions, with a larger d-prime value observed in NI than PWA ($F(1, 48)=7.53$, $p<.10$ for SV-No, $F(1, 48)=12.65$, $p<.10$ for SV-PP, and $F(1, 48)=24.78$, $p<.000$). However, group differences were not significant in the FG-dependency condition ($F(1, 48)=4.99$, $p=.03$ for FG-No, $F(1, 48)=4.57$, $p=.04$, and $F(1, 48)=0.01$, $p=.99$).

Table 7. Mean (SD) of the d-prime values for each condition in both groups

	SV-No	SV-PP	SV-RC	FG-No	FG-PP	FG-RC
NI	3.2 (0)	3.18 (0.13)	3.19 (0.03)	1.39 (1.30)	1.36 (1.38)	0.82 (0.87)
PWA	2.6 (1.08)	2.51 (1.03)	2.34 (0.94)	0.59 (1.32)	0.67 (1.01)	0.86 (1.33)

Note: NI=Normal Individuals; PWA=Persons with Aphasia; SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-

No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

To summarize the data from the analyses of variance using the number of errors and d-prime values as dependent measures, both NI and PWA groups showed dependency effects with greater difficulties observed in FG than SV. However, there were differences in the modifier effects. The NI group showed greater difficulties in RC-modifier than the other two types of modifiers, especially in FG-dependency conditions. However, PWA did not show any significant effect of modifier. PWA showed more errors and were less sensitive than NI overall at detecting the signal. These group differences were significant only in SV-dependency, however, indicating that older adults' abilities to detect the signal were as low as those of PWA in the FG-dependency condition. These results are consistent with the observations of high rate of chance-level performance not only in PWA but also in NI.

4.1.1.4. Analyses of the presentation order and stimuli effects

In the stimuli for yes/no questions, three reciprocal verbs (REC-V) were identified (hug, date, and marry). Also three yes/no questions out of thirty were identified as EASY questions to which participants could respond without referring to the actual sentences by only relying on the thematic relations due to the high plausibility between the two arguments in relation to the verb ("Did the fans love the star?", "Did the farmer threaten the rebels?", and "Did the dragon wound the knight?").

Given that the same yes/no questions were repeated over the four lists of trials, it was examined whether the number of errors changed according to the presentation order.

The same questions were extracted from each list for each participant. The questions were divided into the three verb groups: 1) reciprocal verbs (REC-V), 2) easy verbs (EASY), and 3) the rest of the verbs (REST). A three-way ANOVA was computed with Verb-Type (REC-V, EASY, REST) and presentation order (List 1, List 2, List 3, List 4) as within-subject factors and Group as a between-subject factor in order to examine the effects or presentation order and verb type. None of the main effects were significant for Verb-Type, $F(2, 96)=1.52$, $p=.23$, and presentation order, $F(4, 144)=1.56$, $p=.93$. Neither of these two factors significantly interacted with Group.

4.1.2. Reading Times on the Verbs (RT-V) and Response Times (RT)

RT-V and RT data were extracted only from the correct responses and from those participants who showed above-chance-level performance, given that reading time data from chance-level performance were not interpretable. Due to the very limited number of participants who performed above-chance-level in all six conditions, the analyses were conducted separately for SV- and FG-dependency conditions.

4.1.2.1. SV-dependency

All NI participants (n=30) and 13 individuals with aphasia performed above chance in all three SV-dependency conditions. In order to examine the effects of modifier on the verb reading times in the SV-dependency conditions, a mixed two-way ANOVA was computed, with Modifier as a within-subject factor and Group as a between-subject factor. According to Mauchly's test of sphericity, data were not normally distributed for a within-subject factor: Modifier, p=.006. Thus, p-values reported from below were obtained from the Huynh-Feldt tests.

There was a significant main effect for Group, $F(1, 43)=238.91$, $p<.000$, with PWA showing significantly longer verb reading times than NI. The main effect for Modifier was not significant, $F(2, 86)=.32$, $p=.73$. The two-way interaction between Modifier and Group was significant, $F(2, 86)=4.38$, $p<.50$. NI showed significantly longer RT-V for RC modifiers than No and PP modifiers ($p<.05$). However, for PWA, there were no significant differences in RT-V as a function of modifier type. Figure 2 illustrates the reading times on the verbs in SV-dependency condition for both groups.

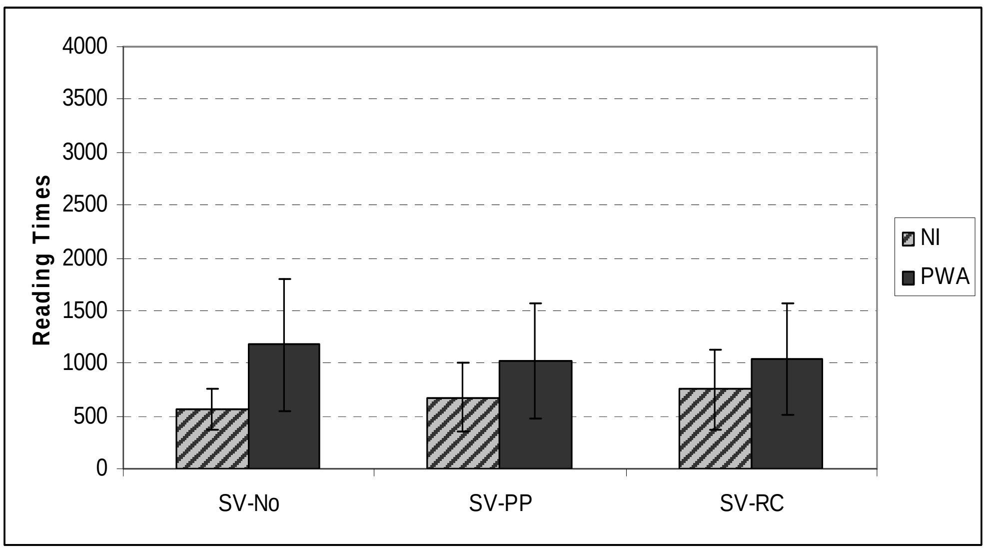

Figure 2. Reading times (ms) on the verb in Subject-Verb dependency conditions for both groups
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier

In order to examine the effects of modifier on the response times in the SV-dependency conditions, a mixed two-way ANOVA was computed with Modifier as a within-subject factor and Group as a between-subject factor. According to Mauchly's test of sphericity, data were normally distributed for Modifier, p=.571.

There was a significant main effect for Group, F(1, 43)=34.25, p<.000, with PWA showing significantly longer response times than NI. The main effect for Modifier was not significant, F(2, 86)=.59, p=.56. The two-way interaction between Modifier and Group was also not significant, F(2, 86)=1.45, p=.24. Figure 3 illustrates the response times in the SV-dependency condition for both groups.

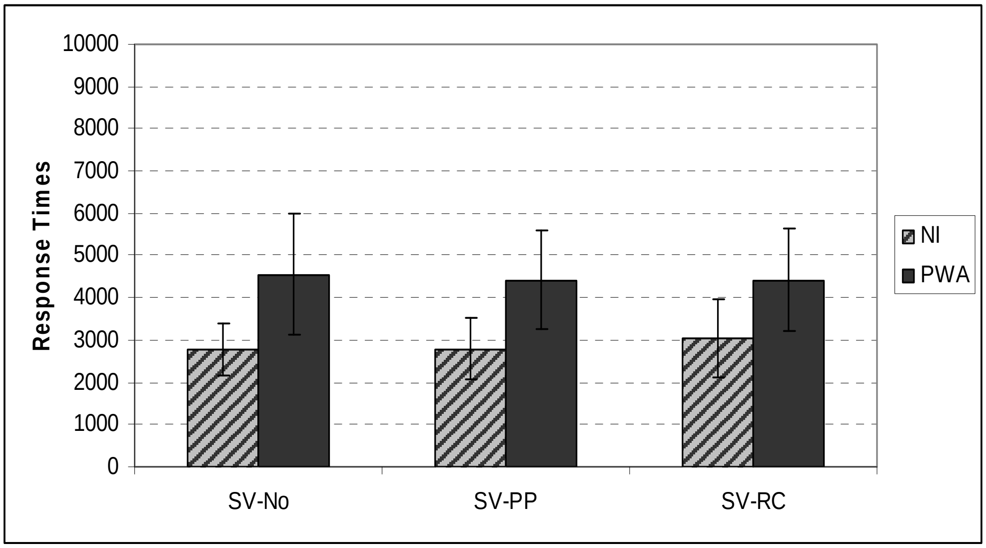

Figure 3. Response times (ms) in Subject-Verb dependency conditions for both groups
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier

4.1.2.2. FG-dependency

Inferential statistics would not be valid in the FG-dependency conditions for RT-V and RT, due to the limited and unequal number of observations for each group and for each condition. There were 15, 15, and 7 normal individuals who performed significantly better than chance for FG-No, FG-PP, and FG-RC, respectively. Their group performance is illustrated for RT-V in Figure 4 and for RT in Figure 5. Above-chance-level performers in the NI group showed increased reading times in the FG-PP condition compared to the FG-No condition. However, the shortest RT-V was found in the most complex condition (FG-RC). In contrast, RT systematically increased for these individuals as distance increased (Figure 5).

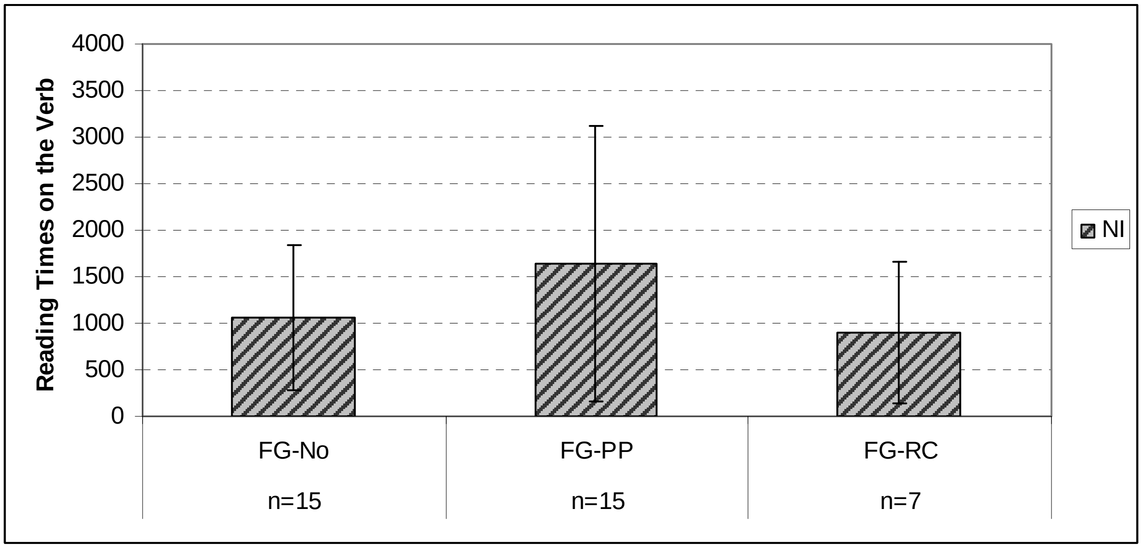

Figure 4. Reading times (ms) on the verbs in the Filler-Gap condition for normal individuals who performed above chance
Note: FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier.

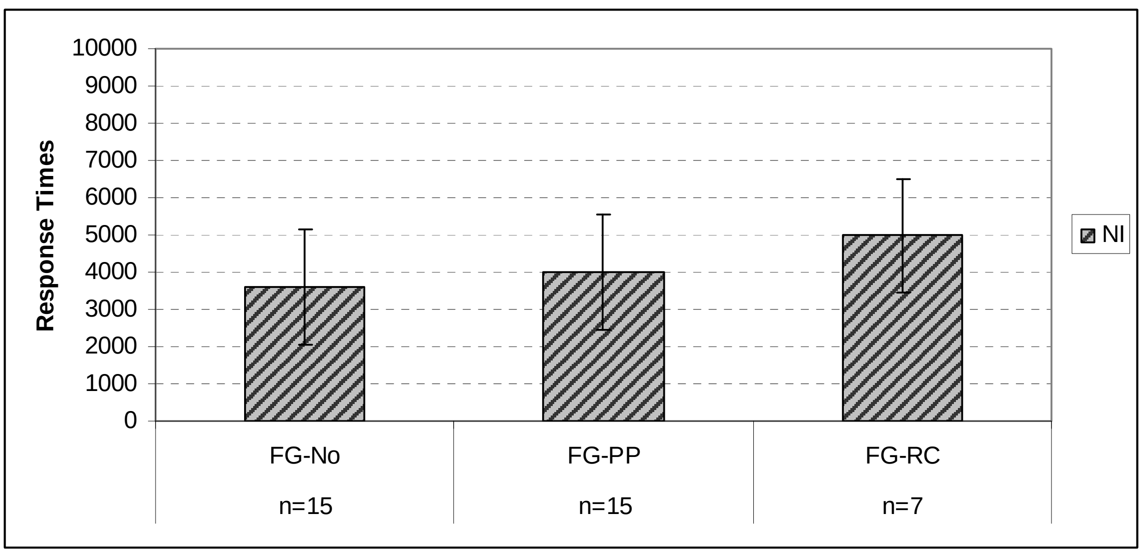

Figure 5. Response times (ms) in the Filler-Gap condition for normal individuals who performed above chance
Note: FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier.

There were only three NI participants (participants 105, 112, and 115) who performed above chance in all three FG conditions. Figure 6 illustrates their heterogeneous RT-V performance. None of their performances aligned with Gibson (1998; 2000)'s reading time predictions. However, one of them (112) showed a systematic increase in RT-V as a function of modifier in the FG conditions (Figure 7).

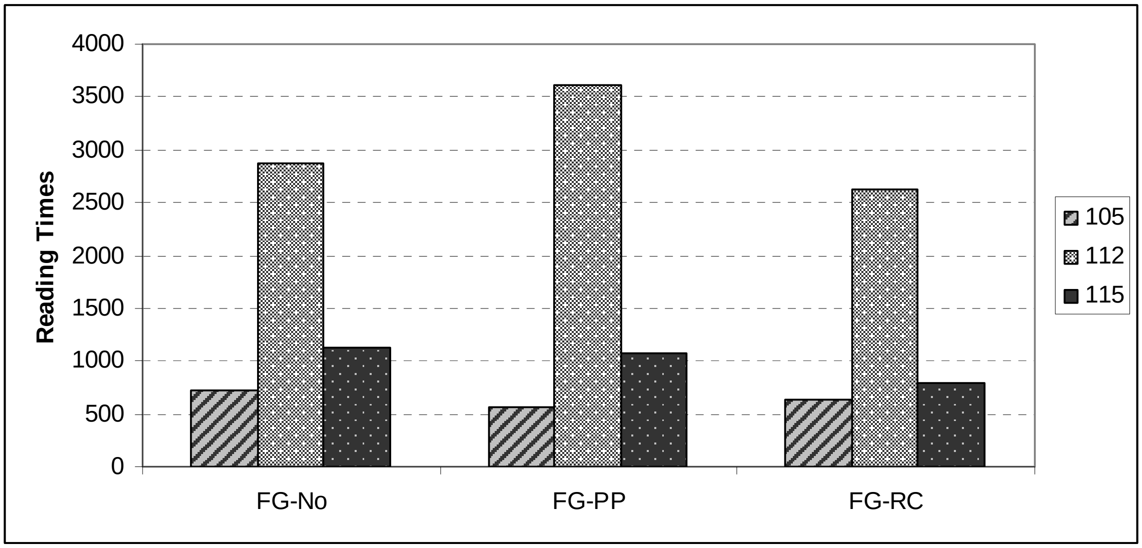

Figure 6. Reading times (ms) on the verb in three normal individuals with above chance-level performance in all of the three Filler-Gap conditions
Note: FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier.

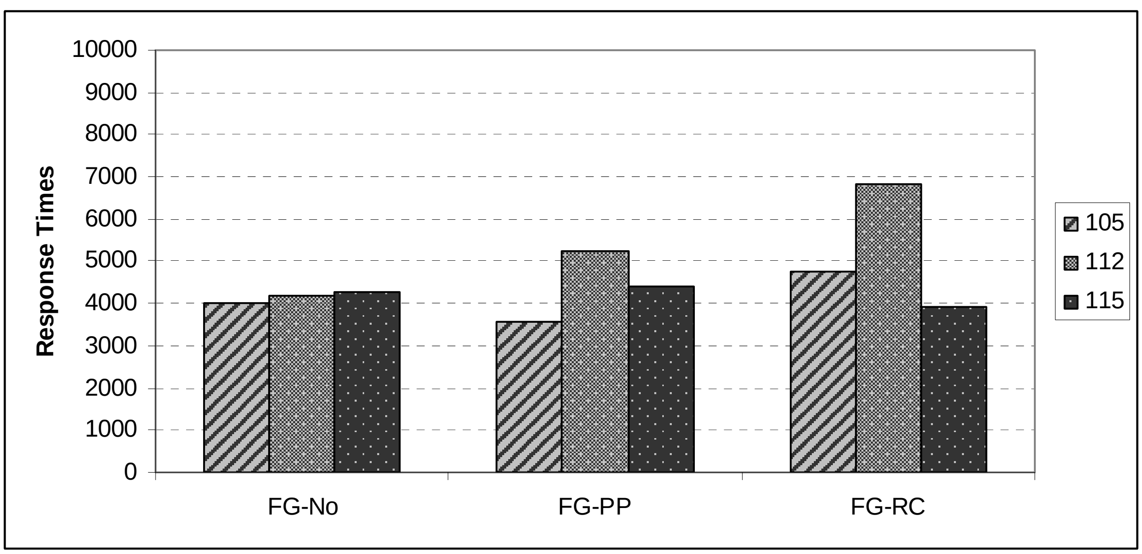

Figure 7. Response times (ms) in three normal individuals with above chance-level performance in all of the three Filler-Gap conditions

Note: FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier.

There were one (Participant ID=218), four (Participant ID = 206, 210, 216, 218), and three (Participant ID =210, 212, 218) PWA with aphasia who performed significantly better than chance for the FG-No, FG-PP, and FG-RC conditions, respectively. Individual variability was huge, illustrated in Figure 8 for RT-V and Figure 9 for RT. There was only one individual with aphasia who showed significantly better than chance-level performance in all of the three FG conditions (ID=218). In contrast to the locality predictions, Participant 218 showed longer RT-V and RT in the FG-No than FG-PP and FG-RC.

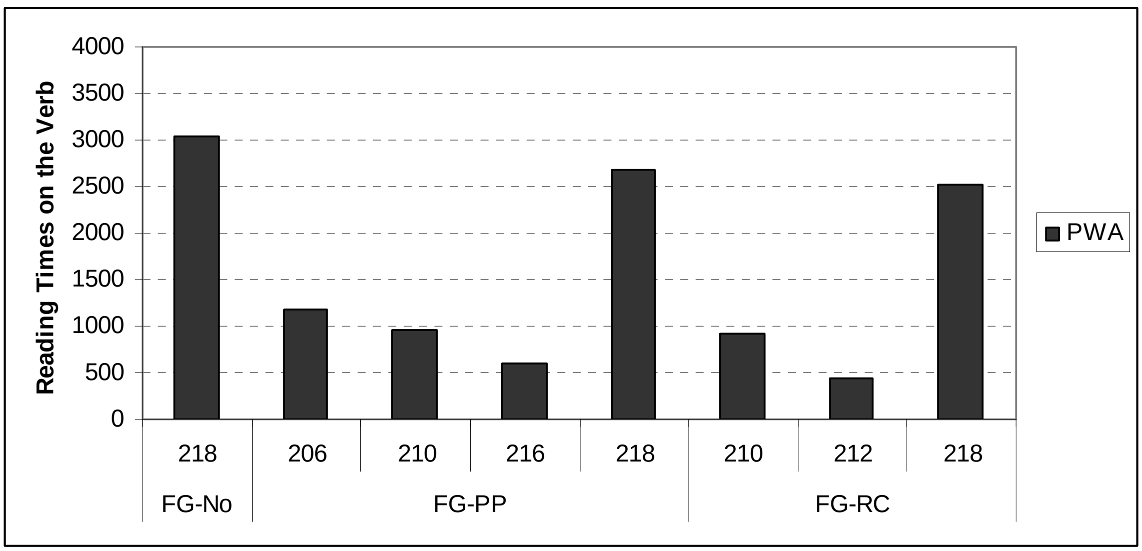

Figure 8. Reading times (ms) on the verb in individuals with aphasia who showed significantly better than chance-level performance in all of the three Filler-Gap conditions

Note: FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier.

