Published in final edited form as:

Aphasiology. 2020 ; 34(8): 943–969. doi:10.1080/02687038.2019.1622647.

Effects of executive attention on sentence processing in aphasia

Eleni Peristeri,

University of Thessaly, Greece

Ianthi Maria Tsimpli,

University of Cambridge, UK

Efthimios Dardiotis,

University of Thessaly, Greece

Kyrana Tsapkini

Johns Hopkins University, USA

Abstract

Background: In the recent years there has been increasing interest in the effects of attentional control on syntactic comprehension, as measured in garden path sentence resolution. Persons with aphasia (PWA) experience greater penalties in garden path sentences compared to language-unimpaired adults but the origin of this deficit remains a controversial issue. One of the possible deficits has been claimed to be disambiguation of lexical cues in the sentence. However, in languages such as English with little morphological variation this connection is hard to establish. To test this hypothesis we used garden path sentences in a morphologically rich language, Greek, where morphological cues may resolve garden path at the lexical level. We further tested whether domain-general attentional control abilities and in particular shifts in attentional control predict garden path resolution in PWA and age- and education-matched controls.

Aim: This study aimed to determine whether PWA were able to integrate disambiguating morphological (Case) cues while processing garden path sentences. In addition, we tested whether domain-general attentional control and in particular attentional shift from global to local and local to global information (as defined by Navon, 1977) correlates directly with garden path resolution in PWA and healthy controls.

Methods & Procedure: Fifteen participants with non-fluent/agrammatic aphasia along with fifteen age- and education-matched language-unimpaired adults performed an online self-paced reading and grammaticality judgment task that included object/subject ambiguous sentences. Syntactic ambiguity was created by the optional transitivity of verbs, while the garden path effect was resolved by morphological Case. The individuals' executive attention skills were tested through an online non-verbal global-local attention shifting task that measured costs stemming from shifting attention from the global to the local level, and vice versa.

Contact: Eleni Peristeri, eperiste@enl.auth.gr University of Thessaly, Department of Medicine, Larissa 412 22, Greece.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Outcomes & Results: PWA were slower and more erroneous than controls in integrating Case cues to disambiguate garden path sentences as manifested in the self-paced reading and grammaticality judgment task. In the global local task, PWA exhibited greater global-to-local (vs. local-to-global) attention shifting costs, while controls did not exhibit dissociation. In the regression analysis, garden path resolution in PWA was significantly predicted by global-to-local attention shifting costs, while controls' garden path resolution was significantly predicted by local-to-global attention shift costs.

Conclusions: The present study showed for the first time that morphological cues can shed light in sentence comprehension deficits exhibited by PWA. Furthermore, domain-general attentional control abilities were significantly associated with sentence comprehension abilities in both healthy controls and PWA.

Keywords

non-fluent aphasia; Broca's aphasia; garden path; case morphology; attention shifting; attention deficit

Introduction

Sentence comprehension is one of the major deficits in post-stroke non-fluent/agrammatic aphasia. This is particularly revealed in garden path sentences, wherein PWA's revision of initial interpretative commitments is either considerably slower than controls (Novick et al., 2009; Vuong & Martin, 2015) or unsuccessful, thus leading to inaccurate interpretations of the sentences (Tyler et al., 2011; Sheppard et al., 2017; Huck et al., 2017). Several interpretations have been put forth to explain garden path costs in aphasia, such as a deficit in inhibitory mechanisms at the lexical level (Novick et al., 2009; Vuong & Martin, 2015) and/or deficient integration of disambiguating information (Sheppard et al., 2017). A reason that previous studies were not able to answer this question may be because they looked only at inhibitory deficits in PWAs. Given that attending to specific words in garden path sentences is a prerequisite for forcing the re-analysis of the sentence and the resolution of the garden path effect, investigating possible associations between garden path processing and attentional control is crucial to understanding sentence comprehension deficits in PWAs.

A number of studies have put forth attentional deficits in explaining variability in sentence comprehension in PWA. Tasks making substantial demands on attentional control processes, such as attention switching and divided attention, have been found to result in poor morpho-syntactic production and comprehension (Korda & Douglas, 1997; Murray, 2000; Murray, Keeton, & Karcher, 2006; Murray, Holland, & Beeson, 1997; Murray et al., 2018). According to relevant psycholinguistic models (Hula & McNeil, 2008; Murray, 1999), attention in aphasia is a limited processing resource, so that when task demands exceed the patients' capacity limits, processing of language information is increasingly bottlenecked resulting in delayed language performance. Despite the aforementioned evidence for attentional deficits in aphasia and their correlation to sentence comprehension, the explanations that have been put forth are not conclusive or specific on the specific attentional mechanisms that are correlated with sentence comprehension and, in particular, with garden path resolution .