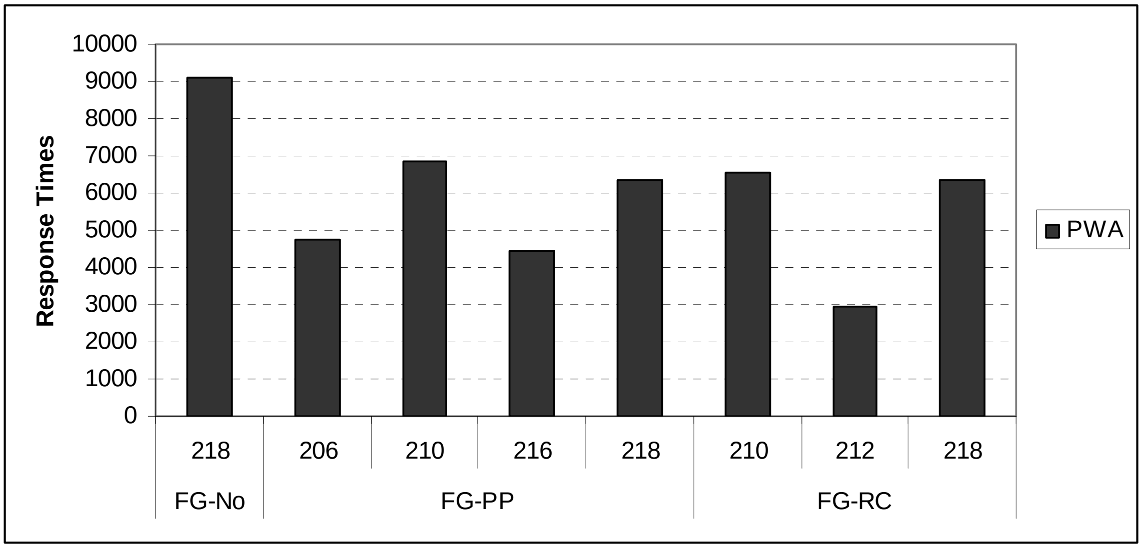

Figure 9. Response times (ms) in individuals with aphasia who showed significantly better than chance-level performance in all of the three Filler-Gap conditions
Note: FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier.

4.1.3. Description of performance on the three dependent measures in all conditions

The number of errors, RT-V and RT data are described below for both above-chance and at-chance-level performers, to provide a broad picture of performance. Inferential statistics were not valid used because different participants contributed different numbers of observations in the repeated conditions.

Above-chance performers in the NI group showed a relatively systematic increase of errors as a function of distance manipulation, as shown in Figure 10. In contrast, no consistent pattern can be observed for above-chance PWA performers, as illustrated in Figure 11. PWA with at-chance-level performance appeared to make more errors in the FG- than SV-dependency, but no obvious pattern of errors is observed as a function of modifier.

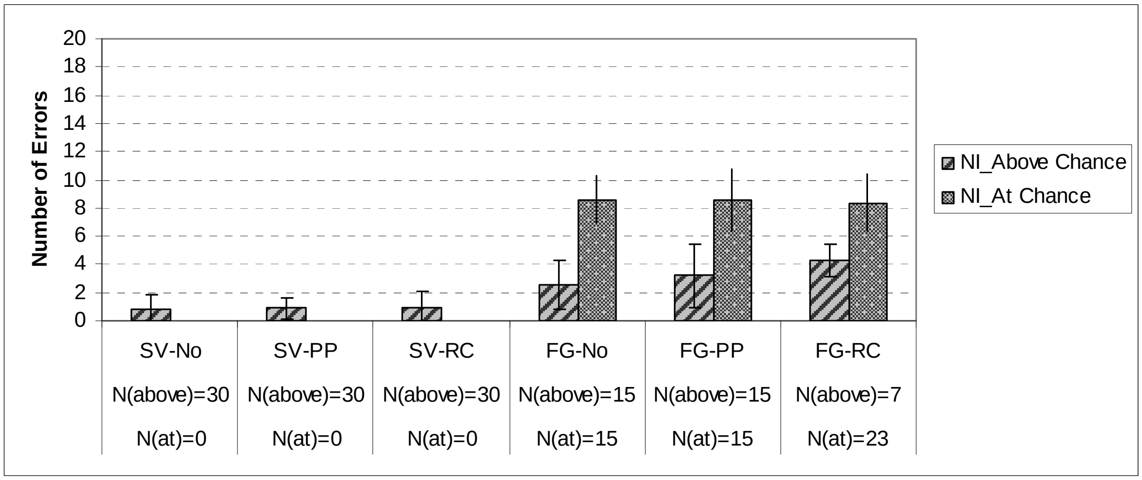

Figure 10. Number of errors in each condition for normal individuals with both above-chance and at-chance-level performance

Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; NI_Above Chance=Normal Individuals with Above-Chance performance; NI_At Chance= Normal Individuals with At-Chance performance; N(above)=Number of participants with above-chance performance; N(at)=Number of participants with at-chance performance.

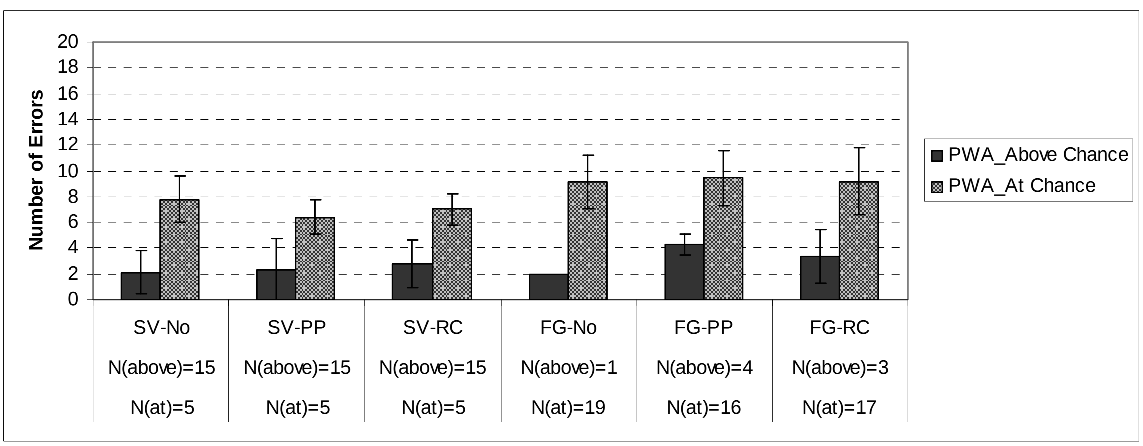

Figure 11. Number of errors in each condition for PWA with both above-chance and at-chance-level performance

Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; PWA_Above Chance=Persons with Aphasia with Above-Chance performance; PWA_At Chance= Persons with Aphasia with At-Chance performance; N(above)=Number of participants with above-chance performance; N(at)=Number of participants with at-chance performance.

NI with above-chance performance (Figure 12) showed a relatively systematic increase in RT-V, with the exception of the FG-RC condition. RT data from NI with above-chance performance are consistent with the locality predictions, showing an increase of RT as a function of distance manipulation (Figure 13). However, NI with at-chance performance did not show any systematic patterns in RT-V and RT data.

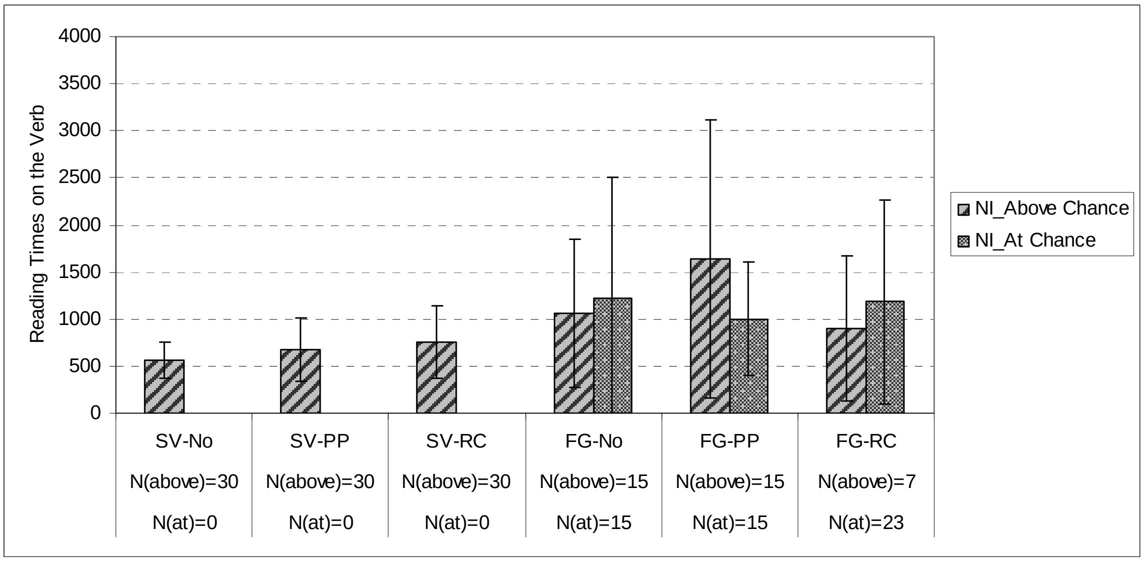

Figure 12. Reading times (ms) on the verb in each condition for normal individuals with both above-chance and at-chance-level performance
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; NI_Above Chance=Normal Individuals with Above-Chance performance; NI_At Chance= Normal Individuals with At-Chance performance; N(above)=Number of participants with above-chance performance; N(at)=Number of participants with at-chance performance.

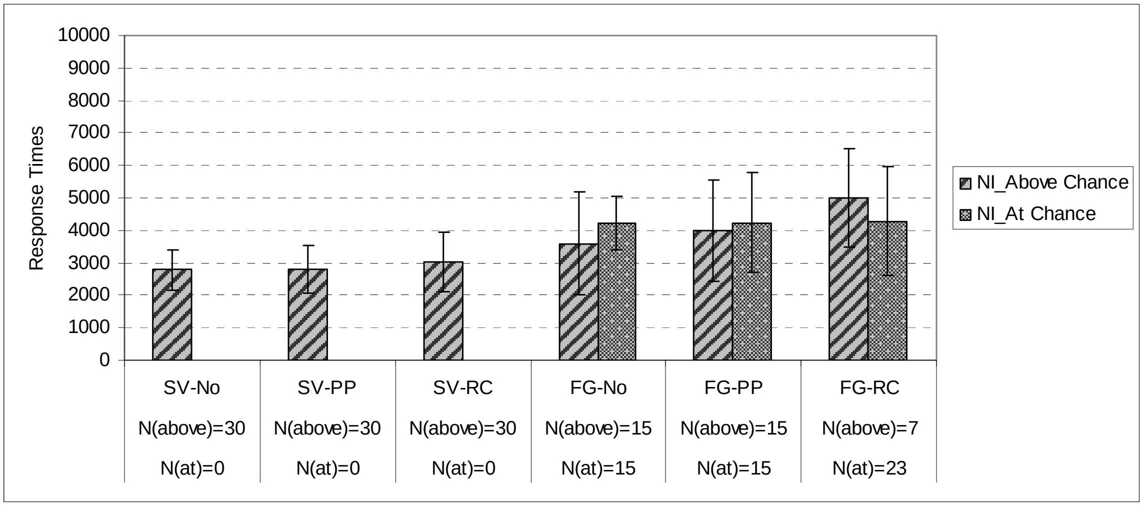

Figure 13. Response times (ms) in each condition for normal individuals with both above-chance and at-chance-level performance

Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; NI_Above Chance=Normal Individuals with Above-Chance performance; NI_At Chance= Normal Individuals with At-Chance performance; N(above)=Number of participants with above-chance performance; N(at)=Number of participants with at-chance performance.

For both chance and above-chance-level performers in the PWA group, neither RT-V nor RT appears to increase as a function of type of modifier in SV-dependency (see Figure 14 for RT-V and Figure 15 for RT). For the FG conditions, group performance cannot be described, due to the very limited sample size. For this condition, the individual data are more relevant, as shown above (Figure 8 for RT-V and Figure 9 for RT).

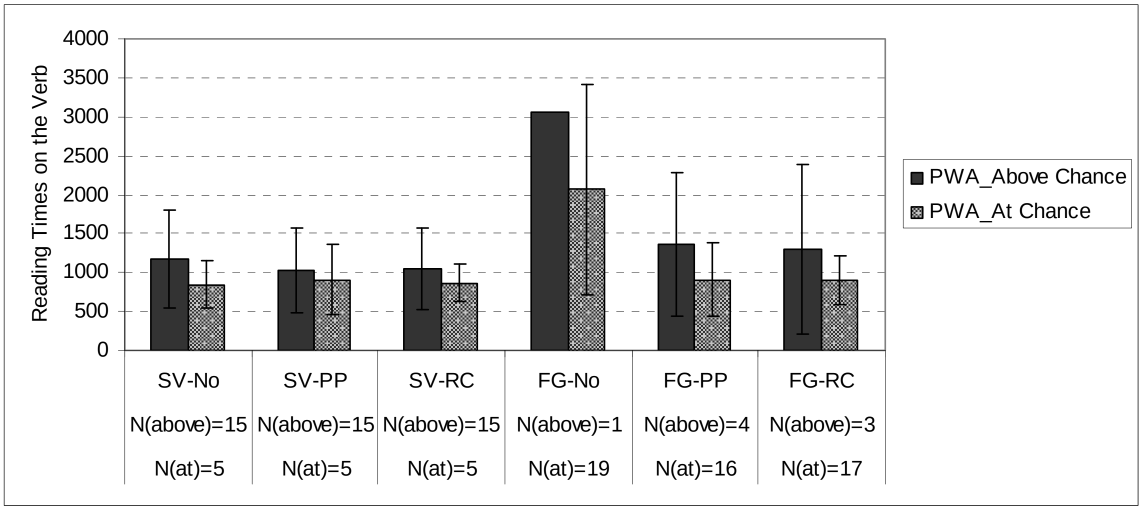

Figure 14. Reading times (ms) on the verb in each condition for PWA with both above-chance and at-chance-level performance

Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; PWA_Above Chance=Persons with Aphasia with Above-Chance performance; PWA_At Chance= Persons with Aphasia with At-Chance performance; N(above)=Number of participants with above-chance performance; N(at)=Number of participants with at-chance performance.

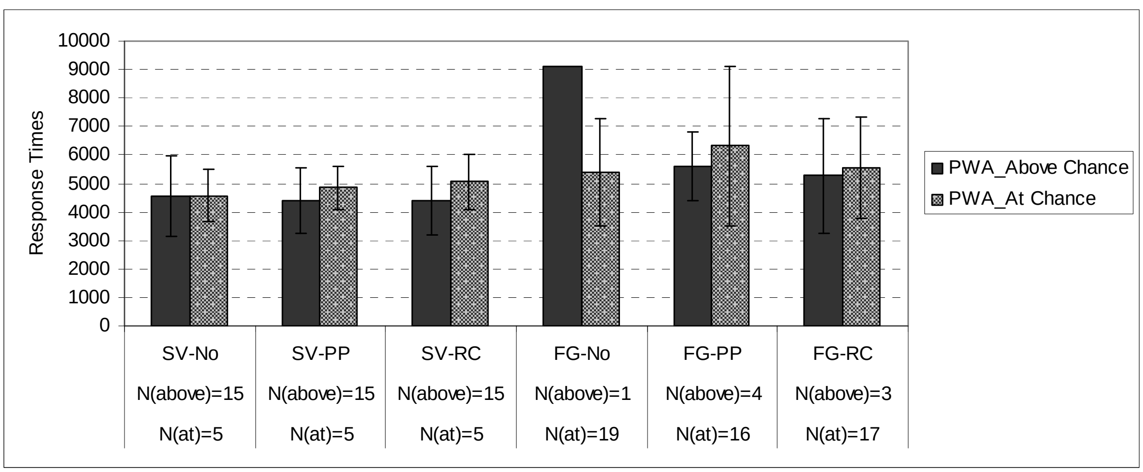

Figure 15. Response times (ms) in each condition for PWA with both above-chance and at-chance-level performance

Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; PWA_Above Chance=Persons with Aphasia with Above-Chance performance; PWA_At Chance= Persons with Aphasia with At-Chance performance; N(above)=Number of participants with above-chance performance; N(at)=Number of participants with at-chance performance.

There were only three normal individuals (105, 112, and 115) who showed significantly better than chance-level performance in all six conditions. Their data were plotted for each dependent measure, in order to examine whether they showed systematic effects of locality. All three individuals made more errors in FG than SV conditions, but their errors did not increase systematically as function of modifier (Figure 16). On the RT-V measure, their performance was variable. Participant 112 showed increased RT-V as a function of distance manipulation consistently with the locality theory except for the most complex condition (FG-RC condition) as shown in Figure 17. This pattern was consistent with that of other normal individuals with above-chance performance (see Figure 12). Participant 112 was the only individual who showed a relatively systematic increase of RT as a function of locality (Figure 18), consistent with the results of the NI group with above-chance performance.

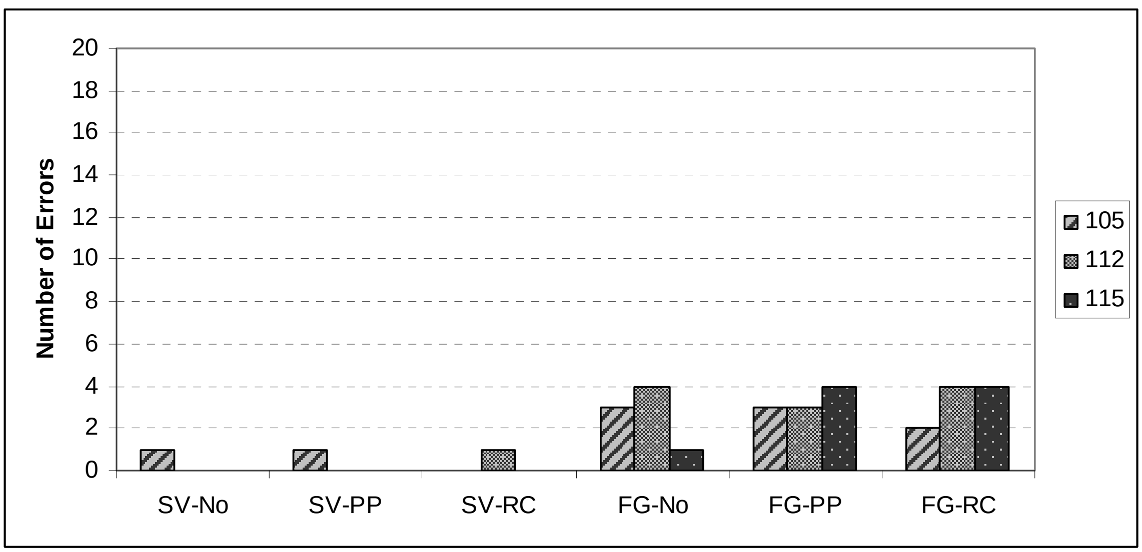

Figure 16. Number of errors in each condition for three normal individuals who showed above-chance performance in all of the six conditions
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

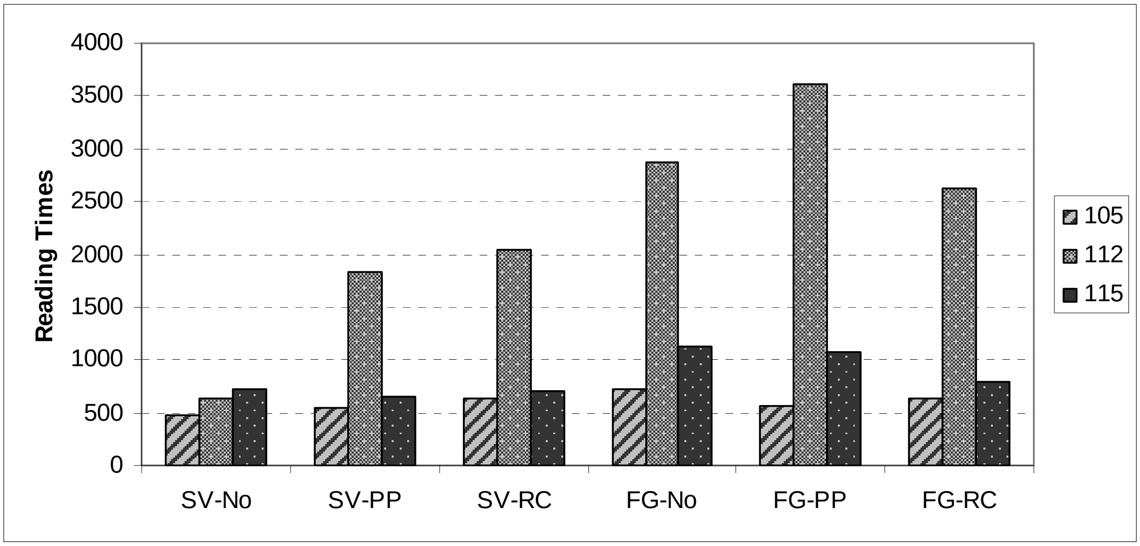

Figure 17. Reading times (ms) on the verb in each condition for three normal individuals who showed above-chance performance in all of the six conditions
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

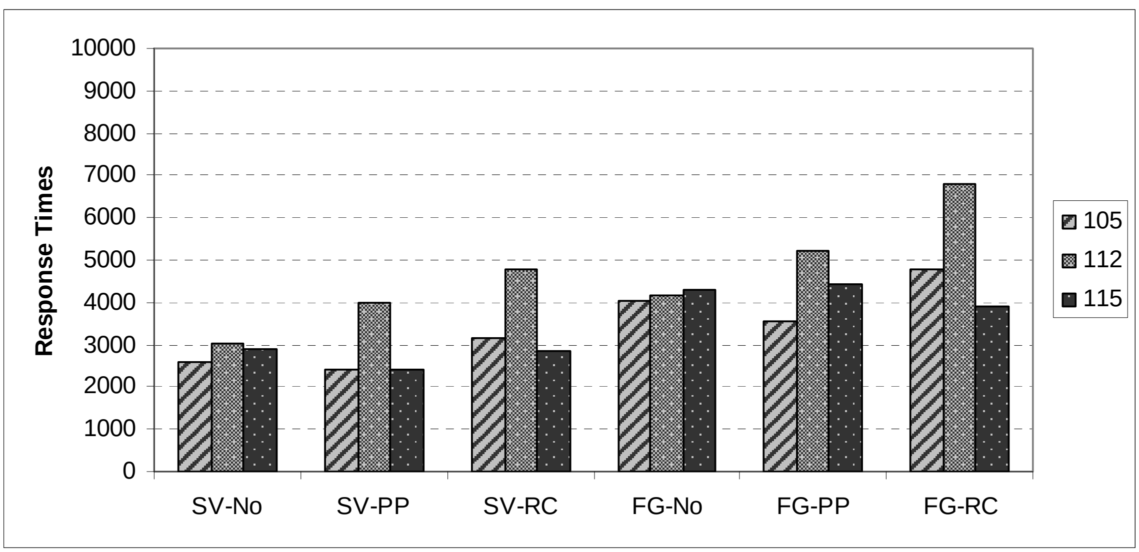

Figure 18. Response times (ms) in each condition for three normal individuals who showed above-chance performance in all of the six conditions
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

There was only one individual with aphasia who had significantly better than chance performance in all six conditions. This participant (218) did not show any systematic pattern of errors, RT-V, and RT as a function of modifier, but this participant showed the effect of dependency on all of the three dependent measures with greater difficulties observed in the FG- than SV-dependency. This individual's data were plotted in Figure 19 for errors, Figure 20 for RT-V, and Figure 21 for RT.

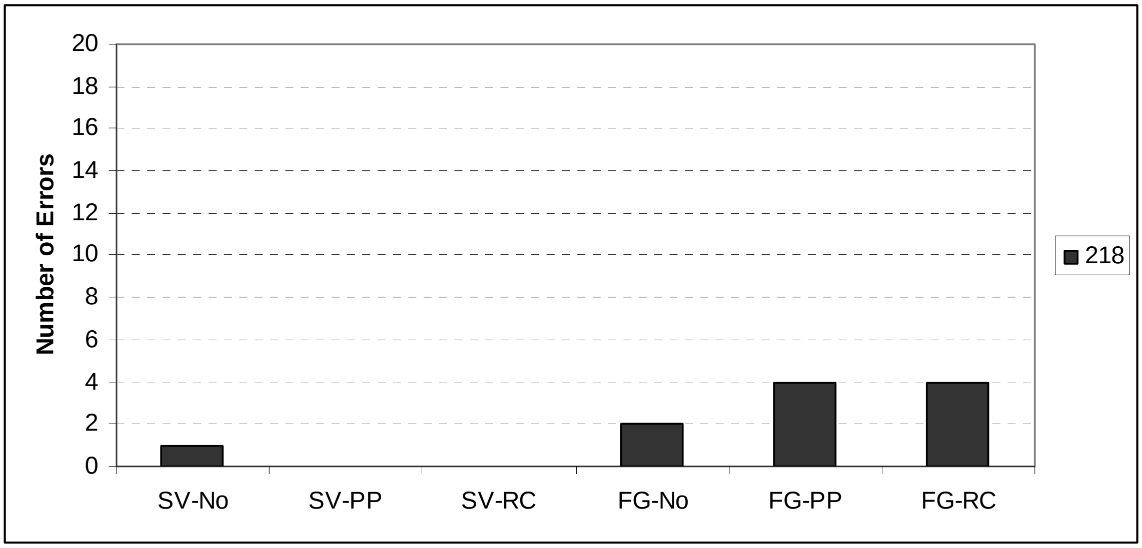

Figure 19. Number of errors in each condition for participant 218 with aphasia who showed above-chance performance in all of the six conditions.
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

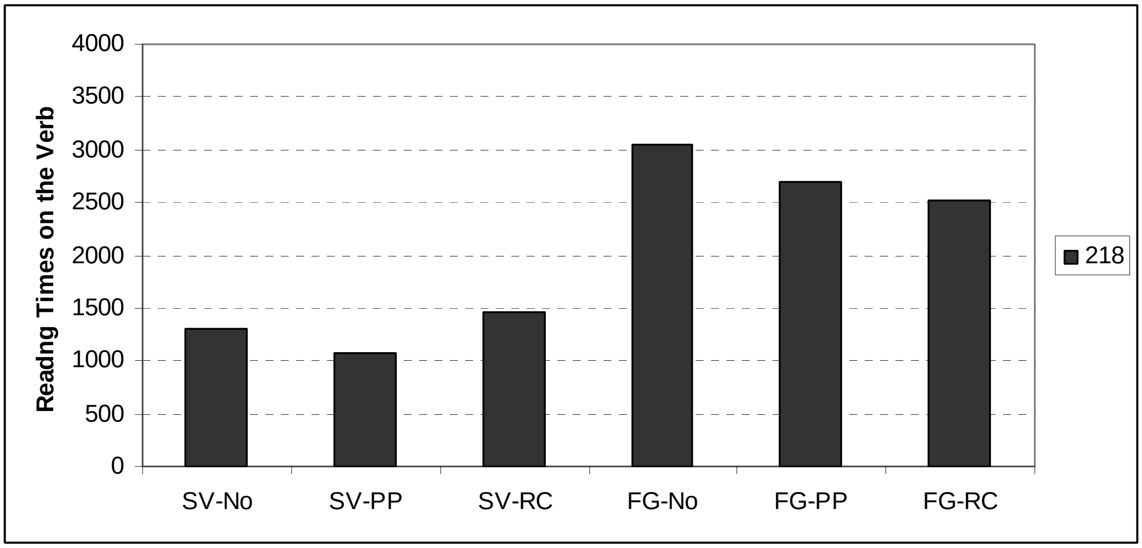

Figure 20. Reading times (ms) on the verb in each condition for participant 218 with aphasia who showed above-chance performance in all of the six conditions
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

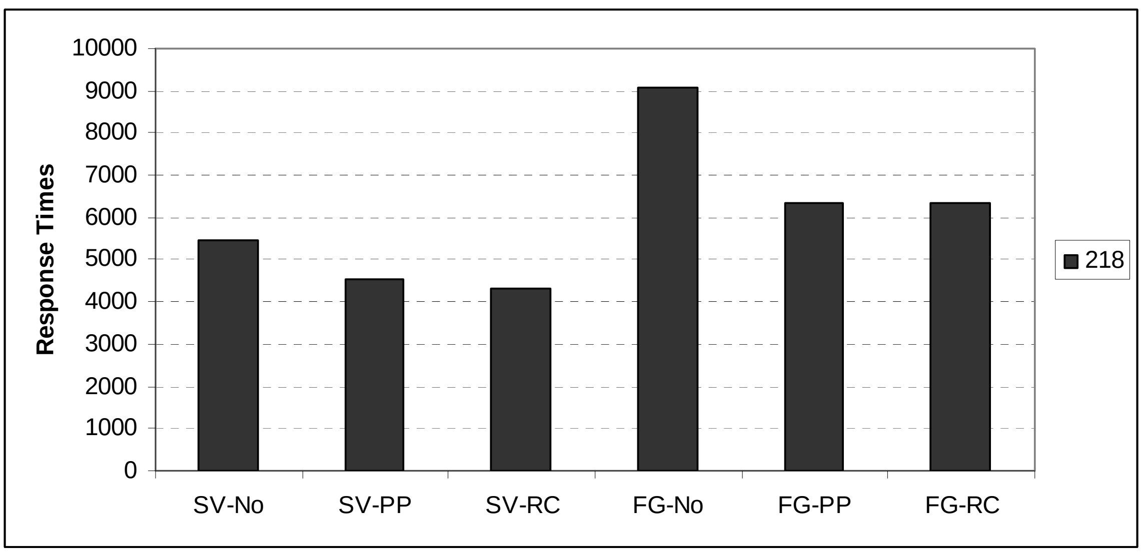

Figure 21. Response times (ms) in each condition for participant 218 with aphasia who showed above-chance performance in all of the six conditions
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

4.1.4. Exploratory Analyses

4.1.4.1. Analyses of individual differences in language severity measures, working memory span measures, age and education

Given the large variability in performance on the dependent measures, it was examined whether individual differences in sentence comprehension could be accounted for by factors such as WM, age, education, or language severity measures.

To assess the WM variable, the four span measures (Digit-Forward, Digit-Backward, Word-Forward, and Word-Backward) were assessed by Principal Component Analysis (PCA), separately for the NI and PWA groups, to determine if they loaded on a single factor. Results revealed that a one-factor solution accounted for 78% and 81% of the variance for the NI and PWA groups, respectively. Based on these results, an index of WM capacity was created by averaging the scores of the four WM span measures. The mean (and SD) of this composite measure was 5.4 out of 8 (SD=0.78) for NI and 3.67 (0.94) for PWA. CRTT-Auditory and CRTT-Reading scores served as language severity measures.

For each dependent measure in each group, it was examined whether the data were normally distributed using Shaprio-Wilk's test of normality. Given that the data were not normally distributed for reading times in both NI (all *p*s $<.001$) and PWA (all *p*s$<.05$), non-parametric correlation coefficients were computed using Spearman's rank correlations for all dependent measures to be consistent across the dependent variables. The alpha level was adjusted to .01 (0.05/6 variables = 0.01).

In the NI group, the number of errors was significantly and negatively correlated with WM in SV-RC (r=-0.59), FG-No (r=-0.51), and FG-PP (r=-0.55), indicating that those who had lower WM capacity generally made more errors. Error data were significantly and negatively correlated with age only in the SV-PP condition (r=-0.59).

In the PWA group, the number of errors were significantly and negatively correlated with the PICA for the conditions such as SV-No (r=-0.57), SV-PP (r=-0.68), and SV-RC (r=-0.66) and with CRTT-R-WF for the conditions of SV-No (r=-0.58) and SV-PP (r=-0.53), indicating that those who had lower scores in the PICA and the CRTT-R-WF generally made more errors. WM was negatively and significantly correlated with the number of errors in the SV-PP condition (r=-0.56), indicating that those who had lower WM made more errors in that condition (Table 8).

Table 8 Correlation coefficients between the number of errors and other linguistic/cognitive factors in both groups

		SV-No	SV-PP	SV-RC	FG-No	FG-PP	FG-RC
NI	PICA	-0.08	0.02	0.18	-0.09	-0.07	-0.19
	CRTT-A	-0.14	-0.03	0.17	0.19	0.15	-0.03
	CRTT-R-WF	0.04	0.14	-0.01	0.26	0.32	0.29
	Age	-0.30	**-0.59**	-0.36	0.01	-0.10	0.00
	Education	-0.12	-0.20	0.20	-0.29	-0.14	-0.14
	WM	-0.37	-0.35	**-0.57**	**-0.51**	**-0.55**	-0.22
PWA	PICA	**-0.57**	**-0.68**	**-0.66**	0.01	-0.23	-0.12
	CRTT-A	-0.21	-0.34	-0.41	-0.10	-0.33	-0.25
	CRTT-R-WF	**-0.58**	**-0.53**	-0.38	0.09	0.07	0.01
	Age	-0.02	-0.04	-0.25	-0.41	-0.31	-0.04
	Education	0.26	0.54	0.26	0.50	0.30	0.46
	WM	-0.48	**-0.56**	-0.48	0.08	-0.06	-0.27

Note: NI=Normal Individuals; PWA=Persons with Aphasia; SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; PICA = Porch Index of Communicative Ability (PICA) (Porch, 2001); CRTT-A = Auditory version of the Computerized Revised Token Test (CRTT) (McNeil, Pratt, Szuminsky et al., 2008), CRTT-R-WF = A reading version of the CRTT
Shaded areas indicate that the correlation was significant at $p<.01$.

None of the correlations was significant for the RT-V in the NI group. In the PWA group, CRTT-A was significantly and negatively correlated with the RT-V in SV-RC condition (r=-0.54), indicating that those who had lower scores in the CRTT-A generally had longer reading times on the verb (Table 9).

Table 9 Correlation coefficients between the reading times on the verb and other linguistic/cognitive factors in both groups

		SV-No	SV-PP	SV-RC	FG-No	FG-PP	FG-RC
NI	PICA	0.03	-0.03	-0.04	0.03	-0.01	0.09
	CRTT-A	0.02	0.02	0.00	-0.04	-0.16	-0.14
	CRTT-R-WF	-0.17	-0.33	-0.29	-0.09	-0.04	-0.06
	Age	0.28	0.42	0.45	0.40	0.27	0.38
	Education	-0.19	-0.14	-0.01	-0.07	0.18	0.09
	WM	-0.13	-0.08	0.00	0.18	0.37	0.25
PWA	PICA	-0.09	-0.09	-0.20	-0.15	0.04	0.00
	CRTT-A	-0.46	-0.49	**-0.54**	-0.45	-0.41	-0.34
	CRTT-R-WF	0.13	0.03	0.04	0.08	0.07	-0.11
	Age	-0.21	-0.13	-0.11	-0.11	-0.10	0.14
	Education	-0.22	-0.02	-0.10	-0.20	-0.16	0.01
	WM	0.00	0.02	-0.10	-0.13	0.13	0.21

Note: NI=Normal Individuals; PWA=Persons with Aphasia; SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; PICA = Porch Index of Communicative Ability (PICA) (Porch, 2001); CRTT-A = Auditory version of the Computerized Revised Token Test (CRTT) (McNeil, Pratt, Szuminsky et al., 2008), CRTT-R-WF = A reading version of the CRTT
Shaded areas indicate that the correlation was significant at p<.01.

RT was significantly and positively correlated only with age in the NI group for FG-No (r=0.44) and FG-RC (r=0.45), indicating that people who were older generally took longer to respond to the yes/no questions. In contrast, for the PWA group, RT was significantly and negatively correlated with the CRTT-A in the SV-RC (r=-0.60) and FG-

RC (r=-0.57). This showed that PWA with lower accuracy in the CRTT took longer to respond to the questions. Table 10 illustrates these correlations.

Table 10 Correlation coefficients between the response times and other linguistic/cognitive factors in both groups

		SV-No	SV-PP	SV-RC	FG-No	FG-PP	FG-RC
NI	PICA	-0.05	-0.17	-0.18	-0.15	0.11	0.01
	CRTT-A	-0.25	0.03	-0.09	0.04	-0.14	0.02
	CRTT-R-WF	-0.22	-0.22	-0.31	-0.26	-0.09	-0.31
	Age	0.25	0.22	0.36	**0.44**	0.24	**0.45**
	Education	-0.17	-0.05	0.01	-0.26	-0.17	-0.12
	WM	-0.22	-0.24	-0.12	-0.10	0.05	0.00
PWA	PICA	-0.44	-0.36	-0.52	-0.18	-0.16	-0.22
	CRTT-A	-0.47	-0.53	**-0.60**	-0.41	-0.51	**-0.57**
	CRTT-R-WF	-0.45	-0.35	-0.32	-0.17	-0.01	-0.05
	Age	0.45	0.29	0.13	0.34	0.13	0.22
	Education	0.06	0.18	0.37	0.10	0.21	0.22
	WM	-0.44	-0.32	-0.38	-0.03	-0.14	-0.20

Note: NI=Normal Individuals; PWA=Persons with Aphasia; SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; PICA = Porch Index of Communicative Ability (PICA) (Porch, 2001); CRTT-A = Auditory version of the Computerized Revised Token Test (CRTT) (McNeil, Pratt, Szuminsky et al., 2008), CRTT-R-WF = A reading version of the CRTT
Shaded areas indicate that the correlation was significant at $p<.01$.

4.1.4.2. Analyses of correlations coefficients between online processing times and offline measures in both groups

In order to examine the relationships between online verb reading time and offline measures (number of errors and response times), correlation coefficients were obtained for each group using Spearman's rank correlations. Correlations between the two offline measures were also examined. The alpha level was adjusted to .01 (0.05/6 variables = 0.01).

In the NI group, there were significant and positive correlation coefficients between RT-V and RT for SV-PP (r=0.64), SV-RC (r=0.67), FG-PP (r=0.58), and FG-RC (r=0.56) conditions. PWA also showed significant and positive correlations between RT-V and RT in SV-RC (r=0.50), FG-PP (r=0.50), and FG-RC (r=0.57). These results suggest that those who spent more time in online verb processing took longer to respond to the yes/no questions (Table 11).

Table 11. Correlation coefficients among reading times on the verbs, response times, and number of errors in both groups.

		SV-No	SV-PP	SV-RC	FG-No	FG-PP	FG-RC
NI	RT-V * Nr. of Error	-0.11	-0.19	-0.08	-0.15	-0.23	0.15
	RT-V * RT	0.45	**0.64**	**0.67**	0.31	**0.58**	0.56
	RT * Nr. of Error	-0.20	-0.01	0.03	0.27	0.04	0.05
PWA	RT-V * Nr. of Error	-0.30	-0.25	-0.23	-0.17	-0.35	-0.02
	RT-V * RT	0.32	0.37	**0.50**	0.42	**0.50**	**0.57**
	RT * Nr. of Error	0.08	0.11	0.21	-0.27	0.15	0.18

Note: NI=Normal Individuals; PWA=Persons with Aphasia; SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier; RT-V*Error=correlation between reading times on the verb and number of errors; RT-V*RT=correlation between reading times on the verb and response times; RT*Error=correlation response times on the verb and number of errors.
Shaded areas indicate that the correlation was significant at $p<.01$.

4.1.4.3. Performance of individuals with agrammatic comprehension

Agrammatic comprehenders were identified based on the SOAP test. There were three individuals with aphasia (Participant IDs= 209, 213, and 219) who performed at chance-level on non-canonical sentences, but significantly above chance-level on canonical sentences, as typical of agrammatic comprehension. In order to examine whether performance of each individual with agrammatic comprehension was significantly different from non-agrammatic comprehenders, modified *t*-tests for each dependent measure were computed for each condition, using the formula from Crawford and Howell (1998).

On the error measure, one individual with agrammatic comprehension (Participant ID= 209) performed significantly worse than the rest of PWA, in the FG-RC condition, $t_{16}=2.66$, $p<.05$. This individual made 16 errors, compared to the mean of 7.97 for the non-agrammatic individuals in the FG-RC condition. Furthermore, this individual was the only participant who performed significantly below chance on the FG-RC condition. The number of errors for the three individuals with agrammatic comprehension was plotted in Figure 22. Participant 209 showed systematic increase of errors consistently with the locality theory. However, the rest of the two participants did not show any systematic pattern in the number of errors.

Reading and response time performance of the three individuals with agrammatic comprehension was not statistically different from that of the rest of the PWA. Furthermore, none of them showed the predicted patterns of reading and response times consistently with the locality theory.