Language variation may be a way to shed light to the relationship between sentence comprehension and attention in aphasia. In English, for example, there is no disambiguating information at the lexical level, and therefore, the garden path phenomenon can only be resolved at the syntactic, whole-sentence level, which requires the confounding (may be) contribution of other cognitive functions such as working memory and inhibition. Languages with rich morphosyntactic paradigms allow the garden path to be directly disambiguated at the lexical level and, thus, provide the necessary disambiguating information without recruiting whole-sentence and demanding processing mechanisms that may be additionally (and independently) impaired as well. Greek is a morphologically rich language where morphological determiners within the word need to be used to resolve the garden path phenomenon in sentence comprehension (Papadopoulou, 2006; Papadopoulou & Tsimpli, 2005). Therefore, garden path resolution happens at the lexical level. Previous studies have shown that language-unimpaired individuals are highly effective at using local morpho-syntactic cues at the lexical level in an unfolding sentence to resolve garden path ambiguities in real time (Meg & Bader, 2000; Papadopoulou & Tsimpli, 2005). If attentional control is needed to integrate disambiguating lexical information at the local, word level, we hypothesized that this could be considered as an indication of local-to-global attentional control shift. If attentional control is needed to disambiguate information at the global sentence level, i.e. after the critical word has been integrated with immediately preceding context, we hypothesized that this could be considered as an indication of global-to-local attentional shift. If the above hypotheses are correct, then a deficit in (global to) local (word level) attentional shift in garden path sentences would be correlated with a global-to-local attentional shift deficit in a non-linguistic task of attentional control such as a global local task (Navon, 1977). The present study aimed to determine whether the global-to-local or local-to-global shift in attentional control is associated with garden path deficits in PWA.

Recent studies suggest that difficulty with garden path sentences in PWA relates to the incomplete integration of disambiguating lexical information, intensifying the need for syntactic repair mechanisms (Sheppard et al., 2017; Huck et al., 2017).. Disambiguating cues so far have included prosody (Sheppard et al., 2017) as well as optional complementizers (Huck et al., 2017) to investigate PWA's Determiner Phrase (DP) attachment preferences in garden path sentences. PWA in Huck and colleagues' (2017) eye-tracking study, for example, showed longer fixation durations and a larger number of regressions than controls when they read the disambiguating region of the sentences. The overall findings on garden path processing suggest that although PWA are sensitive to the wellness of thematic fit in sentences, their processor fails to readily integrate critical disambiguating information. Other research (Hanne, Burchert, & Vasishth, 2015), however, shows that PWA are capable of integrating disambiguating lexical information, such as number-agreement markers on verbs and case markers in noun phrases, in garden path sentences. Therefore, these studies provide evidence that attentional control at the lexical morphology level may be needed for garden path resolution. The present study built on that premise.

The contribution of attention switching in garden path processing in aphasia provides an intriguing test case for the role of domain-general attentional control abilities in PWA's sentence comprehension deficit. The brain is constantly faced with ambiguous information

in the linguistic domain, and has to switch from one possible interpretation to the other to create coherent interpretations of sentences. During this process, the comprehender needs to both track syntactic ambiguity during overall (global) meaning integration processes, and switch attention to locally disambiguating material to resolve syntactic ambiguity. The current study tested whether PWA's difficulty to settle on a syntactic frame over alternative possibilities relates to deficits in attentional control shifting skills, and more specifically, to PWA's ability to shift attention from the global to the local level, and vice versa in a (relatively) non-verbal attentional task. The rich morphology of Greek allows us to examine possible correspondences between non-verbal attention shifting abilities and garden path processing in PWA by addressing the extent to which a global-to-local attentional shift deficit may correlate with the patients' sensitivity to Case-marked DPs that function as local disambiguators in a non-English language. If indeed this is the case, then individuals with a garden path deficit would also exhibit a deficit in attention shifting, and, more importantly, there would be a correlation between these. The present study seeks to determine this relationship and assess whether the global/local type of attentional control is associated with garden path processing in aphasia.