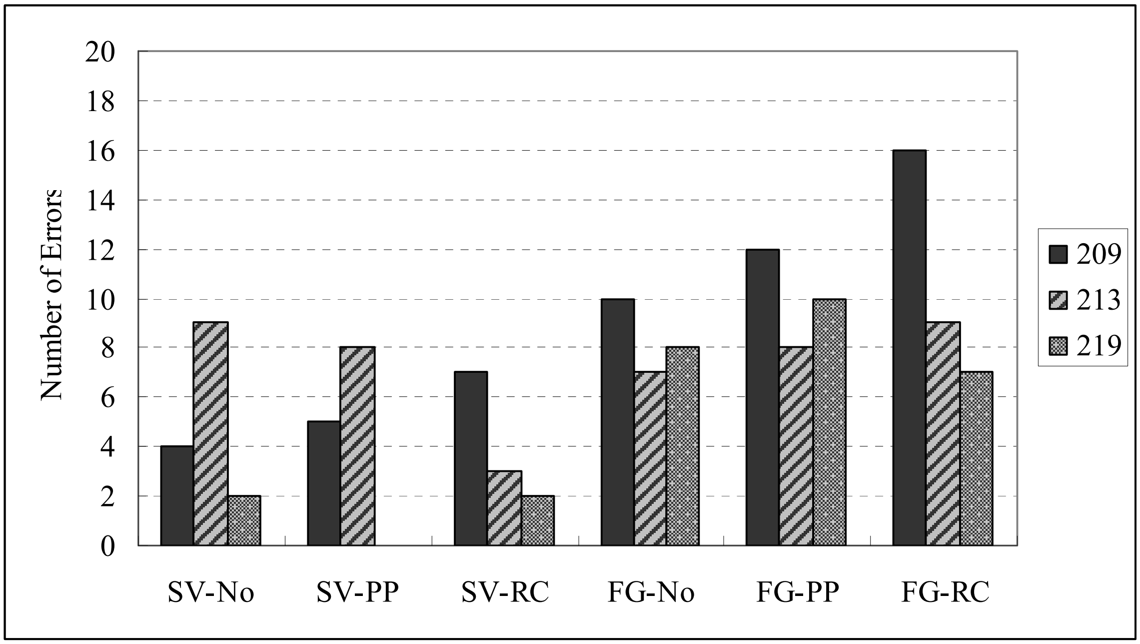

Figure 222. Number of errors in each condition for individuals with agrammatic comprehension
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

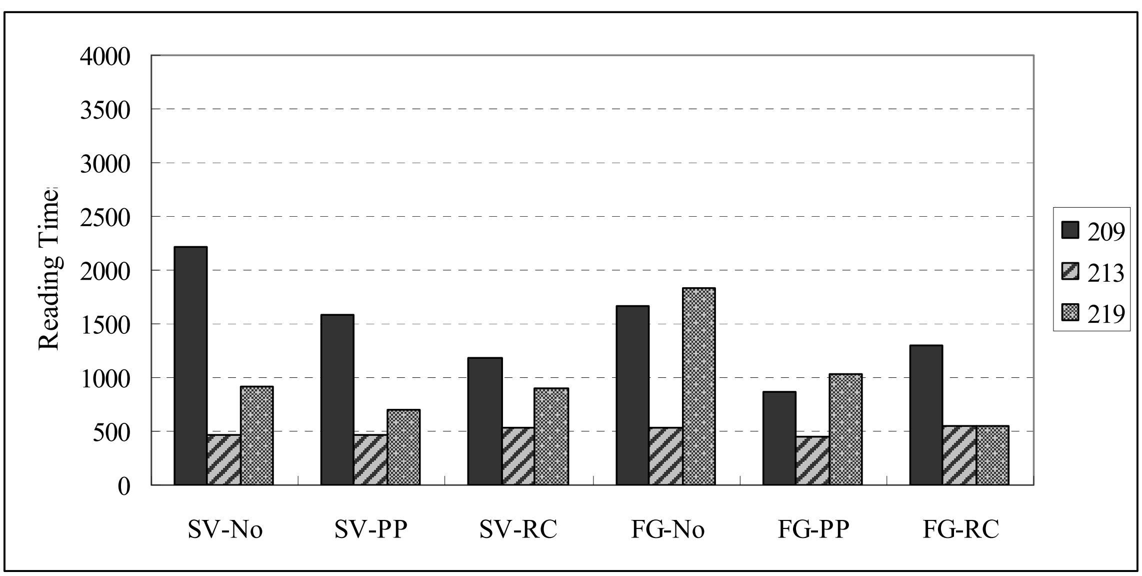

Figure 233. Reading times (ms) on the verb in each condition for individuals with agrammatic comprehension
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

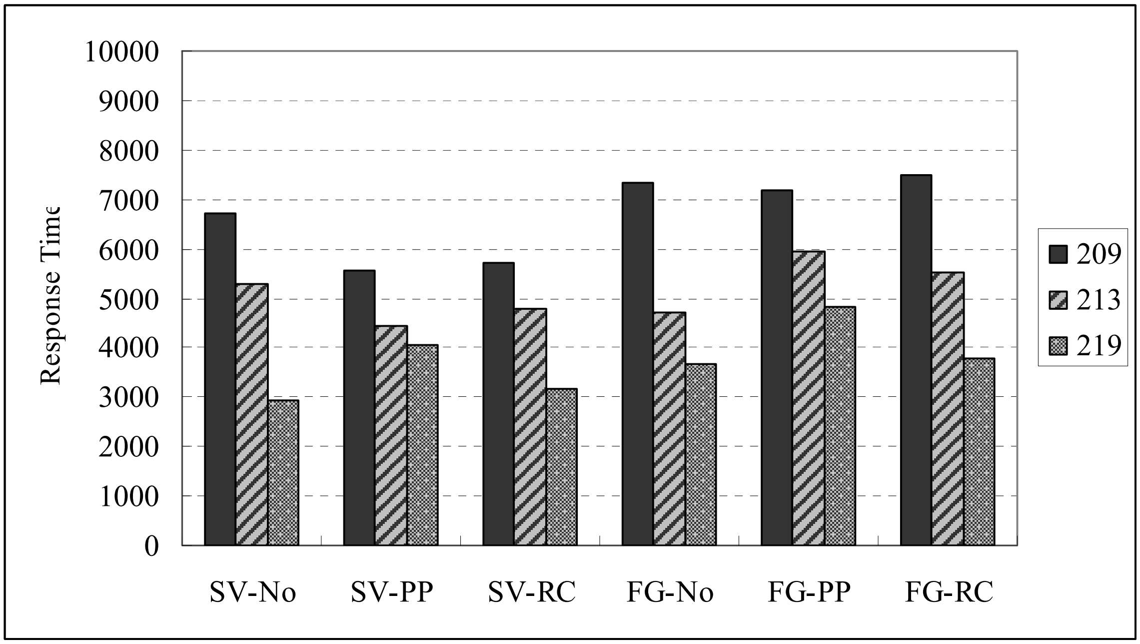

Figure 244. Response times (ms) in each condition for individuals with agrammatic comprehension
Note: SV-No= Subject-Verb dependency with No modifier; SV-PP= Subject-Verb dependency with Prepositional Phrase modifier; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier; FG-PP= Filler-Gap dependency with Prepositional Phrase modifier; FG-RC= Filler-Gap dependency with Relative Clause modifier

4.1.4.4. Results from the plausibility survey

The plausibility survey used a 7-point scale (1 as most implausible and 7 as most plausible) with participants rating the plausibility of a target sentence (e.g., The nurse contacted the doctor) and a reversed sentence (e.g., The doctor contacted the nurse). These were constructed by taking the first two arguments and a verb from each experimental stimulus. The rationale for administering the plausibility survey derived from the experimental stimuli was to provide descriptive information on whether participants relied on the plausibility of yes/no questions without comprehending the sentences that they read.

This was first examined by computing differences in the rating scores between the target and reversed sentences in each group, using a one-way repeated ANOVA. Plausibility scores were significantly higher for the target sentences than the reversed sentences in both NI, $F(1, 29)=28.07$, $p<.000$, and PWA, $F(1, 19)=39.46$, $p<.000$.

These descriptive data were also examined by calculating Pearson correlation coefficients from the difference in scores between the target and the reversed sentences to examine individuals' accuracy of performance relative to verb reading and response times for each group. Differences in plausibility scores were not significantly correlated with any of the dependent measures for any of the six experimental conditions in NI. The range of correlation coefficients was -.27 to .10. In contrast, there were significant correlations between the difference of the rating scores and the number of errors in PWA for SV-No, $r= -.57$, $p<.01$, SV-PP, $r= -.47$, $p<.05$ and SV-RC, $r= -.58$, $p<.01$, conditions. Negative and significant correlations in SV-dependency conditions indicate that PWA generated more errors in yes/no questions when there were fewer differences between the target and reversed sentences. In other words, when the two arguments were equally reversible, the difficulty appears to have been increased by relying on the plausibility of the relationship between the two arguments. However, correlations were not significant for FG-dependency conditions for PWA due to the fact that majority of these individuals performed at chance-level in filler-gap conditions, resulting in a restricted range for the number of errors.

4.2. SPECIFIC AIM II

The second specific aim was to investigate whether there are significant differences between the filler-gap and subject-verb dependencies in PWA compared to the NI, when the distance variable was well controlled.

For the data analysis to answer the second research question, two sentence-type conditions were extracted in which the distance-based integration cost at the verbs was equated. One sentence type involved the filler-gap dependency without modifier (e.g., *The aide who the nurse directed helped the patient in a very friendly manner*), and the other involved the subject-verb dependency with RC modifier (e.g., *The nurse who was from the clinic directed the aide in a very friendly manner*). In these sentences, the integration costs were equated as 3EUs in the embedded verb (for sentences with the filler-gap dependency) or the main verb (for sentences with the subject-verb dependency).

4.2.1. Number of Errors

In order to examine whether there were significant differences in number of errors between FG- and SV-dependency conditions for both groups, a two-way mixed ANOVA was computed with Dependency as a within-subject factor and Group as a between-subject factor. Figure 25 illustrates the significant main effects for Dependency, $F(1, 48)=117.57$, $p<.000$, with more errors found in FG- than SV-dependency, and for Group, $F(1, 48)=261.36$, $p<.000$, with PWA generating more errors than NI. The two-way interaction between Dependency and Group was not significant, $F(1, 48)=.374$, $p>.10$.

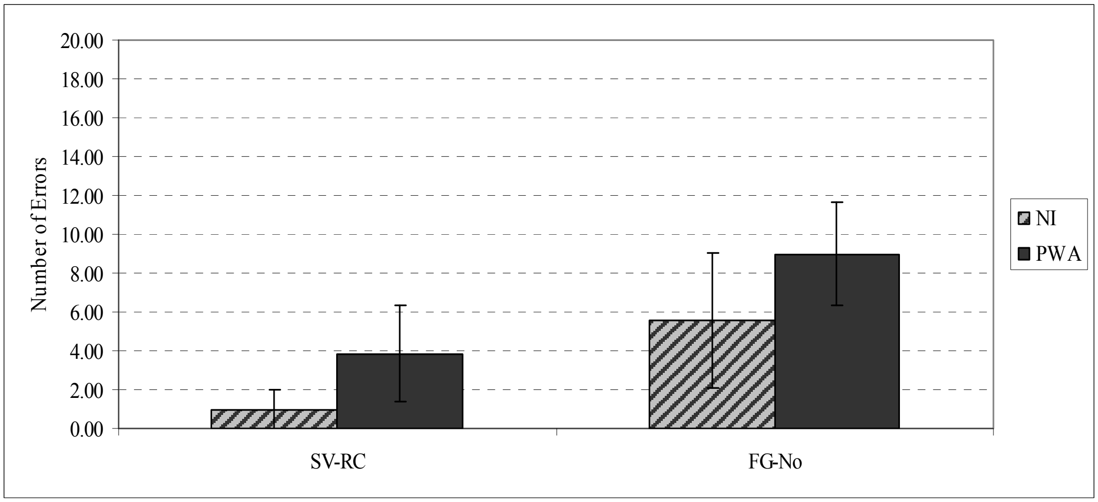

Figure 25. Number of errors for both groups in the SV-RC and FG-No conditions
Note: NI=normal individuals; PWA=persons with aphasia; SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier

4.2.2. Reading Times on the Verb and Response Times

In addition, the RT-V and RT measures were examined for differences between FG- and SV conditions with same integration costs. RT-V and RT data were obtained only from participants who answered the post-sentence Yes/No questions significantly better than chance. Due to the limited observations for PWA, it was not possible to examine for a performance by group interaction.

4.2.2.1. Normal Individuals

First of all, RT-V and RT data obtained from NI with above-chance-level performance in both SV and FG condition (n=15) were entered into two separate one-way repeated ANOVAs, with Dependency as a within-subject factor for each dependent measure. The main effect for Dependency was not significant either in RT-V, F(1, 14)=2.78, p=.12 or RT, F(1, 14)=3.96, p=.67, indicating that NI group did not significantly differ in online processing times and response times between SV and FG condition when the integration cost was equated. RT-V and RT data in NI (n=15) with above chance performance are illustrated in Figure 26 and Figure 27, respectively.

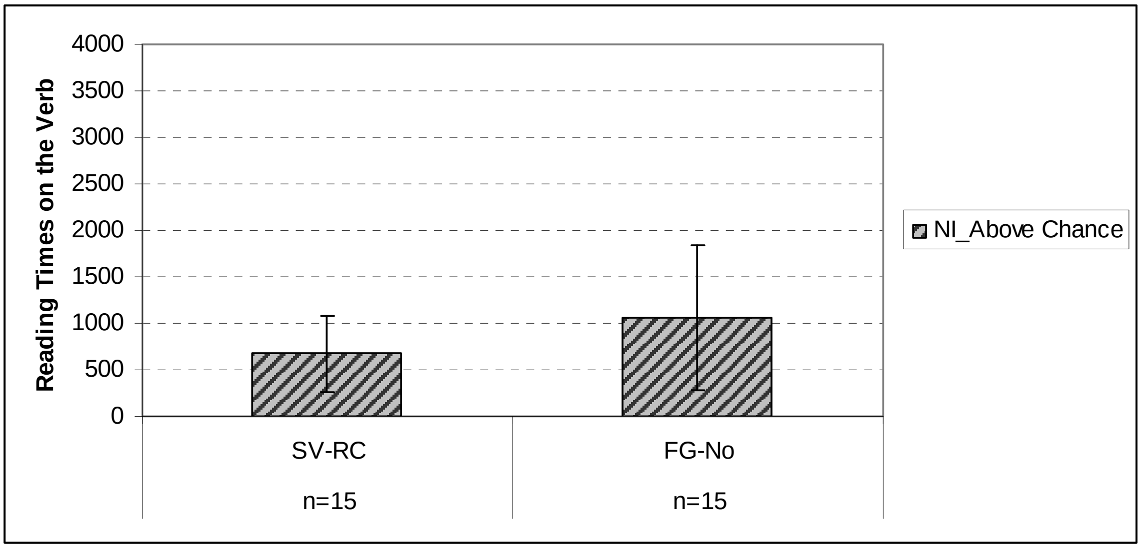

Figure 256. Reading times (ms) on the verb in SV-RC and FG-No conditions in normal individuals who performed above chance
Note: SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier

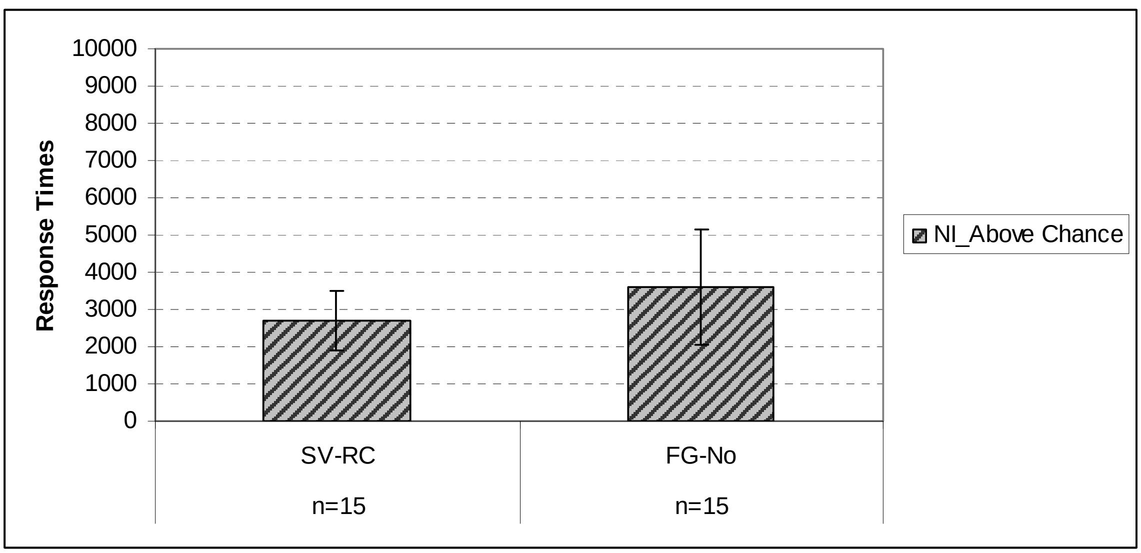

Figure 267. Response times (ms) in SV-RC and FG-No conditions in normal individuals who performed above chance
Note: SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier

In order to examine whether there were significant differences in RT-V and RT between subsets of the NI group (at chance-level vs. above chance-level), two separate one-way ANOVAs were computed for each dependent measure. There were no significant differences between chance and above-chance-level performers either in RT-V, $F(1, 29)=.16$, $p=.69$, or RT, $F(1, 29)=1.92$, $p=.18$. Their performance is shown in Figure 28 for RT-V and Figure 29 for RT.

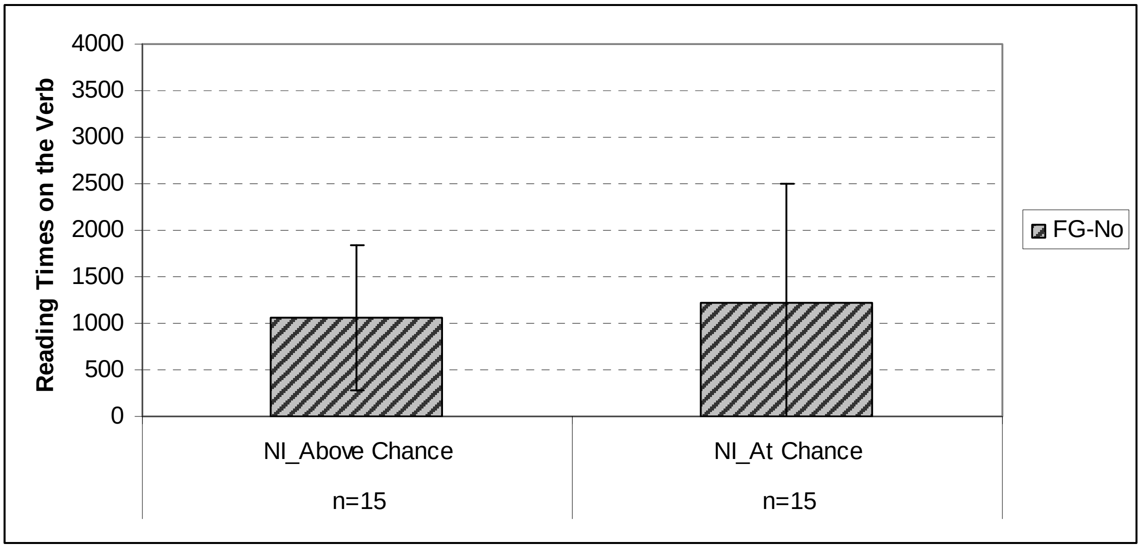

Figure 278. Reading times (ms) on the verb in SV-RC and FG-No conditions in normal individuals who performed at chance and above chance
Note: SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier

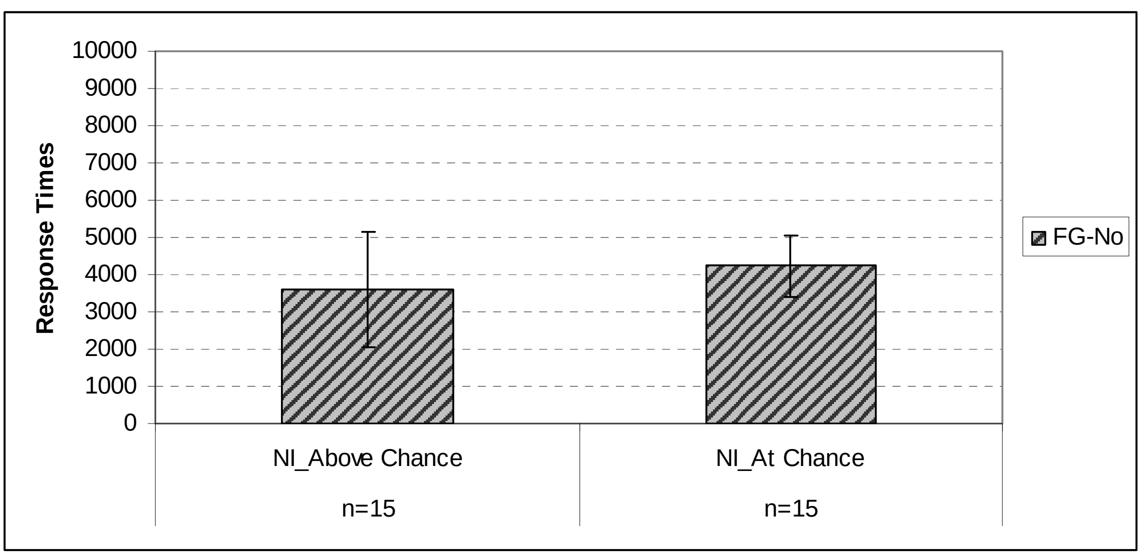

Figure 289. Response times (ms) in SV-RC and FG-No conditions in normal individuals who performed at chance and above chance

Note: SV-RC=Subject-Verb dependency with Relative-Clause modifier; FG-No= Filler-Gap dependency with No modifier

4.2.2.2. Individuals with aphasia

Only one individual with aphasia performed significantly better than chance in FG-No condition, although 15 individuals with aphasia performed better than chance in SV-RC condition. Due to the limited observations and unbalanced sample sizes, inferential statistics were not used for this data set.

It was examined whether this individual (218) performed significantly differently from the rest of the group with aphasia who performed at chance in both RT-V and RT, , using the formula provided from Crawford and Howell (1998) to compute a modified *t*-test. Participant 218 showed significantly longer RT-V than the rest of the group, $t_{19}=-2.40$, $p<.05$ (see Figure 14). This individual's RT was also significantly longer than that of the group with aphasia, $t_{19}=-2.91$, $p<.05$ (see Figure 15).

5.0. DISCUSSION

The first purpose of the current study was to determine the effects systematically manipulating "distance" on sentence comprehension, as measured by online reading time, sentence comprehension errors in yes/no questions, and response times to the questions, in both NI and PWA.

Normal elderly adults showed a systematic increase in the number of errors as a function of distance manipulation, showing that they made more errors in the RC-modifier conditions than No- and PP-modifier; especially in the FG-dependency sentences. These findings are consistent with Gibson (1998; 2000)'s Dependency Locality Theory, which proposed that greater difficulties are imposed as integration cost increases. Older normal adults in the current study also showed a systematic increase in reading times on the verb with a modifier type in the SV-dependency sentences, indicating that they showed longer reading times as the modifier was lengthened. These findings were also consistent with the locality theory. However, the finding of longer reading times in the SV-dependency sentences was not found in young college students by Grodner & Gibson (2005). Although systematic changes in reading times as a function of modifier in SV-dependency sentences were not statistically examined in their paper, there didn't appear to be a systematic change in reading times in the SV conditions in their young adults. In contrast, Grodner and Gibson (2005) noted that they observed slightly increased reading times in PP-modifier than RC-modifier, which they interpreted to be inconsistent with the locality theory.

Normal elderly adults in the current study showed an increase in online reading times as a function of modifier in the SV-dependency conditions. However, they did not show these effects in their offline measures. There were no significant differences in the number of errors or in response times among the three types of modifiers in the SV-dependency sentences. This may suggest that the older adults spent more time online in sentences with longer distance in order to achieve similar performance in offline measures in the same sentences. This pattern was not observed in young college students in the Grodner and Gibson (2005) study, as noted above. In other words, older adults don't seem to perform differently from younger adults as a type of modifier in the SV-dependency in the offline measures, showing that both groups did not present any systematic increase of errors as the modifier gets longer. However, the online reading time measures were sufficiently sensitive to show the changes in processing times in the older adults. These findings were partially consistent with those from Kemper and Kemtes (1999) who reported that older adults with low WM capacity showed longer reading times in a syntactically ambiguous region than those with high WM capacity. However, these patterns were not observed in younger adults in their study. Limitation of the interpretations based on the current study is that the findings were not statistically validated between young and older adults. Further studies need to examine whether online measures are more sensitive than offline measures to show changes in sentence comprehension abilities between the age groups when distance was manipulated.

When performance of older adults was examined for the FG-dependency conditions, about 60% of older adults performed at chance-level. The mean number of errors in the FG-dependency was 6.26 (out of 20 trials) with about 70% accuracy rate. An averaged accuracy rate of 70% is not surprising in FG-dependency sentences for older adults, given that previous literature has reported mean accuracy rates between 44% and 55% in ambiguous sentences with relative clauses when the stimuli were presented using a self-paced word-by-word reading method (Kemtes & Kemper, 1997). However, when individual performance was examined using chance-level criterion, it is surprising to observe the high rate of chance-level performers, even in older adults. In most of the aging literature on sentence processing, individual differences in yes/no questions were not examined using the chance-level performance. Categorizing individuals' performance using a binary distinction creates a risk for loss of statistical power to detect actual differences. However, it is worthwhile to examine individual data by identifying chance-level performance especially when online processing time data are concerned. When the d-prime measure was used instead of the binary categorization, in order to control chance-level performance, d-prime values were not significantly different between older adults and persons with aphasia in the FG-dependency sentences. These results indicate that older adults were as insensitive as persons with aphasia in detecting the correct responses in the FG-dependency conditions. These results are consistent with those of Zurif et al. (1995). These authors found that older adults did not show gap-filling effects with the longer distance condition between the two linguistic elements to be integrated, whereas they did demonstrate priming effects in filler-gap computations when the distance was shortened. They argued that older adults had difficulties with filler-gap computations when their memory capacity was exceeded, implicating the role of short term or working memory in the accomplishment of the computation.

Reading times and RT data were examined separately for at-chance and above-chance-level performance. Older adults with above-chance performance showed relatively systematic effects of the distance on errors and RT data, whereas at-chance-level performers did not show systematic patterns as a function of distance in offline measures. In online reading time performance, older adults with above-chance-level performance showed increased RT-V except for the most complex condition (FG-RC) where they showed decreased RT-V compared to FG-No and FG-PP conditions. It appears that there is an online and offline performance trade-off in the FG-RC condition in older adults with above-chance-level performance. It is possible that spending not enough time in online syntactic processing resulted in poor performance in offline measures especially in the most complex sentences in which participants' WM capacity was sufficiently taxed or exceeded.

PWA produced significantly more errors, longer online reading times and longer response times than NI. PWA also generated more errors in the FG- than SV-dependency, consistent with the previous findings which used an auditory moving window (e.g., Caplan & Waters, 2003). However, there were no significant effects of modifier on any of the dependent measures. These findings are partially consistent with the findings from Friedmann and Gvion (2003), but not with Berndt et al, (1997). Friedmann and Gvion manipulated the distance between the antecedent and the gap in two different sentences with subject- and object-relative clauses by padding adjective and prepositional phrases. They found that three individuals with agrammatic aphasia showed above chance-level performance on sentences with subject-relative clause, but their performance on sentences with object-relative clause was not significantly different from chance. Three individuals with conduction aphasia performed significantly better than chance on all sentences types. However, performance of both groups with agrammatic and conduction aphasia was not affected by the manipulation of modifiers in either type of sentence. Based on these findings, the authors suggested that the distance manipulation by padding the number of words between the antecedent and the gap did not decrease sentence comprehension in either aphasia group. However, the syntactic manipulation affected only individuals with agrammatic aphasia who showed chance-level performance on the object-relative sentences.

Results from the current study are partially consistent with the findings from Friedmann and Gvion (2003) in that performance of individuals with aphasia was affected by the dependency manipulation, but not by modifier manipulation. However, there are differences in the subject selection between the two studies. Six participants were classified using a Hebrew version of the WAB (Soroker, 1997) in the Freidman and Gvion study. However, twenty participants with aphasia were unclassified in the current study. Instead, their language deficits were described by testing overall language impairments across modalities. Friedman and Gvion found that only individuals with agrammatic aphasia failed to understand the object-relative clauses, but not the individuals with conduction aphasia. In contrast, the current study showed that the majority (more than 80%) of individuals with aphasia performed at chance-level on sentences with filler-gap dependencies. Although it is difficult to make direct comparisons of the results between the studies due to the different subject-selection procedures, it is possible that the discrepancy in the syntactic-specific effects between agrammatic and conduction groups in Friedman and Gvion's study might be due to the overall severity of their language or comprehension impairments.

The findings from the current study were not predicted by the specific impairment hypothesis which suggested that only individuals with agrammatic Broca's aphasia would show chance-level performance on the filler-gap sentences. Three individuals with aphasia out of 20 met the criterion for agrammatic comprehension based on their performance on the SOAP in the current study. However, only one individual (209) with agrammatic comprehension (out of three) performed significantly worse than the rest of aphasic group on the FG-RC condition. In other words, three individuals, classified as an 'agrammatic comprehender', performed like the group, except for one participant and only under one condition with a filler-gap dependency. In terms of participant's language production, MLU-w and MLU-m were the only two measures in which 209 performed significantly worse than the rest of the group with aphasia from among several measures used as indicators of agrammatic production. These results indicate that the majority of PWA showed chance-level performance on the yes/no questions regardless of the participants' classification.

Non-significant effects of modifiers found in the current study are not consistent with the findings from Berndt et al. (1997). In that study, PWA showed modifier effects regardless of the type of aphasia. A greater burden imposed by the self-paced reading method in the current study might have created floor effects, especially in sentences with FG-dependency, resulting in the majority PWA performing at chance-level. That these sentence types were challenging is evidenced by the fact that about 60% of normal elderly individuals performed at chance-level on FG-dependency sentences.

One may argue that the high rate of chance-level performance on FG-dependency conditions in PWA is consistent with the specific impairment hypotheses, given that these hypotheses predicted that PWA would performed at chance-level on the filler-gap sentences but above-chance-level on sentences without filler-gap dependencies. However, the specific impairment hypotheses have been exclusively applied to individuals with agrammatic Broca's aphasia. These hypotheses would not predict chance-level performance on the filler-gap sentences in the normal individuals or in the PWA who do not have agrammatic symptoms. Ninety-five percent of the PWA and approximately 50% of NI showed chance-level performance on the most frequently used filler-gap structure without modifiers. Eighty-five percent of PWA performed at chance-level on the most complex FG-dependency with RC-modifier condition. The current results are consistent with resource-related hypotheses, suggesting that when cognitive tasks are taxing enough to exceed one's capacity, performance degradation is predicted regardless of the presence of language impairments and the type of aphasia (e.g., Miyake et al., 1994). These results are, however, not easily accounted for by the specific impairments hypotheses that argue that the locus of syntactic comprehension impairments is a loss of syntactic representations or a computational impairment in filler-gap construction, and that it is uniquely found in persons with agrammatic Broca's aphasia.

There is small number of PWA who showed better than chance-level performance in the FG-dependency conditions. Their online reading time data were individually examined to identify those who showed an increase in reading time as a function of distance manipulation, consistently with Gibson's locality theory. There were one, four, and three PWA who showed this effect in the FG conditions for FG-No, FG-PP, and FG-RC, respectively. None of those individuals showed a systematic pattern of reading times consistent with the distance manipulations. Their online performance was highly variable.

When PWA's performance was examined between chance-level and above-chance-level groups, the above-chance-level group spent more time than the chance-level group (Figure 14). This might indicate that there was an online and offline trade-off in the chance-level group with aphasia. In other words, those PWA who spent less time online were more likely to perform at chance-level in the FG conditions. Negative correlations between the RT-V and number of errors is consistent with this speculation, although their correlation coefficients were not statistically significant (range of correlations was between -.10 to -.40 across the conditions). Again, this speculation needs to be further examined with more number of participants with aphasia using experimental designs to test this hypothesis on the trade-off between online and offline sentence comprehension.

Several researchers investigated the relationship between online processing impairments and disruptions in offline performance. Caplan and colleagues (Caplan & Waters, 2003; Caplan et al., 2007) found that PWA demonstrated fairly normal on-line listening patterns in the region at which the coindexation occurs when they comprehended the sentence correctly. However, they often showed abnormal patterns of on-line listening times at the critical regions when they erred on the end-of-sentence measures. Caplan et al (2007) interpreted these data as indicating that parsing/interpretive and automatic processing mechanisms function "stochastically" (p.145).

Dickey, Choy, and Thompson's (2007) eye-movement study examined on-line processing of wh-movement sentences in individuals with agrammatic Broca's aphasia. The authors found that both normal and individuals with Broca's aphasic demonstrated rapid and automatic processing of wh-movement by fixating on the correct pictures corresponding to the moved elements. However, the two groups differed in the later (post-verbal) regions of the sentence, showing that PWA exhibited more fixations on the competitor than the correct picture in the post-offset region of the sentences, especially when they interpreted the sentence incorrectly. Dickey et al. suggested that disruptions or competitions in the later region of the sentences observed in the incorrect responses might be the source of the comprehension failure in people with Broca's aphasia, in spite of their demonstrated abilities to co-index the gap with its antecedent which were neither impaired nor slowed.

The current study was not designed specifically to examine the exact locus of the impairments in sentence processing for PWA. Nonetheless, an examination of the above-chance-level group suggests that they spent more time online than the chance-level group, reflecting their relative abilities in syntactic computations at the verb (Figure 14). However, in the later region of the sentence, believed to be critical in response selection and decision making processes, the two groups did not show differences (Figure 15). The findings from the current study are more consistent with those from Caplan and colleagues. More studies are required to answer the questions about the relationship between online and offline sentence processing, using easier stimuli than those employed in the current study. Especially for the studies that examine online processing in PWA, it seems to be very important to have stimuli that tax their capacity without exceeding it to the extent to which they produced floor effects.

As additional analyses, several factors that are potentially related to individual differences in sentence comprehension were examined. These included; WM, age, education, and language performance measures (PICA, CRTT-A, CRTT-R-WF) for each group. WM was significantly and negatively correlated with the number of errors in the NI group for SV-RC, FG-No, and FG-RC conditions and in the PWA but only for the SV-PP condition. These findings are consistent with the previous reports in NI (e.g., Just & Carpenter, 1992; King & Just, 1991; Caplan & Waters, 1999) and in PWA (e.g., Caspari et al., 1998; Sung et al., 2009; Wright et al., 2007). However, WM span was not significantly correlated with RT-V in either NI or PWA. These findings are consistent with a multiple WM resource hypotheses which proposed that automatic syntactic processing abilities are not related to individual differences measured by WM tasks that are related to post-interpretive and controlled processing (e.g., Caplan & Waters, 1999).

The measure of general language performance captured by the PICA overall score, significantly and negatively correlated with the number of errors produced for the PWA in the SV-dependency conditions. Likewise, the self-paced reading performance captured by the CRTT-R-WF overall score negatively and significantly correlated with the number of errors for the PWA. The non-self-paced measure of auditory comprehension measured by the CRTT-A was correlated significantly and negatively with the RT-V and RT for the PWA in the SV-RC condition. Together these findings suggest that those PWA who produced lower scores in those language measures had longer reading times and produced more errors in sentence comprehension. Conversely, in the NI group, age was positively and significantly correlated with RT. Results of these analyses indicated that slowed response times are related to aging in normal individuals, but language performance/severity measures were more related to their online and offline sentence comprehension as measured by the current experiments in PWA.

The second purpose of the study was to investigate the effects of dependency on sentence comprehension when distance was controlled between the FG- and SV-dependencies.

When the distance-based integration cost was equated between the FG- and SV-dependency, FG-dependency generated more errors than SV-dependency for both groups. Older normal adults with above-chance performance did not show a significant difference in RT-V between the two linguistic dependencies. This finding is consistent with the predictions from the locality-based integration cost (Gibson, 2000; Grodner & Gibson, 2005). Although there were relatively large differences in the magnitude of reading times (390ms =1062ms of FG – 672ms of SV), the difference was not statistically significant due to the large variability in older normal adults. By contrast, the reading time differences between SV-RC and FG-No conditions in young adults from Grodner and Gibson (2005) was about 100ms. Considering the large differences in reading times between older and younger adults in these two conditions, there appears to be an interaction between age and syntactic complexity in online reading times, indicating that older adults took differentially longer to compute the filler-gap dependency than subject-verb dependency compared to young colleague students when distance was equated. These results are consistent with previous findings that older adults showed longer online reading times than younger adults in processing complex syntactic structures (e.g., Kemper & Kemtes, 1999). However, the current observation is not consistent with the argument that older adults' abilities to compute syntactic dependencies online are not affected by aging (e.g., Waters & Caplan, 2001). More studies are required to examine whether older adults have greater difficulties in computing the filler-gap associations compared to younger adults using both online and offline measures even when the distance is equated between the two linguistic syntactic structures (FG vs. SV).

Although integration cost was equated between the SV-RC and FG-No condition, there are at least two reasons why longer reading times in the FG-No than SV-RC condition should be expected. In Grodner and Gibson's (2005) theoretical framework for the current experimental design, only integration cost was taken into account. However, when the storage cost is considered, the reading times in FG-No condition would be longer than in SV-RC condition. Storage cost is involved in keeping track of incomplete dependencies (Gibson, 1998; 2000). When the verb in SV-RC condition is encountered (e.g., The nurse who was from the clinic called the doctor), there is only one storage cost to predict the recipient of the transitive verb “called”. In contrast, in the FG-No condition (e.g., The doctor who the nurse called visited the patient.) there are two storage costs assigned to the verb “called”: One is for the object of the transitive verb “called” and the other is for the verb associated with the subject of the main clause (noun phrase “the doctor”).

The other possibilities to account for FG sentences compared to SV-RC structures are from the similarity-based interference effects (e.g., Gordon, Hendrik & Johnson, 2002). In the FG sentence used in the current study, semantic similarity between the NP in the main clause and the NP in the embedded clause could create greater interference in processing sentences than the sentence with SV-RC that does not have an adjacent NP in the embedded clause. Syntactically, the FG sentence has a non-canonical order with two different thematic roles assigned to the initial NP. However, the SV-RC sentence has a canonical word order with same thematic role assigned to the NP.

Although there are several reasons to predict different processing times between the two syntactic structures, reading times in the verb for older adults were not significantly different between the two syntactic structures. Non-significant results might be due to the huge variability in older adults in spite of the observation of the large differences in magnitude of the scores between the conditions. Furthermore, only older adults with above-chance-level performance were entered into the reading time analyses, and this reduced the sample size from 30 to 20. Further studies need to examine these other possibilities that might cause greater difficulties in FG computations than SV association even when the distance is equated in both older adults and individuals with aphasia.

Manipulating these other factors can potentially disentangle the relevant components of WM that may differentially contribute to sentence processing in NI and PWA. For example, manipulating the distance while the computational loads are held constant may indicate how the short-term storage can play a role in sentence comprehension. Alternatively, varying the computational loads with distance held constant by creating interference effects may help to isolate the unique contributions of the computational parts of WM to sentence comprehension. Identifying the locus of sentence comprehension difficulties associated with WM limitations will contribute to understanding differential sentence comprehension deficits in individuals with aphasia. More studies need to be conducted by manipulating the memory demands in both older adults and persons with aphasia.

6.0. CONCLUSION

The first specific aim of the current study was to investigate the effects of the distance manipulation on both online and offline sentence comprehension in NI and PWA. Consistent with Gibson's (1998; 2000) locality theory, when distance was systematically manipulated by varying the syntactic dependency and the type of modifiers, NI demonstrated an increase in the number of errors and response times to the yes/no questions as the distance increased. NI also exhibited a relatively systematic increase in online verb reading times and response times as a function of the distance manipulation except for the most complex condition (FG-RC) in which 77% of NI performed at chance-level. More than 60% of normal individuals performed at chance-level in sentences with FG-dependencies. The non-significant differences in the d-prime scores between NI and PWA for the FG-dependency condition are consistent with the high rate of chance performance, indicating that older adults were as insensitive as PWA at detecting correct responses when filler-gap computations were required. Consistent with the previous aging literature, older adults showed decreased sensitivity to compute the filler-gap sentences.