Study goals and research hypotheses

In the present study, garden path processing was tested through a self-paced reading grammaticality judgment task that included unambiguous and garden path sentences, each consisting of a temporal and a main clause. Though grammaticality judgment tests have been extensively used as a data-collection method to investigate PWA's sentence processing abilities, the relationship between grammaticality judgment and comprehension is controversial in aphasia. Offline judgments about the structural well-formedness of utterances have been shown to be relatively easy for PWA despite moderate to severe deficits in the processes by which grammatical knowledge is accessed and used in real time (Bates & Wulfeck, 1989; Bates, Wulfeck, & MacWhinney, 1991; Devescovi et al., 1997; Wulfeck, Bates, & Capasso, 1991). Along with offline data, the self-paced reading part of the online task in the current study gives a continuous, online measure of how garden path sentences were processed as they unfolded in real time. As such, the online task used in the present study, i.e., a combination of reading and grammaticality judgment tasks, was implemented to enable insight into PWA's sensitivity to thematic preferences at the initial steps of garden path sentence processing as well as in the final interpretation of the sentences.

The design of the online grammaticality judgment task manipulated two syntactic properties, namely, Verb transitivity (optionally transitive and intransitive verbs) and Syntactic function of the post-verbal noun (Object, Subject) by manipulating the Case marker of the DP following the embedded verb. More specifically, for the Transitivity manipulation, the embedded clause contained a verb that was either optionally transitive or intransitive, while for the Syntactic function manipulation, the DP following the embedded verb was marked with either Nominative or Accusative case, thus, being assigned a Subject and an Object syntactic role, respectively. Each experimental sentence appeared in four conditions and each quartet included three grammatical and one ungrammatical sentence (see Table 1).

Participants read sentences presented word by word in a self-paced fashion while reading times were recorded on each word. After the participants finished reading the sentence, they had to decide whether the sentence was grammatical or not. Target sentences included: (1) (optionally) Transitive-Subject (TS) structures, which echo with the pattern we see in garden path effects. Specifically, the optionally transitive verb ('erave' / *was sewing*) in the temporal clause of the sentence could locally be combined with the following DP ('i skufi' / *the hats*) to form a transitive sentence (see Late Closure parsing strategy; Frazier & Fodor, 1978; Frazier, 1987; Weinberg, 2001). This combination, however, should be ruled out by the Nominative case of the DP, which cannot be integrated in such a construction. To reach a grammatical interpretation, the verb must be reanalyzed as an intransitive, while the post-verbal DP must be reanalyzed to be attached to the main clause verb 'jlistrisan' / *slipped* as its subject; (2) (optionally) Transitive-Object (TO) structures, in which the post-verbal DP was marked with Accusative case, thus, being attached to the transitive verb as its object. The subject of the main clause verb 'jlistrisan' / *slipped* should be recovered by the verb's inflectional ending, since Greek is a pro-drop language (Rousou & Tsimpli, 2006). Regarding the identity of the referent of the verb's subject, it could be either 'the hats' (that the individual was sewing) or, alternatively, another not-explicitly-mentioned entity that could have slipped from the chair; (3) Intransitive-Subject (IS) structures, in which the subordinate verb was intransitive and the post-verbal DP 'i pinakes' / *the paintings* was marked with Nominative case, so the DP should be interpreted as the subject of the main clause verb 'epesan' / *fell*; and, finally, (4) Intransitive-Object (IO) structures, in which the subordinate verb was intransitive and the following DP appeared in Accusative case, thus, leading to ungrammaticality.

Analyses first focused on TS and TO trials both including optionally transitive verbs with a highly predictable argument structure, namely, an object reading. We hypothesized that the Nominative case-marked DP in TS sentences should result in a garden path effect, namely, reading time increase on the DP region and lower grammaticality judgment accuracy, for both controls and PWA. If the local disambiguating cue of case morphology was not fully integrated in PWA's syntactic representation, the garden path effect in TS sentences should be elevated compared to TO trials, wherein the post-verbal Accusative case-marked DP fits thematic expectations. Regarding IS and IO trials, both including intransitive embedded verbs, we hypothesized no accuracy difference to emerge between the two sentence types. The same pattern was expected to be replicated in PWA based on a number of studies (Kim & Thompson, 2000; Peristeri, Tsimpli, & Tsapkini, 2013; Shapiro, Nagel, & Levine, 1993) showing that individuals with non-fluent Broca's aphasia retain knowledge of the verbs' argument structure.