PWA exhibited the dependency effect with more errors found in the FG- than SV-dependency sentences. However, their sentence comprehension was not affected by the manipulation of the modifiers. Their reading time data were difficult to interpret due to the very limited observations for FG-dependency conditions after chance-level performers were excluded from the reading time analyses. One can argue that the high rate of chance-level performance in PWA especially under the FG conditions is consistent with the specific impairments hypotheses. However, the chance-level performance was not restricted to a certain group of aphasia in the current study. Instead, the current results were more consistent with resource-related hypotheses that propose that sentence comprehension deficits will manifest themselves regardless of the type of aphasia when their capacity is sufficiently taxed but not exceeded to the degree that the task is abandoned.

When distance-based integration cost was held constant between FG- and SV-dependency, FG-dependency generated more errors in both groups. However, the reading times on the verb were not significantly different between the two conditions in the older non-impaired adults. These results are consistent with the locality theory. Considering longer reading time differences observed between the FG- and SV-dependency in older adults than younger adults derived from other studies, non-significant results might be due to the large variability and/or the limited sample size. More research is needed to investigate other possibilities other than distance-based accounts in determining the nature of the comprehension difficulties in older normal adults and persons with aphasia.

Appendix A: Sentence Stimuli and Yes/No Questions

1a. The nurse contacted the doctor in the morning
1b. The nurse from the clinic contacted the doctor in the morning
1c. The nurse who was from the clinic contacted the doctor in the morning
1d. The doctor who the nurse contacted visited the patient in the morning
1e. The doctor who the nurse from the clinic contacted visited the patient in the morning
1f. The doctor who the nurse who was from the clinic contacted visited the patient in the morning.

Q1.: Did the nurse contact the doctor?

2a. The boy dated the girl for three years.
2b. The boy in the classroom dated the girl for three years.
2c. The boy who was in the classroom dated the girl for three years.
2d. The girl who the boy dated ignored the classmates for three years.
2e. The girl who the boy in the classroom dated ignored the classmates for three years.
2f. The girl who the boy who was in the classroom dated ignored the classmates for three years.

Q2: Did the girl date the boy?

3a. The fans loved the star very much.
3b. The fans at the concert loved the star very much.
3c. The fans who was at the concert loved the star very much.
3d. The star who the fans loved injured a spectator very much.
3e. The star who the fans at the concert loved injured a spectator very much.
3f. The star who the fans who were at the concert loved injured a spectator very much.

Q3: Did the fans love the star?

4a. The rebels threatened the farmer in the evening.
4b. The rebels in the jungle threatened the farmer in the evening.
4c. The rebels who were in the jungle threatened the farmer in the evening.
4d. The farmer who the rebels threatened called the neighbor in the evening.
4e. The farmer who the rebels in the jungle threatened called the neighbor in the evening.
4f. The farmer who the rebels who were in the jungle threatened called the neighbor in the evening.

Q4: Did the farmer threaten the rebels?

5a. The soldier phoned the reporter in the evening.
5b. The soldier from the war phoned the reporter in the evening.
5c. The soldier who was from the war phoned the reporter in the evening.
5d. The reporter who the soldier phoned bothered the passenger in the evening
5e. The reporter who the soldier from the war phoned bothered the passenger in the evening.

5f. The reporter who the soldier who was from the war phoned bothered the passenger in the evening.

Q5: Did the soldier phone the reporter?

6a. The uncle welcomed the aunt in the afternoon.
6b. The uncle by the gate welcomed the aunt in the afternoon.
6c. The uncle who was by the gate welcomed the aunt in the afternoon.
6d. The aunt who the uncle welcomed hugged the cousins in the afternoon.
6e. The aunt who the uncle by the gate welcomed hugged the cousins in the afternoon.
6f. The aunt who the uncle who was by the gate welcomed hugged the cousins in the afternoon.

Q6: Did the aunt welcome the uncle?

7a. The maid burned the cook just this morning.
7b. The maid in the kitchen burned the cook just this morning.
7c. The maid who was in the kitchen burned the cook just this morning
7d. The cook who the maid burned offended the butler just this morning.
7e. The cook who the maid in the kitchen burned offended the butler just this morning.
7f. The cook who the maid who was in the kitchen burned offended the butler just this morning.

Q7: Did the maid burn the cook?

8a. The detective questioned the officer at the scene.
8b. The detective on the case questioned the officer at the scene.
8c. The detective who was on the case questioned the officer at the scene.
8d. The officer who the detective questioned consulted the expert at the scene.
8e. The officer who the detective on the case questioned consulted the expert at the scene.
8f. The officer who the detective who was on the case questioned consulted the expert at the scene.

Q8: Did the officer question the detective?

9a. The dragon wounded the knight during the battle.
9b. The dragon in the tower wounded the knight during the battle.
9c. The dragon who was in the tower wounded the knight during the battle.
9d. The knight who the dragon wounded married the princess during the battle
9e. The knight who the dragon in the tower wounded married the princess during the battle.
9f. The knight who the dragon who was in the tower wounded married the princess during the battle.

Q9: Did the dragon wound the knight?

10a. The nanny hugged the child after nap time.
10b. The nanny on the chair hugged the child after nap time.
10c. The nanny who was on the chair hugged the child after nap time.

10d. The child who the nanny hugged helped the mother after nap time.
10e. The child who the nanny on the chair hugged helped the mother after nap time.
10f. The child who the nanny who was on the chair hugged helped the mother after nap time.

Q10: Did the child hug the nanny?

11a. The audience disliked the singer for the bad performance.
11b. The audience at the club disliked the singer for the bad performance.
11c. The audience who was at the club disliked the singer for the bad performance.
11d. The singer who the audience disliked insulted the pianist for the bad performance.
11e. The singer who the audience at the club disliked insulted the pianist for the bad performance.
11f. The singer who the audience who was at the club disliked insulted the pianist for the bad performance.

Q11: Did the audience dislike the singer?

12a. The baker hated the chef a great deal.
12b. The baker at the shop hated the chef a great deal.
12c. The baker who was at the shop hated the chef a great deal.
12d. The chef who the baker hated annoyed the manager a great deal.
12e. The chef who the baker at the shop hated annoyed the manager a great deal.
12f. The chef who the baker who was at the shop hated annoyed the manager a great deal.

Q12: Did the chef hate the baker?

13a. The husband divorced the wife after the holidays.
13b. The husband at the party divorced the wife after the holidays.
13c. The husband who was at the party divorced the wife after the holidays.
13d. The wife who the husband divorced called the family after the holidays.
13e. The wife who the husband at the party divorced called the family after the holidays.
13f. The wife who the husband who was at the party divorced called the family after the holidays.

Q13: Did the husband divorce the wife?

14a. The lawyer trusted the client despite the rumors.
14b. The lawyer in the office trusted the client despite the rumors.
14c. The lawyer who was in the office trusted the client despite the rumors.
14d. The client who the lawyer trusted betrayed the friend despite the rumors.
14e. The client who the lawyer in the office trusted betrayed the friend despite the rumors.
14f. The client who the lawyer who was in the office trusted betrayed the friend despite the rumors.

Q14: Did the client trust the lawyer?

15a. The students watched the surgeon in the morning.
15b. The students at the operation watched the surgeon in the morning.

15c. The students who were at the operation watched the surgeon in the morning.
15d. The surgeon who the students watched contacted the nurse in the morning.
15e. The surgeon who the students at the operation watched contacted the nurse in the morning.
15f. The surgeon who the students who were at the operation watched contacted the nurse in the morning.

Q15: Did the students watch the surgeon?

16a. The professor assessed the students at semester's end.
16b. The professor at the talk assessed the students at semester's end.
16c. The professor who was at the talk assessed the students at semester's end.
16d. The students who the professor assessed confused the committee at semester's end.
16e. The students who the professor at the talk assessed confused the committee at semester's end.
16f. The students who the professor at the talk assessed confused the committee at semester's end.

Q16: Did the students assess the professor?

17a. The man bothered the operator in the afternoon.
17b. The man on the phone bothered the operator in the afternoon.
17c. The man who was on the phone bothered the operator in the afternoon.
17d. The operator who the man bothered alerted the manager in the afternoon.
17e. The operator who the man on the phone bothered alerted the manager in the afternoon.
17f. The operator who the man who was on the phone bothered alerted the manager in the afternoon.

Q17: Did the man bother the operator?

18a. The readers supported the writer with great consistency.
18b. The readers from the university supported the writer with great consistency.
18c. The readers who were from the university supported the writer with great consistency.
18d. The writer who the readers supported lobbied the editor with great consistency.
18e. The writer who the readers from the university supported lobbied the editor with great consistency.
18f. The writer who the readers who were from the university supported lobbied the editor with great consistency.

Q18: Did the writer support the readers?

19a. The president confronted the politician in the afternoon.
19b. The president at the convention confronted the politician in the afternoon.
19c. The president who was at the convention confronted the politician in the afternoon.
19d. The politician who the president confronted provoked the citizens in the afternoon.
19e. The politician who the president at the convention confronted provoked the citizens in the afternoon.

19f. The politician who the president who was at the convention confronted provoked the citizens in the afternoon.

Q19: Did the president confront the politician?

20a. The baby surprised the parents in the morning.
20b. The baby in the yard surprised the parents in the morning.
20c. The baby who was in the yard surprised the parents in the morning.
20d. The parents that the baby surprised blamed the babysitter in the morning.
20e. The parents that the baby in the yard surprised blamed the babysitter in the morning.
20f. The parents that the baby who was in the yard surprised blamed the babysitter in the morning.

Q20: Did the parents surprise the baby?

21a. The kid pushed the girl after school today.
21b. The kid on the slide pushed the girl after school today.
21c. The kid who was on the slide pushed the girl after school today.
21d. The girl that the kid pushed found the mother after school today.
21e. The girl that the kid on the slide pushed found the mother after school today.
21f. The girl that the kid who was on the slide pushed found the mother after school today.

Q21: Did the kid push the girl?

22a. The natives captured the sailor following the wreck.
22b. The natives on the island captured the sailor following the wreck.
22c. The natives who were on the island captured the sailor following the wreck.
22d. The sailor who the natives captured irritated the chief following the wreck.
22e. The sailor who the natives on the island captured irritated the chief following the wreck.
22f. The sailor who the natives on the island captured irritated the chief following the wreck.

Q22: Did the sailor capture the natives?

23a. The scientists invited the researcher at the conference.
23b. The scientists in the lab invited the researcher at the conference.
23c. The scientists in the lab invited the researcher at the conference.
23d. The researcher who the scientists invited offended the assistant at the conference.
23e. The researcher who the scientists in the lab invited offended the assistant at the conference.
23f. The researcher who the scientists who were in the lab invited offended the assistant at the conference.

Q23: Did the scientists invite the researcher?

24a. The thief passed the driver in the dark.
24b. The thief in the van passed the driver in the dark.

24c. The thief who was in the van passed the driver in the dark.
24d. The driver who the thief passed hit the deer in the park.
24e. The driver who the thief in the van passed hit the deer in the park.
24f. The driver who the thief who was in the van passed hit the deer in the park.

Q24: Did the driver pass the thief?

25a. The workers doubted the leader after the strike.
25b. The workers at the rally doubted the leader after the strike.
25c. The workers who were at the rally doubted the leader after the strike.
25d. The leader who the workers doubted calmed the crowd after the strike.
25e. The leader who the workers at the rally doubted calmed the crowd after the strike.
25f. The leader who the workers at the rally doubted calmed the crowd after the strike.

Q25: Did the workers doubt the leader?

26a. The stewardess praised the pilot during the interview.
26b. The stewardess from the flight praised the pilot during the interview.
26c. The stewardess who was from the flight praised the pilot during the interview.
26d. The pilot who the stewardess praised thanked the official during the interview.
26e. The pilot who the stewardess from the flight praised thanked the official during the interview.
26f. The pilot who the stewardess who was from the flight praised thanked the official during the interview.

Q26: Did the pilot praise the stewardess?

27a. The director married the secretary despite the rumors.
27b. The director at the company married the secretary despite the rumors.
27c. The director who was at the company married the secretary despite the rumors.
27d. The secretary who the director married liked the colleagues despite the rumors.
27e. The secretary who the director at the company married liked the colleagues despite the rumors.
27f. The secretary who the director who was at the company married liked the colleagues despite the rumors.

Q27: Did the director marry the secretary?

28a. The actor assisted the actress throughout the filming.
28b. The actor at the show assisted the actress throughout the filming.
28c. The actor who was at the show assisted the actress throughout the filming.
28d. The actress who the actor assisted admired the staff throughout the filming.
28e. The actress who the actor at the show assisted admired the staff throughout the filming.
28f. The actress who the actor who was at the show assisted admired the staff throughout the filming.

Q28: Did the actress assist the actor?

29a. The contractor called the plumber in the morning.
29b. The contractor in the bathroom called the plumber in the morning.
29c. The contractor who was in the bathroom called the plumber in the morning.
29d. The plumber who the contractor called accompanied the assistant in the morning.
29e. The plumber who the contractor in the bathroom called accompanied the assistant in the morning.
29f. The plumber who the contractor in the bathroom called accompanied the assistant in the morning.

Q29: Did the contractor call the plumber?

30a. The historian offended the student in the afternoon.
30b. The historian on the stage offended the student in the afternoon.
30c. The historian who was on the stage offended the student in the afternoon.
30d. The student who the historian offended shocked the audience in the afternoon.
30e. The student who the historian on the stage offended shocked the audience in the afternoon.
30f. The student who the historian who was on the stage offended shocked the audience in the afternoon.

Q30: Did the student offend the historian?

Appendix B: Filler Sentences and Yes/No Questions

1. Jenny's English teacher threw a piece of chalk at the blackboard because he was angry.

    Q: Was Jenny's teacher angry?

2. Thirty thousand people showed up to protest against the relocation of the power plant.

    Q: Did people like the relocation of the power plant?

3. The volunteer fireman sped around the corner on his way to the firehouse.

    Q: Was the volunteer fireman on his way to the firehouse?

4. The children turned over a rock and poked sticks at the bugs.

    Q: Did the children find the bugs under the rock?

5. Betty went to a famous restaurant to have a dinner with her boyfriend.

    Q: Did Betty go to the restaurant with her father?

6. George only went to his parents' house when he wanted to do laundry.

    Q: Does George usually go to his parents' house for doing laundry?

7. Peter had to pry the can of paint open with a screwdriver because the lid was stuck on.

    Q: Was the paint can easy to open?

8. Mandy liked playing the piano, but she was very poor at playing tennis.

    Q: Was Mandy good at playing the tennis?

9. Every Friday evening my grandparents play bingo.

    Q: Do my grandparents play bingo on Mondays?

10. Sometimes the farmers in town would meet at the feed shop and talk about the weather.

    Q: Did the farmers sometimes talk about the weather?

11. The chef used black pepper in every dish that he prepared on his popular cooking show.

    Q: Did the chef have a popular cooking show?

12. The astronaut looked out the window of his lunar module.

    Q: Did the astronaut look out the window?

13. Sally wrapped her arms around her baby to keep it warm.

    Q: Did Sally keep her baby cold?

14. Kendra couldn't open the can of tomato sauce without using a towel to grip the lid.

    Q: Could Kendra can open the can without using a towel?

15. The cowboys were riding around the ranch, looking for a lost calf.

Q: Were the cowboys looking for a lost calf?

16. Barbara used a lot of salt and potatoes in her homemade chicken soup.

Q: Did Barbara use a lot of pepper in her chicken soup?

17. David's mother couldn't understand why he didn't like tomatoes.

Q: Did David like tomatoes?

18. The photographer used his new camera lenses to create a soft halo around all of the light sources in the photograph.

Q: Did the photographer use the new camera lenses?

19. The assistant of the consultant hated having to proof read documents late at Night.

Q: Did the assistant like proof reading documents at Night?

20. The actress' manager talked to the producers about increasing her salary.

Q: Did the manager talk about increasing the actress' salary?

21. Sometimes the town's butcher and baker would go hiking together and discuss food.

Q: Did the butcher and barber go hiking together?

Yes No

22. Donna knew that the neighbor's dog didn't bite, but she was still scared of it.

Q: Did the neighbor's dog bite?

23. The Porche squealed around the curve, spewing smoke behind it.

Q: Did the Porche squeal around the curve?

24. Danny used a flashlight to read comic books under the covers after his mother kissed him good Night and closed the door.

Q: Did Danny like to read?

25. The barber stood by the door of his shop, enjoying the warm air and bright sun.

Q: Did the barber stand by the window to enjoy the sunshine?

26. The nurse used the intercom to get the doctor's attention, because he had forgotten to write out a prescription for a patient.

Q: Did the doctor remember to write out a prescription for a patient?

27. The pilot announced that no one would be able to leave their seat for the first thirty minutes of the flight.

Q: Can people leave their seat for the first minutes of the flight?

28. Paula honked loudly at the delivery truck that was blocking her driveway.

Q: Was Paula unable to get into her driveway?

29. The woman thought about painting her fingernails green for St. Patrick's Day, but decided not to.

Q: Did the woman paint her fingernails green for St. Patrick's Day?

30. People used the microwave in the lab mostly for making popcorn.

Q: Did people use the microwave for making popcorn?

31. The housekeeper shook her finger at the maid and scolded her for not remembering to polish the silverware.

Q: Did the maid forget to polish the silverware?

32. Last Thursday Night Billy planned to take Sheila out on a date, but she cancelled because she got the flu.

Q: Did Billy date Sheila on last Thursday?

33. An investor called his broker, complaining about the high surcharges on his account.

Q: Did investor complain about the high surcharges on his account?

34. The used car salesman convinced the young couple to buy a station wagon

Q: Did the salesman suggest a cute little convertible?

35. The intramural floor hockey teams waited for the gym while the basketball team finished practicing free throws.

Q: Did the basketball team practice in the gym while the hockey teams were waiting?

36. The delivery man dropped a fragile package on the floor by mistake.

Q: Did the delivery man make a mistake?

37. A bodybuilder used the internet to order megavitamins from an on-line store.

Q: Did the bodybuilder buy the megavitamins at the store?

38. The apple orchard down the road offered free apples to church groups that were willing to take the ones that had fallen on the ground.

Q: Did the apple orchard sell the apples that had fallen on the ground at a good price?

39. Kenny expected the girl next door to come over when she was finished with her homework.

Q: Did Kenny wait for the girl next door to come over?

40. The cashier forgot to ring up the laundry detergent in the bottom of the customer's cart.

Q: Did the cashier forget to ring up an item?

41. One of the aerobics instructors at the gym forgot her sneakers last Monday.

Q: Did one aerobic instructor forget her sneakers last Friday?

42. The preacher gave a rousing sermon last Sunday.

Q: Was the sermon very stimulating?

43. Judy used a new brand of shampoo the other day and liked the way it made her hair smell.

Q: Did Judy dislike the new shampoo she tried?

44. The landlord asked the tenant whether the heat was working in the apartment.

Q: Did the landlord ask the tenant whether the heat was okay?

45. Kimberly used her mild case of the flu as an excuse for not going to the gym for a week.

Q: Did Kimberly skip going to the gym for a week?

46. The protestors marched down the middle of the street and shouted anti-war slogans to the beat of drums.

Q: Did people protest against war?

47. The women's field hockey team made it to the conference tournament on the backs of their seniors.

Q: Did the women's hockey team fail to make it to the conference tournament?

48. The saleswoman closed the ladies' fitting room because the ceiling was leaking.

Q: Did the saleswoman close the men's fitting room?

Yes No

49. The farmer drove his tractor up and down the field, plowing the earth in preparation for planting.

Q: Did the farmer plan to plant on the earth?

50. After the book signing, Zadie called her publicist and asked her not to schedule any others for a few weeks.

Q: Did Zadie want to continue the book signing?

51. The journalist asked every editor at the paper whether his article was good enough to make the front page.

Q: Did the journalist make sure that his article was good to be on the front page?

52. Henry's brother ordered a tuxedo for the prom.

Q: Did Henry's brother order a tuxedo for the Christmas party?

53. The veterinarian told his assistant to sedate the sick cat in preparation for surgery.

Q: Was the vet getting ready to operate on a cat?

54. Jake did not realize that he had to alter his diet to improve until his illness got serious.

Q: Did Jake realize that he needed to change his diet after he got ill?

55. The truck driver stopped at the truck stop for breakfast after driving all Night.

Q: Did the truck driver stop for dinner?

56. Amy has spoken Chinese since she was a child.

Q: Did Amy learn Japanese when she was a child?

57. Many churches in the city offered shelter to the homeless on cold Nights.

Q: Did the churches provide the homeless with a place to stay at Nights?

58. The doctor advised Mary to cut down on salt.

Q: Did the doctor ask Mary to reduce salt in her diet?

59: The place where Peter worked was one hour from the city.

Q: Did Peter work in the city?

60. The sales figures looked impressive, but the company was losing money.

Q: Did the company lose money?

61. The nurse who called the doctor visited the patient after the meeting.

Q: Did the doctor call the nurse?

62. The soldier who phoned the reporter bothered the passenger after the battle.

Q: Did the soldier phone the reporter?

63. The boy who dated the girl ignored the classmates for three years.

Q: Did the girl date the boy?

64. The fans who loved the star injured a spectator very much.

Q: Did the fans love the star?

65. The rebels who threatened the farmer called the neighbor in the evening.

Q: Did the farmer threaten the rebels?

66. The uncle who welcomed the aunt hugged the cousins in the dark.

Q: Did the uncle welcome the aunt?

67. The maid who burned the cook offended the butler just this morning.

Q: Did the cook burn the maid?

68. The detective who questioned the officer consulted the expert at the scene.

Q: Did the detective question the officer?

69. The dragon who wounded the knight married the princess during the battle.

Q: Did the knight wound the dragon?

70. The nanny who hugged the child helped the mother after nap time.

Q: Did the nanny hug the child?

71. The audience who disliked the singer insulted the pianist for the bad performance.

Q: Did the singer dislike the audience?

72. The baker who hated the chef annoyed the manager a great deal.

Q: Did the baker hate the chef?

73. The husband who divorced the wife called the family after the holidays.

Q: Did the wife divorce the husband?

74. The lawyer who trusted the client betrayed the friend despite the rumors.

Q: Did the lawyer trust the client?

75. The students who watched the surgeon contacted the nurse in the morning.

Q: Did the surgeon watch the students?

76. The professor who assessed the students confused the committee at semester's end.

Q: Did the professor assess the students?

77. The man who bothered the operator alerted the manager in the afternoon.

Q: Did the operator bother the man?

78. The readers who supported the writer lobbied the editor with great consistency.

Q: Did the reader support the writer?

79. The president who confronted the politician provoked the citizens in the afternoon.

Q: Did the politician confront the president?

80. The baby who surprised the parents blamed the babysitter in the morning.

Q: Did the baby surprise the parents?

81. The kid who pushed the girl found the mother after school today.

Q: Did the girl push the kid?

82. The natives who captured the sailor irritated the chief following the wreck.

Q: Did the natives capture the sailor?

83. The scientists who invited the researcher offended the assistant at the conference.

Q: Did the researcher invite the scientists?

84. The thief who passed the driver hit the deer in the dark.

Q: Did the thief pass the driver?

85. The worker who doubted the leader calmed the crowd following the strike.

Q: Did the leader doubt the worker?

86. The stewardess who praised the pilot thanked the official during the interview.

Q: Did the stewardess praise the pilot?

87. The director who married the secretary liked the colleagues despite the rumors.

Q: Did the secretary marry the director?

88. The actor who assisted the actress admired the staff throughout the filming.

Q: Did the actor assist the actress?

89. The contractor who called the plumber accompanied the assistant in the morning.

Q: Did the plumber accompany the contractor?

90. The historian who offended the student shocked the audience in the afternoon.

Q: Did the historian offend the student?

Appendix C: Survey Form for Plausibility Rating

Participant ID: ________________,   Date: ________________

Please rate the plausibility of each sentence based on a scale of 1 (implausible) to 7 (plausible)

An example for a plausible sentence: The nurse consulted the doctor.
(Or) The doctor consulted the nurse.

An example for an implausible sentence: The thief arrested the policeman.

	Implausible					Plausible
The baker hated the chef.	1	2	3	4	5	6	7
The client trusted the lawyer	1	2	3	4	5	6	7
The president confronted the politician	1	2	3	4	5	6	7
The student offended the historian.	1	2	3	4	5	6	7
The cook burned the maid.	1	2	3	4	5	6	7
The maid burned the cook	1	2	3	4	5	6	7
The star loved the fans	1	2	3	4	5	6	7
The chef hated the baker	1	2	3	4	5	6	7
The baby surprised the parents	1	2	3	4	5	6	7
The plumber called the contractor.	1	2	3	4	5	6	7
The surgeon watched the students	1	2	3	4	5	6	7
The fans loved the star	1	2	3	4	5	6	7
The pilot praised the stewardess.	1	2	3	4	5	6	7
The professor assessed the student	1	2	3	4	5	6	7
The workers doubted the leader	1	2	3	4	5	6	7
The detective questioned the officer.	1	2	3	4	5	6	7
The sailor captured the natives	1	2	3	4	5	6	7
The officer questioned the detective.	1	2	3	4	5	6	7
The audience disliked the singer	1	2	3	4	5	6	7
The dragon wounded the knight	1	2	3	4	5	6	7
The driver passed the thief.	1	2	3	4	5	6	7
The husband divorced the wife	1	2	3	4	5	6	7
The students watched the surgeon	1	2	3	4	5	6	7
The uncle welcomed the aunt	1	2	3	4	5	6	7
The researcher invited the scientists	1	2	3	4	5	6	7
The doctor called the nurse	1	2	3	4	5	6	7
The boy dated the girl	1	2	3	4	5	6	7

The contractor called the plumber	1	2	3	4	5	6	7
The parents surprised the baby.	1	2	3	4	5	6	7
The student assessed the professor.	1	2	3	4	5	6	7
The director married the secretary	1	2	3	4	5	6	7
The knight wounded the dragon.	1	2	3	4	5	6	7
The kid pushed the girl	1	2	3	4	5	6	7
The thief passed the driver	1	2	3	4	5	6	7
The wife divorced the husband	1	2	3	4	5	6	7
The nurse called the doctor.	1	2	3	4	5	6	7
The singer disliked the audience.	1	2	3	4	5	6	7
The historian offended the student	1	2	3	4	5	6	7
The writer supported the readers	1	2	3	4	5	6	7
The girl pushed the kid	1	2	3	4	5	6	7
The operator bothered the man	1	2	3	4	5	6	7
The nanny hugged the child.	1	2	3	4	5	6	7
The child hugged the nanny.	1	2	3	4	5	6	7
The reporter phoned the soldier	1	2	3	4	5	6	7
The actress assisted the actor	1	2	3	4	5	6	7
The rebels threatened the farmer	1	2	3	4	5	6	7
The leader doubted the workers.	1	2	3	4	5	6	7
The aunt welcomed the uncle.	1	2	3	4	5	6	7
The actor assisted the actress	1	2	3	4	5	6	7
The girl dated the boy	1	2	3	4	5	6	7
The soldier phoned the reporter	1	2	3	4	5	6	7
The lawyer trusted the client.	1	2	3	4	5	6	7
The man bothered the operator	1	2	3	4	5	6	7
The scientists invited the researcher	1	2	3	4	5	6	7
The readers supported the writer	1	2	3	4	5	6	7
The politician confronted the president	1	2	3	4	5	6	7
The farmer threatened the rebels.	1	2	3	4	5	6	7
The natives captured the sailor.	1	2	3	4	5	6	7
The secretary married the director	1	2	3	4	5	6	7
The stewardess praised the pilot	1	2	3	4	5	6	7

Appendix D: Edinburgh Handedness Inventory

Edinburgh Handedness Inventory

Participant # _________ Date: ___________

Please indicate your preferences in the use of hands in the following activities by putting a check in the appropriate column.

1) Where the preference is so strong that you would never try to use the other hand, unless absolutely forced to, put **2** checks.
2) If in any case you are really indifferent, put a check in ***both*** columns.

Some of the activities listed below require the use of both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in parentheses.

Please try and answer all of the questions, and only leave a blank if you have no experience at all with the object or task.

		Left	Right
1	Writing	□ □	□ □
2	Drawing	□ □	□ □
3	Throwing	□ □	□ □
4	Scissors	□ □	□ □
5	Toothbrush	□ □	□ □
6	Knife (without fork)	□ □	□ □
7	Spoon	□ □	□ □
8	Broom	□ □	□ □
9	Striking Match (match)	□ □	□ □
10	Opening box (lid)	□ □	□ □
TOTAL			

Difference (Rt – Lt)-(1)	Cumulative Total (Lt.+Rt.)-(2)	Result : (1)/(2) x 100

Scoring:
Add up the number of checks in the "Left" and "Right" columns and enter in the "TOTAL" row for each column. Add the left total and the right total and enter in the "Cumulative TOTAL" cell. Subtract the left total from the right total and enter in the "Difference" cell. Divide the "Difference" cell by the "Cumulative TOTAL" cell (round to 2 digits if necessary) and multiply by 100; enter the result in the "Result" cell.
Interpretation (based on Result):

below -40 = left-handed

between -40 and +40 = ambidextrous
above +40 = right-handed

References

Avrutin, S. (2006). Weak Syntax. In Y. Grodzinsky & K. Amunts (Eds.), *Broca's region*. Oxford: Oxford University Press.

Baddeley, A., & Hitch, G. (1974). Working memory. In G.A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47-90). New York: Academic Press.

Badecker, W., & Caramazza, A. (1985). On considerations of methods and theory governing the use of clinical categories in neurolinguistics and cognitive neuropsychologly: the case against agrammatism. *Cognition, 20*, 97-125.

Balota, D. A., Cortese, M. J., Hutchison, K. A., Neely, J. H., Nelson, D. L., Simpson, G. B. et al. (2004). The English Lexicon Project: A web-based repository of descriptive and behavioral measures for 40,481 English words and nonwords. Retrieved July 2002 - July 2004 from: http://elexicon.wustl.edu/

Baum, S. (1991). Sensitivity to syntactic violations across the age span: Evidence from a word-monitoring task. *Journal of Clinical Linguistics and Phonetics, 5*, 317-328.

Berndt, R. S., Mitchum, C. C., & Haendiges, A. N. (1996). Comprehension of reversible sentences in "agrammatism": a meta-analysis. *Cognition, 58,* 289-308.

Berndt, R. S., Mitchum, C. C., & Wayland, S. (1997). Patterns of sentence comprehension in aphasia: a consideration of three hypotheses. *Brain and Language, 60,* 197-221.

Berndt., R.S., & Caramazza, A. (1980). A redefinition of Broca's aphasia: Implications for a neuropsychological model of language. *Applied Psycholinguistics, 1*, 225-278.

Berndt., R.S., & Caramazza, A. (1999). How “regular” is sentence comprehension in Broca’s aphasia? It depends on how you select the patients. *Brain and Language, 67*, 242

Blackwell, A. & Bates, E. (1995). Inducing agrammatic profiles in normals: Evidence for the selective vulnerability of morphology under cognitive resource limitation. *Journal of Cognitive Neuropsychology, 7,* 228-257.

Burkhardt, P., Piñango, M. M., & Wong, K. (2003). The role of the anterior left hemisphere in real-time sentence comprehension: Evidence from split intransitivity. *Brain and Language, 86*, 9-22.

Caplan, D. & Waters, G. S. (1999). Verbal Working Memory and Sentence Comprehension. *Behavioral and Brain Sciences, 22,* 77-126.

Caplan, D. & Waters, G. S. (1999). Verbal Working Memory and Sentence Comprehension. *Behavioral and Brain Sciences, 22,* 77-126.

Caplan, D. (1992). *Language: Structure, processing, and disorders*. Cambridge, MA: MIT Press.

Caplan, D. (1995). Issues arising in contemporary studies of disorders of syntactic processing in sentence comprehension in agrammatic patients. *Brain and Language, 50*, 325-338.

Caplan, D. (2001). The measurement of chance performance in aphasia, with specific reference to the comprehension of semantically reversible passive sentences: a note on issues raised by Caramazza, Capitani, Rey, and Berndt (2001) and Drai, Grodzinsky, and Zurif (2001). *Brain and Language, 76*, 193-201.

Caplan, D., & Hildebrandt, N. (1988). *Disorders of syntactic comprehension*. Cambridge, MA: MIT Press (Bradford Books).

Caplan, D., Baker, C., & Dehaut, F. (1985). Syntactic determinants of sentence comprehension in aphasia. *Cognition, 21,* 117-175.

Caplan, D., DeDe, G., Gutman, R., Liu, J., & Waters, G (2008). Rasch models of aphasic deficits of syntactic comprehension. Paper presented at the annual meeting of the 38th Clinical Aphasiology Conference, Teton Village, WY.

Caplan, D., Hildebrandt, N., & Makris, N (1996). Location of lesions in stroke patients with deficits in syntactic processing in sentence comprehension. *Brain, 119*, 933-949.

Caplan, D., Waters, G. S., DeDe, G., Michaud, J., & Reddy, A. (2007). A study of syntactic processing in aphasia I: Behavioral (psycholinguistic) aspects. *Brain and Language, 101,* 103-150.

Caplan, D., Waters, G., & Hildebrandt, N. (1997). Determinants of sentence comprehension in aphasic patients in sentence-picture matching tasks. *Journal of Speech and Hearing Research, 40*, 542-555.

Caramazza, A. & Zurif, E. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: evidence from aphasia. *Brain and Language, 3,* 572-582.

Caramazza, A., & Badecker, W. (1989). Patient classification in neuropsychological research. *Brain and Cognition, 10*, 256-295.

Caramazza, A., & Berndt, R.S. (1978). Semantic and syntactic processes in aphasia: A review of the literature. *Psychological Bulletin, 85*, 898-918.

Caramazza, A., & Berndt, R.S. (1985). A multiple deficit view of agrammatic Broca's aphasia. In M. Kean (Ed.). *Agrammatism*. Orlando, FL: Academic Press.

Caramazza, A., & Hillis, A.E. (1989). The disruption of sentence production: some dissociations. *Brain and Language, 35*, 625-650.

Caramazza, A., & Miceli, G. (1991). Selective impairment of thematic role assignment in sentence processing. *Brain and Language, 41*, 402-436.

Caramazza, A., Capasso, R., Capitani, E., & Miceli, G. (2005). Patterns of comprehension performance in agrammatic Broca's aphasia: A test of the Trace Deletion Hypothesis. *Brain and Language, 94*, 43-53.

Caspari, I., Parkinson, S. R., LaPointe, L. L., & Katz, R. C. (1998). Working Memory and Aphasia. *Brain and Cognition, 37,* 205-223.

Cattell, R. N. (1973). *Measuring intelligence with the Culture Fair tests*. Champaign, IL: Institute for Personality and Ability Testing.

Chen, E., Gibson, E., & Wolf, F. (2005). Online syntactic storage costs in sentence comprehension. *Journal of Memory and Language, 52,* 144-169.

Chomsky, N. (1977). On Wh movement. In P. Culicover, T., Wasow, & A. Akmajian (Eds.), *Formal syntax*, New Your: Academic Press.

Chomsky, N. (1986). *Barriers*. Cambridge, MA: MIT Press.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30,* 163-183.

Corporation.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104*, 163-191.

Cowan, N. (1995). *Attention and Memory: An integrated framework*. Oxford: Oxford University Press.

Crawford, J. R., & Garthwaite, P. H. (2005). Testing for suspected impairments and dissociations in single-case studies in neuropsychology: Evaluation of alternatives using Monte Carlo simulations and Revised Tests for Dissociations. *Neuropsychology. 19*, 318-331.

Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist, 12*, 482-486.

Daneman, M. & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450-466.

Davis, G. A., & Ball, H. E. (1989). Effects of age on comprehension of complex sentences in adulthood. *Journal of Speech and Hearing Research, 32*, 143-150.

DeDe, G., & Caplan, D. (2006). Factor analysis of aphasic syntactic comprehension disorders. *Aphasiology, 20*, 123-135.

Dick, F., Bates, E., Wulfeck, B., Utman, J. A., & Dronkers, N. (2001). Language deficits, localization, and grammar: Evidence for a distributive model of language breakdown in aphasic patients and neurologically intact individuals. *Psychological Review, 108,* 759-788.

Dickey, M. W., & Thompson, C. K. (2004). The resolution and recovery of filler-gap dependencies in aphasia: Evidence from on-line anomaly detection. *Brain and Language*, *88*, 108-127.

Dickey, M. W., Choy, J. J., & Thompson, C. K. (2007). Real-time comprehension of wh-movement in aphasia: Evidence from eyetracking while listening. *Brain and Language*, *100*, 1-22.

Drai, D., & Grodzinsky, Y. (2006). A new empirical angle on the variability debate: Quantitative neurosyntactic analyses of a large data set from Broca's Aphasia. *Brain and Language, 96*, 117-128.

Emery, O. (1985). Language and aging. *Experimental Aging Research, 11*, 3-60.

Engle, R. W. & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The psychology of learning and motivation* (pp. 145-199). New York: Academic Press.

Engle, R. W. (2001). What is working memory capacity? In H. L. Roediger III, J. S. Nairne, I. Neath, & A. M. Surprenant (Eds.), *The nature of remembering: Essays in honor of Robert G. Crowder* (pp. 297-314). NE: American Psychological Association.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science,* 19-23.

Engle, R. W., Cantor, J., & Carullo, J. J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 972-992.

Engle, R. W., Carullo, J. J., & Collins, K. W. (1991). Individual differences in working memory for comprehension and following direction. *Journal of Educational Research, 84*, 253-262.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128,* 309-331.

Fedorenko, E., Gibson, E., & Rohde, D. (2006). The nature of working memory capacity in sentence comprehension: Evidence against domain-specific working memory resources. *Journal of Memory and Language, 54*, 541-553.

Feier, C. D., & Gerstman, L. J. (1980). Sentence comprehension abilities throughout the adult life span. *Journal of Gerontology, 35,* 722-728.

Ferreira, F., & Clifton, C (1986). The independence of syntactic processing. *Journal of Memory and Language, 25*, 348-368.

Fodor, J. A. (1983). *Modularity of mind*, Cambridge, MA: MIT Press.

Ford, M. (1983). A method for obtaining measures of local parsing complexity throughout sentences. *Journal of Verbal Learning and Verbal Behavior, 22*, 203-218.

Frazier, L., & Flores d'Arcais, G. (1989). Filler driven parsing: A study of gap filling in Dutch. *Journal of Memory and Language, 28*, 331-344.

Frazier, L., & Friederici, A. D. (1991). On deriving the properties of agrammatic comprehension. *Brain and Language, 40,* 51-66.

Friederici, A. D., & Frazier, L. (1992). Thematic analysis in agrammatic comprehension: syntactic structures and task demands. *Brain and Language, 42*, 1−29.

Friederici, A. D., & Kilborn, K. W. (1989). Temporal constraints on language processing: syntactic priming in Broca's aphasia. *Journal of Cognitive Neuroscience, 1*, 262−272.

Friedmann, N. & Gvion A. (2003). Sentence comprehension and working memory limitation in aphasia: A dissociation between semantic-syntactic and phonological reactivation. *Brain and Language, 86,* 23-39.

Gibson, E. & Warren, T. (2004). Reading-time evidence for intermediate linguistic structure in long-distance dependencies. *Syntax, 7,* 55-78.

Gibson, E. (1998). Linguistic complexity: locality of syntactic dependencies. *Cognition, 68,* 1-76.

Gibson, E. (2000). The dependency locality theory: A distance-based theory of linguistic complexity. In Y. Miyashita, A. Marantz, & W. O'Neil (Eds.), *Image, language, brain* (pp. 95-126). Cambridge, MA: MIT Press.

Gibson, E. (2006). The interaction of top–down and bottom–up statistics in the resolution of syntactic category ambiguity. *Journal of Memory and Language, 54*, 363-388.

Goodglass, H., & Kaplan, E. (1983). *The assessment of aphasia and related disorders* (2nd ed.). Philadelphia, PA: Lea & Febiger.

Gordon, P.C., Hendrick, R., & Levine, W.H. (2002). Memory-load interference in syntactic processing. *Psychological Science, 13*, 425- 430.

Gordon, P.C., Hendrick, R., & Levine, W.H. (2002). Memory-load interference in syntactic processing. *Psychological Science, 13*, 425- 430.

Grodner, D. & Gibson, E. (2005). Consequences of the serial nature of linguistic input for sentenial complexity. *Cognitive Science, 29,* 261-290.

Grodzinsky, Y. (1984). The syntactic characterization of agrammatism. *Cognition, 16,* 99-120.

Grodzinsky, Y. (1986). Language deficits and the theory of syntax. *Brain and Language, 27,* 135-159.

Grodzinsky, Y. (1989). Agrammatic comprehension of relative clauses. *Brain and Language, 37*, 480-499.

Grodzinsky, Y. (1995). Trace deletion, theta roles, and cognitive strategies. *Brain and Language, 51*, 469-497.