On the other hand, the non-verbal global local switching task (Navon, 1977) manipulated two properties, namely, attention switching and within-shape congruency. More specifically, global shapes in this task consisted of smaller shapes that were either the same as (congruent) or different from the global shape (incongruent). In the first two blocks of the task, subjects had to constantly attend to global (global-to-global non-switch trials) and local shapes (local-to-local non-switch trials), respectively, thus, no switching was involved. In the third block, participants had to attend to global and local shapes interchangeably; they had to attend to the global shape when the preceding trial was local (local-to-global switch), and vice versa, i.e. attend to the local shape when the preceding trial was global (global-to-local

switch). Besides switching attention between global and local stimuli, participants also had to inhibit misleading cues in the incongruent trials of the task where the global and local shape did not match (e.g. see the first stimulus on the third row of Figure 1 where the global shape is a triangle that consists of small (local) Xs). Participants' local-to-global and global-to-local switch costs were measured in terms of time and response accuracy.

In the attentional control task we hypothesized that PWA would experience greater processing cost in attention switch trials compared to controls due to attention switching deficits that have been well reported in the literature (Murray, 2000; Murray et al., 2006; Murray et al., 1997). We further hypothesized that PWA may be more affected than controls by the increasing attentional demands for the inhibition of distracting incongruent information in the task.

Finally, to test the hypothesis that PWA's garden path deficit is related to an attention shifting deficit, we ran a stepwise multiple regression analysis with local-to-global and global-to-local switch accuracy and RT costs in congruent and incongruent trials as independent predictors, and accuracy/RT on grammaticality judgments and reading times on the DPs of TS garden path sentences as the dependent variables separately for each group. If the global-to-local attention shifting skills in PWAs were deficient, we expected that high global-to-local costs in the attention task would be correlated to low grammaticality judgment accuracy in TS sentences or/and elevated reading times on the DP disambiguating region.

Methods

Participants

The same groups of PWA and control participants were tested in two experiments. A group of 15 individuals with post-stroke aphasia characterized with agrammatism participated in the study (age range 42–74; mean age: 61;3 yrs., Standard Deviation (*SD*): 8.5). They were all pre-morbidly right-handed, native Greek male speakers who had suffered a single left hemisphere stroke (two of them suffered from right hemiplegia). Across patients, damage covered frontal and pre-frontal areas of the left hemisphere including left inferior and middle frontal gyri, superior and middle temporal gyri, and basal ganglia. The patients were tested a minimum of 2 years post-stroke. All of them had normal or corrected-to-normal visual and auditory acuity. No participant had a previous history of other infarcts, drug abuse, psychiatric illness or other brain disorder or dysfunction (see Table 2 and Appendix A for details on PWA's assessment measures).

A group of 15 age- and education-matched Greek-speaking male adults (mean age: 57;6 yrs., *SD*: 13.5; mean years of education: 11;4, *SD*: 1.6) served as the control group. The study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Written informed consent was obtained from all the PWA prior to inclusion in the study.

Materials and Procedure

Grammaticality judgment task—The sentences employed in this experiment were adapted from Papadopoulou and Tsimpli's (2005) study with children and language-unimpaired adults. The experimental items comprised 96 sentences each consisting of a temporal and a main clause. The sentences were distributed across four conditions by manipulating the Transitivity of the embedded verb and the syntactic role of the DP following the embedded verb (see Table 1). All sentences were grammatical except for the IO condition (n=24), wherein the intransitive verb was followed by an Accusative case-marked DP (see Table 1). The sentences were closely matched for length, with the number of words being eight in each sentence, and the words across sentences were matched in frequency (taken from Institute for Language and Speech Processing (ILSP) database) across conditions. We also controlled for the animacy of the DPs following the embedded verb by using inanimate nouns only. Ninety-six unambiguous sentences were added to the materials as fillers, half of them ungrammatical and the other half grammatical (see examples (1) and (2) below). Ungrammaticality in the filler items was always driven by subject-verb agreement violation. Participants received stimuli in two different testing sessions with 96 trials each, separated by a minimum duration of 1 week. A 10-practice item session preceded the actual experiment to familiarize participants with the procedure.

Filler sentence-ungrammatical:

(1) *To pedhi me tis majikes botes efijan klejodas the boy_{NOM.SG} with the magic boots left_{PAST.PERF.3PL} crying “The boy with the magic boots left crying.”