Grodzinsky, Y. (2000). The neurology of syntax: language use without Broca's area. *Behavioral and Brain Sciences, 23,* 1-71.

Grodzinsky, Y., Piñango, M.M., Zurif, E., & Drai, D. (1999). The critical role of group studies in neuropsychology: comprehension regularities in Broca's aphasia. *Brain and Language, 67,* 134-147.

Grodzinsky, Y., Wexler, K., Chien, Y.C., Marakovitz, S., & Solomon, J. (1993). The breakdown of binding relations. *Brain and Language, 45*, 396-422.

Haarmann, H. J., & Kolk, H. H. (1991). Syntactic priming in Broca's aphasics: evidence for slow activation. *Aphasiology, 5*, 247–263.

Haarmann, H. J., Just, M. A., & Carpenter, P. A. (1997). Aphasic sentence comprehension as a resource deficit: a computational approach. *Brain and Language, 59,* 76-120.

Hageman, C.F., McNeil, M.R., Rucci-Zimmer, S. & Cariski, D.M. (1982). The Reliability of Patterns of Auditory Processing Deficits: Evidence from the Revised Token Test. *Clinical Aphasiology, 12,* 230-234.

Hakes, B., Evans, J., & Brannon, L. (1976). Understanding sentences with relative clauses. *Memory and Cognition, 4*, 283-296.

Heilman, K., & Scholes, R. (1976). The nature of comprehension errors in Broca's, conduction, and Wernicke's aphasics, *Cortex, 12*, 258-265.

Hickok, G., & Avrutin, S. (1995). Representation, referentiality, and processing in agrammatic comprehension: two case studies. *Brain and Language, 50*, 10-26.

Hickok, G., Zurif, E., Canseco-Gonzalez, E. (1993). Structural description of agrammatic comprehension. *Brain and Language, 45*, 371-395.

Hildebrandt, N., Caplan, D., & Evans, K. (1987). The manei left ti without a trace: A case study of aphasic processing of empty categories. *Cognitive Neuropsychology, 4*, 257-302.

Holmes, V. M., & O'Regan, J. K. (1981). Eye fixation patterns during the reading of relative clause sentences. *Journal of Verbal learning and Verbal Behavior, 20*, 417-430.

Just, M. A. & Carpenter, P. A. (1992). A Capacity Theory of Comprehension: Individual Differences in Working Memory. *Psychological Review, 99,* 122-149.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.

Kane, M. J. & Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to stroop interference. *Journal of Experimental Psychology: General, 132,* 47-70.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin and Review, 9*, 637-671.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General, 130,* 169-183.

Kane, M. J., Poole, B. J., & Tuholski, S. W., & Engle, R.W. (2006). Working memory capacity and the top-down control of visual search: exploring the boundaries of "executive attention". *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 749-777.

Kay, J., Lesser, R., & Coltheart, M. (1992). *PALPA: Psycholinguistic Assessments of Language Processing in Aphasia*. Lawrence Erlbaum Associates, Hove.

Kemper, S. (1986). Imitation of complex syntactic constructions by elderly adults. *Applied Psycholinguistics, 7*, 277-287.

Kemper, S., & Kemtes, K. (1999). Limitations on syntactic processing. In S. Kemper & R. Kliegl (Eds.), *Constraints on language: Aging, grammar, and memory* (pp. 79–105). Boston: Kluwer Academic.

Kemtes, K., & Kemper, S. (1997). Younger and older adults' on-line processing of syntactically ambiguous sentence. *Psychology and Aging, 12*, 362–371.

Kertesz, A. (1979). *Aphasia and associated disorders: Taxonomy, localization and recovery*. New York: Grune & Stratton.

Kilborn, K. (1991). Selective impairment of grammatical morphonolgy due to induced stress in normal listeners: implications for aphasia. *Brain and Language, 41,* 275-288.

King, J. & Just, M. A. (1991). Individual differences in syntactic processing: the role of working memory. *Journal of Memory and Language, 30,* 580-602.

Kolk, H. H. J. & Weijts, M. (1996). Judgments of semantic anomaly in agrammatic patients: argument movement, syntactic complexity, and the use of heuristics. *Brain and Language, 54,* 86-135.

Kolk, H.H.J., & van Grunsven, M.M.F. (1985). Agrammatism as a variable phenomenon, *Cognitive Neuropsychology, 2,* 347-384.

Kolk, H.H.J., van Grunsven, M.M.F., & Keyser, A. (1985). On the parallelism between production and comprehension in agrammatism. In M.L. Kean (Ed.), *Agrammatism* (pp. 165-206). New York: Academic Press.

LaPointe, L. L., & Erickson, R. J. (1991). Auditory vigilance during divided task attention in aphasic individuals. *Aphasiology, 5*, 511-520.

Linebarger, M. C. (1990). Neuropsychology of sentence parsing. In A. Caramazza (Ed.), *Cognitive neuropsychology and neurolinguistics* (pp. 55-122). Hillsdale, NJ: Lawrence Erlbaum Associates.

Linebarger, M. C., Schwartz, M. F., & Saffran, E. M. (1983). Sensitivity to grammatical structures in so-called agrammatic aphasics. *Cognition, 13,* 361-392.

Love, T., & Oster, E. (2002). On the categorization of aphasic typologies: The SOAP (A test of syntactic complexity). *Journal of Psycholinguistic Research, 31*, 503-529.

Love, T., Swinney, D., & Zurif, E. (2001). Aphasia and the time-course of processing long distance dependencies. *Brain and Language, 79*, 169-170.

Love, T., Swinney, D., Walenski, M., & Zurif, E (in press). How left inferior frontal cortex participates in syntactic processing: Evidence from aphasia. *Brain and Language*.

MacDonald, M. C., Just, M., A, & Carpenter, P. A. (1992). Working memory constraints on the processing of syntactic ambiguity. *Cognitive Psychology, 24*, 56-98.

Macmillan, N. A., & Creelman, C. D. (2005). *Detection Theory: A User's Guide* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Marascuilo, L.A., and Serlin, R.C. (1988). Statistical methods for the social and behavioral sciences. New York: W.H. Freeman

Martin, N., Kohen, F., & Kalinyak-Fliszar, M. (2008). A diagnostic battery to assess language and short-term memory deficits in aphasia. Poster presentation at Clinical Aphasiology Conference, Teton Village, WY.

Martin, R.C., & Blossom-Stach, C. (1986). Evidence of syntactic deficits in a fluent aphasic. *Brain and Language, 28*, 196-234.

Martin, R.C., Blossom-Stach, C., Yaffee, L.S., & Wetzel, W.F. (1995). Consequences of a motor programming deficit for rehearsal and written sentence comprehension. *The Quarterly Journal of Experimental Psychology, 48*, 536-572.

Martin, R.C., Wetzel, W.F., Blossom-Stach, C., & Feher, E. (1989). Syntacitc loss versus processing deficit: an assessment of two theories of agrammatism and syntactic comprehension deficits. *Cognition, 32*, 157-191.

Mauner, G., Fromkin, V.A., & Cornell, T.L. (1993). Comprehension and acceptability judgments in agrammatism: Disruption in the syntax of referential dependency. *Brain and Language, 45*, 340-370.

McNeil, M. R. (1981). Auditory comprehension in aphasia: A language deficit or a reduced efficiency of processes supporting languages? *Clinical Aphasiology, 11*, 342-345.

McNeil, M. R. (1982). The nature of aphasia in adults. In N. J. Lass, L. McReynolds, J. Northern, & D. Yoder (Eds.), *Speech, language, and hearing* (Vol. II). Philadelphia: Saunders.

McNeil, M. R. (1988). Aphasia in the adult. In N. J. Lass, L. V. McReynolds, F., Northern, & D. E. Yoder (Eds.), *Handbook of speech-language pathology and audiology* (pp. 738-783). Toronto: B. C. Decker.

McNeil, M. R., & Kimelman, M. D. Z. (1986). Toward an integrative information-processing structure of auditory comprehension and processing in adult aphasia. *Seminars in Speech and Language, 7*, 123-146.

McNeil, M. R., Odell., K., & Tseng, C. H. (1991). Toward an integration of resource allocation into a general theory of aphasia. *Clinical Aphasiology, 20*, 21-39.

McNeil, M.R. & Prescott, T.E. (1978). *Revised Token Test*. Austin, Pro-Ed.

McNeil, M.R. (1983). Aphasia: Neurological Considerations. *Topics in Language Disorders, 3* (4), 1-19.

McNeil, M.R., Darley, F.L., Olson, W.O., & Rose, D.E. (1984). Effects of Intensity Variations on Auditory Processing in Aphasia, Part I. Equal intensities at each ear. *Audiology, 22* (6), 560-581

McNeil, M.R., Darley, F.L., Rose, D.E., & Olson, W.O. (1984). Effects of Intensity Variations on Auditory Processing in Aphasia, Part II. Different intensities at each ear. *Audiology, 22* (6), 582-615.

McNeil, M.R., Odell, K.H. & Campbell, T.F. (1982). The Frequency and Amplitude of Fluctuating Auditory Processing in Aphasic and Nonaphasic Brain Damaged Persons. *Clinical Aphasiology, 12,* 220-229.

McNeil, M.R., Pratt, S.R., Sung, J.E., Szuminsky, N., Ventura, M., Kim, A., Fossett, T., Doyle, P., & Musson, N. (2008). Test-retest reliability of the auditory *Computerized Revised Token Test* (CRTT) and three experimental reading CRTT-R versions in normal elderly individuals and persons with aphasia. Poster presentation at Clinical Aphasiology Conference, Teton Village, WY.

McNeil, M.R., Pratt., S.R., Szuminsky, N., Fossett, T.R.D., Eberwein, D., Sung, J.E., & Doyle, P.J. (2008). Conceptual, technical and psychometric development of the *Computerized Revised Token Test*s: Auditory (CRTT) and Reading (CRTT-R). Manuscript in preparation.

McNeil, M.R., Sung, J.E., Pratt, S.R., Szuminsky, N., Kim, A., Ventura, M., Fassbinder, W., Fossett, T., Doyle, P., & Musson, N. (2008). Concurrent validation of the *Computerized Revised Token Test* (CRTT) and three experimental reading CRTT-R versions in normal elderly individuals and persons with aphasia. Presented at Clinical Aphasiology Conference, Teton Village, WY.

McNeil, M.R., Sung, J.E., Yang, D., Pratt, S., Pavelko, S., Fossett, T.R.D., Smolky, B., Doyle, P.J. (2007). Comparing connected language elicitation procedures in persons with Aphasia: Concurrent validation of the story retelling procedure. *Aphasiology*, 21, 775-790.

Miceli, G., Mazzucchi, A., Menn, L., & Goodglass, H. (1983). Contrasting cases of Italian agrammatic aphasia without comprehension disorder. *Brain and Language, 19*, 65-97.

Miller, J., & Chapman, R. (1998). SALT: Systematic analysis of language transcripts. [Windows versions 1.0–5.0]. Madison, WI: Language Analysis Laboratory, Waisman Center, University of Wisconsin.

Mitchum, C.C., Haendiges, A.N., & Berndt, R.S. (1995). Treatment of thematic mapping in sentence comprehension: Implications for normal processing. *Cognitive Neurospsychology, 12*, 503-547.

Miyake, A., Carpenter, P. A., & Just, M. S. (1994). A capacity approach to syntactic comprehension disorders: Making normal adults perform like aphasic patients. *Cognitive Neuropsychology, 11,* 671-717.

Miyake, A., Carpenter, P. A., & Just, M. S. (1995). Reduced resources and specific impairments in normal and aphasic sentence comprehension. *Cognitive Neuropsychology, 12,* 651-679.

Murray, L. L., Holland, A. L., & Beeson, P. M. (1997a). Auditory processing in individuals with mild aphasia: A study of resource allocation. *Journal of Speech, Language, and Hearing Research, 40*, 792-809.

Murray, L. L., Holland, A. L., & Beeson, P. M. (1997b). Grammaticality judgments of mildly aphasic individuals under dual-task conditions. *Aphasiology, 11*, 993-1016.

Naeser, M. A., Mazurski, P., Goodglass, H., Peraino, M., Laughlin, S., & Leaper, W. C. (1987). Auditory syntactic comprehension in nine aphasia groups (with CT scans) and children: differences in degree but not order of difficulty observed. *Cortex, 23,* 359-380.

Navon, D. (1984). Resources—A theoretical soup stone? *Psychological Review, 91*, 216–234.

Nespoulous, J.L., Dordain, M., Perron, C., Ska, B., Bub, D., Caplan, D., Mehler, J., & Lecours, A.R. (1988). Agrammatism in sentence production without comprehension deficits: reduced availability of syntactic structures and/or of grammatical morphemes: a case study. *Brain and Language, 33*, 273-295.

Obler, L. K., Fein, D., Nicholas, M., & Alber, M. L. (1991). Auditory comprehension and aging: Decline in syntactic processing. *Applied Psycholinguistics, 12*, 433-452.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9,* 97-113.

Piñango, M. M. (1998). *Some syntactic and semantic operations and their neurological underpinnings*. Doctoral dissertation, Brandeis University, Waltham, MA.

Piñango, M. M. (2000). Canonicity in Broca's sentence comprehension. In Y. Grodzinsky, L. Shapiro, & D. Swinney (Eds). *Language and the brain: representation and processing* (pp. 327-350) San Diego: Academic Press

Prather, P., Zurif, E. B., Stern, C., & Rosen, T. J. (1992). Slowed lexical access in non-fluent aphasia: A case study. *Brain and Language, 43*, 336-348.

Raven, J C., Court, J. H., & Raven, J. (1977). *Raven's Progressive Matrices and Vocabulary Scales*. New York: Psychological Corporation.

Raven, J. C. (1965). *The Coloured Progressive Matrices*. New York: The Psychological

Robin, D. A., & McNeil, M. R. (1994). The use of signal detection theory to evaluate aphasia diagnostic accuracy and clinician bias. *Clinical Aphasiology, 22*, 165-179.

Saffran, E., Schwartz, M., & Linebarger, M. (1998). Semantic influences on thematic role assignment: evidence from normals and aphasics. *Brain and Language, 62*, 255-297.

Saffran, E., Schwartz, M., & Marin, O. (1980). The word order problem in agrammatism: II. Production. *Brain and Language, 10*, 263-280.

Schuell, H., & Jenkins, J.J. (1959). The nature of language deficit in aphasia. *Psychological Review, 66*, 45-67

Schwartz, M. F., Linebarger, M. C., & Saffran, E. M. (1985). The status of the syntactic deficit theory of Agrammatism. In M. Kean (Ed.). *Agrammatism*. Orlando, FL: Academic Press.

Schwartz, M. F., Linebarger, M. C., Saffran, E. M., & Pate, D. (1987). Syntactic transparency and sentence interpretation in aphasia. *Language and Cognitive Processes*, *2,* 85-113.

Schwartz, M.F., Saffran, E., & Marin, O. (1980). The word order problem in agrammatism. I: Comprehension. *Brain and Language, 10*, 249-262.

Shapiro, L., & Levine, B. (1990). Verb processing during sentence comprehension in aphasia. *Brain and Language, 38*, 21-47.

Silkes, J.P., McNeil, M.R., & Drton, M. (2004). Simulation of aphasic naming performance in non-brain-damaged adults. *Journal of Speech, language, and Hearing Research, 47*, 610-623.

Slansky, B. L., & McNeil., M. R. (1997). Resource allocation in auditory processing of emphatically stressed stimuli in aphasia. *Aphasiology, 11*, 461-472.

Soroker, N. (1997). *Hebrew western aphasia battery*. Ra'anana, Israel: Loewenstein Hospital Rehabilitation Center.

Stine-Morrow, E., Ryan, S., & Leonard, J. S. (2000). Age differences in on-line syntactic processing. *Experimental Aging Research, 26*, 315-322.

Sung, J.E., McNeil, M.R., Pratt, S.R., Dickey, M.W., Hula, W.D., Szuminsky, N., & Doyle, P.J. (2008). Verbal working memory and its Relationship to sentence-level reading and listening comprehension in persons with aphasia. Manuscript submitted for publication.

Swinney, D., Nicol, J., & Zurif, E. (1989). The effects of focal brain damage on sentence processing: An examination of the neurological organization of a mental module. *Journal of Cognitive Neuroscience, 1*, 25-37.

Swinney, D., Onifer, W., Prather, P., & Hirshkowitz, M. (1979). Semantic facilitation across sensory modalities in the processing of individuals words and sentences. *Memory and Cognition, 7*, 159-165.

Swinney, D., Zurif, E., Prather, P., & Love, T. (1996). Neurological distribution of processing resources underlying language comprehension. *Journal of Cognitive Neuroscience, 8,* 174-184.

Thompson C. K., Ballard, K. & Tait, M. E. (2008). *Northwestern Assessment of Verbs and Sentences-Revised* (NAVS-R). Unpublished data, Northwestern University.

Thompson C. K., Shapiro, L. P., Tait, M. E., Jacobs, B., Schneider, S., & Ballard, K. (1995). A system of the linguistic analysis of agrammatic language production. *Brain and Language, 51*, 124-129. [Abstract]

Tompkins, C. A., Bloise, C. G. R., Timko, M. L., & Baumgaertner, A. (1994). Working memory and inference revision in brain-damaged and normally aging adults. *Journal of Speech and Hearing Research, 37,* 896-912.

Tseng, C. H., McNeil, M. R., & Milenkovic, P. (1993). An investigation of attention allocation deficits in aphasia. *Brain and language, 45*, 276-296.

Wanner, E. & Maratos, M. (1978). An ATN approach in comprehension. In M. Halle, J. Brensens, & G. Miller (Eds), *Linguistic theory and psychological reality*, (pp. 119-161). Cambridge, Mass: MIT Press.

Warren, T. & Gibson, E. (2002). The influence of referential processing on sentence complexity. *Cognition, 85,* 79-112.

Warren, T., McConnell, K., & Grodner, D. (2008). Eye movement evidence for resource-based constraints on syntactic complexity. Manuscript submitted for publication.

Waters, G. S. & Caplan, D. (1996). Processing resource capacity and the comprehension of garden path sentences. *Memory and Cognition, 24,* 342-355.

Waters, G. S. & Caplan, D. (2001). Age, working memory, and on-line syntactic processing in sentence comprehension. *Psychology and Aging, 16,* 128-144.

Waters, G. S. & Caplan, D. (2004). Verbal working memory and on-line syntactic processing: Evidence from self-paced listening. *The Quarterly Journal of Experimental Psychology, 57A,* 129-163.

Waters, G. S. & Caplan, D. (2005). The relationship between age, processing speed, working memory capacity, and language comprehension. *Memory, 13,* 403-413.

Waters, G. S., Caplan, D., & Yampolsky, S. (2003). On-line syntactic processing under concurrent memory load. *Psychonomic Bulletin & Review, 10,* 88-95.

Waters, G.S., Caplan, D., & Hildebrandt, N. (1991). On the Structure of Verbal Short-term Memory and its Functional Role in Sentence Comprehension: Evidence from Neuropsychology. *Cognitive Neuropsychology, 8*, 81-126.

Webber, B. L. (1988). *Tense as discourse anaphor. Computational Linguistics, 14*, 61-73.

Wertz, R. T., Deal, J. L., & Robinson, A. J. (1984) Classifying the aphasias: A comparison of the Boston Diagnostic Aphasia Examination and the Western Aphasia Battery. Presented at the 14th Clinical Aphasiology Conference, Seabrook Island, SC.

Wickens, C. D. (1984). Processing resources in attention. In R.Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 63-102). New York: Academic Press.

Wilson, R.H. & Antablin, J.K. (1980). A Picture identification task as an estimate of word recognition performance in nonverbal adults. *Journal of Speech-Language and Hearing Disorders, 45*, 223-238.

Wright, H. H., Downey, R. A., Gravier, M., Love, T., & Shapiro, L. P. (2007). Processing distinct linguistic information types in working memory in aphasia. *Aphasiology, 21*, 802-813.

Zurif, E. B., & Piñango, M. M. (1999). The existence of comprehension patterns in Broca's aphasia. *Brain and Language, 70*, 133-138.

Zurif, E., Swinney, D., Prather, P., Solomon, J., & Bushell, C. (1993). An on-line analysis of syntactic processing in Broca's and Wernicke's aphasia. *Brain and Language, 45,* 448-464.

Zurif, E., Swinney, D., Prather, P., Wingfield, A., & Brownell, H. (1995). The allocation of memory resources during sentence comprehension: Evidence from the elderly. *Journal of Psycholinguistic Research, 24*, 165-182.