Filler sentence-grammatical:

(2) To ble aftokinito apenadi aniki ston filo mu the blue_{NOM.SG} car_{NOM.SG} across belong_{PRES.3SG} to the_{ACC.SG} friend_{ACC.SG} my “The blue car across the street belongs to my friend”

Procedure.: We designed a self-paced reading grammaticality judgment task with E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). All sentences were presented in the middle of the screen on a portable laptop computer using a self-paced word by-word presentation (indicated by “/” in Table 1), with each previous word disappearing with the onset of the following word. Words were written in lower case letters of Arial 36-point font size and were displayed in the middle of the screen. Font-type and size selection were made according to most suitable characteristics for online reading (Marinis, 2003; Shneiderman, 1998). Participants were instructed to read each word aloud and to pace their way through each item by pressing a button on a response box interfaced with the computer. After reading the last word of each sentence, participants heard a tone to signal the sentence was over and viewed a question mark [?] that remained on the centre of the screen until the subject's response. At this point, subjects were asked to make a grammaticality judgment, i.e. to press the green-colored [] button on the response box if they thought the sentence was grammatical and the red-colored [X] button if the sentence was ungrammatical. Following the answer (i.e. ‘yes’ or ‘no’) to the question probe, the next trial was initiated by pressing the spacebar. Response times (i.e. time in msec from the appearance of the question mark to

the participant's button-press) and accuracy (%) of grammaticality judgments were recorded in E-Prime. Response times for each button press were also recorded by E-Prime; the measures of interest were participants' reading times on the Determiner (item 3) and noun (item 4) segment of the DP (see items in bold letters in Table 1).

Global-local attentional control task—The global local task was modeled after Navon's (1977) study in which the stimuli consist of shapes. Each global shape (circle, X, triangle or square) was composed of smaller/local ones that were either the same (congruent) or different from the global shape (incongruent) (see Figure 1). Participants were instructed to indicate the number of lines needed to form either the big global figure, or the small local figure, i.e. press '1' for circles, '2' for Xs, '3' for triangles, and '4' for squares. Participants completed three blocks of trials: two non-switch blocks (global-to-global, local-to-local), and a third switch block in which participants had to attend either to the global shape when the preceding trial was local (local-to-global switch), or to the local shape when the preceding trial was global (global-to-local switch).

Procedure.: Each shape appeared on the center of the computer screen and remained visible until a response was made, unless the time granted for responding elapsed (3000 msec after the stimulus display's onset). Each block comprised 64 trials. Participants were instructed to respond as quickly as possible without compromising accuracy. Before the switch block participants were instructed about the order of the trials (i.e., global-local-global-local etc.). The task was presented using E-Prime software (Schneider et al., 2002) and participants were tested individually. The beginning of each block was preceded by a 12-item practice session to familiarize the participants with the task.

The measures that were of interest were local-to-global and global-to-local switch costs in both RT and accuracy (%) separately for congruent and incongruent trials. For the RT measure, the local-to-global switch cost was calculated by subtracting RT on global-to-global non-switch from global switch trials, while the global-to-local switch cost by subtracting RT on local-to-local non-switch from local switch trials. For the accuracy measure, the local-to-global switch cost was calculated by subtracting accuracy on global switch from global-to-global non-switch trials, while the global-to-local switch cost was calculated by subtracting accuracy on local-to-local switch from local switch trials.

Results

Grammaticality judgment task: RT & Accuracy

In this section, we report on the data from the grammaticality judgement task. Prior to statistical analyses, subject-by-subject RT on judgments which were smaller than 250 msec and over 2 *SDs* from the mean RT for each sentence type (TO, TS, IO, IS) were defined as outliers and were replaced by the mean for each participant. This procedure yielded 2.1% of the data for the control group and 5.3% for the Broca group as outliers. Groups' accuracy performance in the filler items of the task were calculated; PWA scored 88.7% (range: 82–94, *SD*: 4.1), while controls scored 96.5% (range: 82–100, *SD*: 6.5). Bivariate Pearson correlations between RT and accuracy scores revealed no trade-off effects between processing cost and grammaticality judgment accuracy in either condition.

In Figure 2, the response times are presented per group.

A mixed-design ANOVA was conducted with Group (Broca, controls) as between-subjects factor, and Transitivity (transitive verb, intransitive verb) and Syntactic function (subject, object) as within-subjects factors (see Table 3 for descriptive statistics). There was a significant Group effect, which was due to the fact that PWA were overall slower than controls. Main effects for Transitivity and Syntactic function were not found to be significant. We did, however, find a significant two-way interaction between Transitivity and Group, as well as a significant three-way interaction among Group, Transitivity and Syntactic function.

Separate repeated measures ANOVAs for each group were conducted to unpack the significant interaction. For PWA, the analysis revealed a significant Transitivity effect, a non-significant Syntactic function effect, and a significant two-way interaction between Transitivity and Syntactic function. Subsequent paired-samples *t* tests showed that TS trials were considerably slower than TO trials, $t(14) = 3.213$, $p = .006$; also, IO trials were significantly slower than IS trials, $t(14) = 3.252$, $p = .006$. For controls, the same analysis revealed a non-significant effect for Syntactic function, yet, there was a significant Transitivity effect, which was due to the fact that transitive sentences were considerably slower than intransitive ones. The interaction between Transitivity and Syntactic function was not found to be significant.

In order to identify individual patterns of performance in TS and TO trials, i.e. whether the discrepancy between RT on the two sentence types for each patient significantly differed from the corresponding discrepancy in controls, statistical analyses using Crawford and Garthwaite's (2002) DISSOCS software program were carried out. The difference between RT on TS and TO trials was significantly larger than that observed for controls for six (out of the 15) patients, and marginally larger than controls for four patients (see Appendix B for *p*-values of DISSOCS tests).

Figure 3 presents accuracy data for each group.

The mixed-design ANOVA on accuracy data revealed a significant Group effect, which was due to the fact that the Broca group's overall accuracy performance was considerably lower than controls (see Table 4). The analysis also revealed significant effects for Transitivity and Syntactic function, a significant two-way interaction between Transitivity and Syntactic function, and a significant three-way interaction among Group, Transitivity and Syntactic function.

To unpack the significant three-way interaction, separate repeated measures ANOVAs were conducted for each group. For PWA, the analysis showed significant Transitivity and Syntactic function effects, as well as a significant two-way interaction between Transitivity and Syntactic function. Subsequent paired samples *t*-tests showed that TS trials were considerably less accurate than TO trials, $t(14) = 10.977$, $p < .001$. There wasn't any significant difference between IS and IO trials, $t(14) = .326$, $p = .749$. For controls, the analyses revealed non-significant effects for Transitivity and Syntactic function; the

interaction between Transitivity and Syntactic function was not found to be significant either.

Finally, Crawford and Garthwaite's (2002) DISSOCS analyses revealed that the difference between accuracy scores on TS and TO trials was significantly larger than that observed for controls for eleven patients, and marginally significantly larger than controls for two patients (see Appendix B for p -values of DISSOCS tests).

Grammaticality Judgements: Response times on Determiner and Noun in TS and TO trials

In this section, we report on the reading times on the Determiner and Noun regions of TS and TO sentences, i.e. segments 3 and 4 in the moving-windows task (see items in bold in Table 1). Figures 4 and 5 depict the reading times per group and sentence-type (TS, TO) on the two critical regions.

We first report on the results on the Determiner region. A mixed-design ANOVA was conducted with Group (Broca, controls) as between-subjects factor and Syntactic function (subject, object) as within-subjects factor. The analysis revealed non-significant effects for Group, $F(1, 28) = 2.203$, $p = .150$, $\eta^2 = .07$, and Syntactic function, $F(1, 28) = 2.410$, $p = .104$, $\eta^2 = .09$; yet, there was a significant interaction between Group and Syntactic function, $F(1, 28) = 3.822$, $p < .05$, $\eta^2 = .19$. Separate ANOVAs per group revealed that the Broca group was significantly slower on the Determiner region of TS (vs. TO) trials, $F(1, 14) = 3.894$, $p = .04$, $\eta^2 = .22$. For controls, there was no timing difference between TS and TO trials on the Determiner, $F(1, 14) = .128$, $p = .725$, $\eta^2 = .01$.

For the noun segment, the same analysis revealed no significant effects for Group, $F(1, 28) = 1.366$, $p = .252$, $\eta^2 = .04$, and Syntactic function, $F(1, 28) = .117$, $p = .735$, $\eta^2 = .01$. The interaction between Group and Syntactic function was not found to be significant either, $F(1, 28) = .930$, $p = .343$, $\eta^2 = .03$.

Non-verbal global local attentional control task

Prior to statistical analyses, subject-by-subject RT which were smaller than 250 msecs and over 2 SD s from the mean RT for each condition (global-to-global non-switch, local-to-local non-switch, local-to-global switch, global-to-local switch) were defined as outliers and were replaced by the mean for each participant. This procedure yielded 4.1% of the data for controls and 6.6% for PWA as outliers. Figures 6 and 7 present the groups' local-to-global and global-to-local switch costs on the task's congruent and incongruent trials separately for the RT and accuracy measure (see Appendix C for the groups' mean RT (in msecs) and accuracy (%) in the global-to-global and local-to-local non-switch, and switch trials).

Local-to-global and global-to-local switch costs in RT—A mixed-design ANOVA was conducted with Group (Broca, controls) as between-subjects factor, and Switch level (local-to-global, global-to-local) and Within-shape congruency (congruent, incongruent) as within-subjects factors (see Table 5). The analysis revealed non-significant effects for Group and Within-shape congruency, and a significant Switch level effect, $F(1, 28) = 34.547$, $p < .001$, $\eta^2 = .56$, which was attributed to the fact that the global-to-local switch cost was about double (1077 msecs) the local-to-global switch cost (589 msecs). The two-way

interaction between Within-shape congruency and Group, as well as the three-way interaction among Group, Within-shape congruency and Switch level were not found to be significant; yet, there was a significant two-way interaction between Group and Switch level.

Subsequent repeated measures analyses conducted for each group revealed a significant Switch level effect for the Broca group only; this effect stemmed from the fact that the global-to-local switch cost was significantly higher than the local-to-global switch cost (1298 msec > 454 msec). The same analysis revealed that the Within-shape congruency effect and the two-way interaction between Switch level and Within-shape congruency were not significant. For controls, the analysis revealed non-significant effects for either the Switch level or Within-shape congruency; the two-way interaction between Switch level and Within-shape congruency was not found to be significant either.

Crawford and Garthwaite's (2002) DISSOCS analyses showed that the RT difference between global-to-local and local-to-global switch costs was significantly larger and marginally significantly larger than controls for nine and one patient, respectively (see Appendix B for *p*-values of DISSOCS tests).

Local-to-global and global-to-local switch costs in accuracy—The same mixed-design ANOVA analysis was conducted on accuracy (see Table 6). The analysis revealed a significant effect for Group, which stemmed from the fact that the Broca group scored less accurately than controls, as well as a significant Switch level effect, which was due to the fact that the global-to-local switch cost was considerably higher (35.3%) than the local-to-global switch cost (8.9%). The analysis did not reveal any significant effect for Within-shape congruency, neither significant interactions between Group and the within-subjects variables.

Regressions between groups in the TS trials of the grammaticality judgment task and switch costs in the global local task

To examine which variable(s) of the global local task best explained the variance of the groups' performance in TS trials (accuracy (%), RT on grammaticality judgments, and reading times on the Determiner and the noun regions) stepwise linear regressions were used. Independent variables included local-to-global and global-to-local switch costs in congruent and incongruent trials. For PWA, we found that RT in the global-to-local switch cost were negatively associated with RT on grammaticality judgments in TS trials, suggesting that garden path sentence processing speeded-up as PWA experienced greater global-to-local switch costs, i.e. greater interference from global information in local trials. Furthermore, PWA's accuracy in TS sentences was positively associated with global-to-local switch costs, which implies that grammaticality judgment accuracy increased once global biases were stronger. Controls, on the other hand, were faster at reading Determiners when the local-to-global switch cost was intensified, i.e. when interference from local onto global trials was stronger. Predictive effects for the groups' performance in TS trials were observed only for the incongruent (vs. congruent) trials of the global local task (see Table 7 for the detailed output of the regression analyses).

Discussion

In the present study, we compared sentence comprehension in garden path performance of a group of PWA (non-fluent/agrammatic) to a group of age- and education-matched language-unimpaired adults using an online self-paced reading grammaticality judgment task. We further tested whether a deficit in garden path processing correlates to a deficit in PWA's attention shifting skills. First, we replicated the finding that PWA show stronger garden path resolution deficits than unimpaired adults, as determined in previous studies (Huck et al., 2017; Novick et al., 2009; Sheppard et al., 2017; Tyler et al. 2011; Vuong & Martin, 2015); PWA's low accuracy scores and slow reading times at the disambiguating phrase of garden path sentences indicated a garden path effect. Second, we showed that PWA exhibited an attention shifting deficit, and more specifically, they had greater difficulty than controls disengaging attention from the global to the local perceptual level whereas controls showed no dissociation between global-to-local and local-to-global attention shift costs in either the RT or the accuracy measure. Finally, we demonstrated that while controls' garden path resolution ability was associated with local-to-global attention shift costs, PWA's garden path resolution ability was associated with global-to-local attention shift costs.

In the online grammaticality judgment task, PWA's performance in IS and IO trials, where no garden path effect was involved, hints in the direction that the patients' access to the categorical argument structure information of the verbs was largely preserved. PWA's accuracy in IS and IO trials was considerably above chance level (>74%), while their elevated RT in IO trials implies that the aphasic parser was sensitive to theta grid violations. Interestingly, PWA scored significantly lower than controls in TO trials which is rather surprising given that TO sentences allow one to fall back on the 'default' interpretation of the sentence by assigning a theme role to the post-verbal DP. We assumed that the optional transitivity of the verbs imposed extra processing load on PWA's short-term memory by triggering the activation of two parallel structures; if we assume that transitive and intransitive parsing options operated incrementally and in parallel, then this could have made TO sentences more vulnerable to misinterpretation for PWA.

We now turn to the interpretation of PWA's accuracy ratings and RT on TS trials, i.e. garden path sentences having an optionally transitive verb followed by a DP-subject. Both grammaticality judgment accuracy and RT reflect the degree of processing disruption stemming from a mismatch between the verb's argument prediction and the encountered argument. PWA were considerably more likely to reject TS structures as ungrammatical (48.1%), whereas controls' accuracy level was high (83.3%) and it did not differ from the rest of the sentence types in the task. Actually, the majority of PWA scored lower than controls in TS trials, which suggests that they failed to map the initial theme to an agent interpretation that was imposed by the explicit morphological marking (with Nominative case) of the DP, and that they probably never returned down the garden path. The finding that judgments on TS trials were significantly slower than the unambiguous TO trials for nearly half of the patients further implies that the Broca group formed hard-to-revise predictions about the language dependencies between the optionally transitive verb and the post-verbal DP, so that recovery from violations of these predictions was more effortful for PWA compared to controls.

We further explored how a local morphological cue, namely Case morphology which is a reliable predictor of argument structure in Greek, may shape the patients' ability to revise initial (mis)parses of garden path sentences. High surprisal at the disambiguating Nominative case-marked DP in TS sentences would indicate a garden path effect because Nominative case mismatches with the parser's favored (transitive) continuation. We thus used word-by-word reading times on the critical DP region as an analogue of the groups' (in)ability to overcome strong *a priori* expectations about the subcategorization frame of the optionally transitive verb. The findings show that PWA had difficulty rapidly overcoming the disfavored continuation of the sentence even in the highly constraining context of the Nominative Case-marked DP. Determiners in TS sentences considerably slowed down PWA's reading times relative to TO sentences, which implies that morphological cues were overridden by PWA's thematic role assignment preferences; in TS trials, PWA tended to assign to post-verbal DPs an object interpretation, even if the Determiner was marked with Nominative case. On the next segment, i.e. the noun, the object reading was dismissed in favor of grammaticality.

Morphological Case marking on the DPs in the garden path sentences was treated as a local lexical cue that PWA had to pay attention to in order to revise the sentences' structural ambiguity. Their reduced sensitivity to disambiguating morphological Case cues seems to validate the hypothesis that PWA exploited semantic cues (i.e. verb transitivity) rather than local morphology for structure building operations; late morphological cues, such as Case marking on the Determiner, were probably less influential than early verb thematic (optional transitivity) cues, because the more the analysis of the sentence progressed, the harder was for PWA to revise their initial parsing option. Long-lasting tendencies to form semantically (vs. syntactically)-specific predictions in sentence processing in aphasia have been well attested in previous literature (e.g. Dapretto & Bookheimer, 1999; Hanne et al., 2015) and may explain PWA's high susceptibility for effortful recovery when these predictions were violated. For controls, heuristics-based interpretation processes, such as the bias to interpret post-verbal DPs as themes, were less dominant than for PWA; there was no timing difference between subject and object readings on the critical DP region across garden path (TS) and unambiguous (TO) sentences, which suggests that controls processed sentences faithfully to grammar in contrast to PWA who tended to apply heuristic-based strategies. Besides the fact that the optional transitivity of the verbs in TS structures encouraged a hard-to-revise selection of a theme interpretation given the verbs' dominant transitive event schema, PWA's failure to rapidly integrate morphological Case cues may also be attributed to a short-term memory deficit. Previous work (Martin & He, 2004) demonstrates that PWA exhibit difficulty maintaining lexical and structural information in short-term memory, which severely compromises their ability to maintain unintegrated word meanings and syntactic structures during sentence comprehension. The increased demands posed by garden path processing in the current study may have prompted PWA to adopt a heuristic-based approach in order to deal with the rapid flow of linguistic information. Though the relationship between garden path sentence processing and short-term memory is beyond the scope of the current study, deficient temporary maintenance of linguistic information may have played a critical role in PWA's failure to readily integrate disambiguating morphological cues in the online task.

Regarding performance in the Navon-like global local attention switch task, local-to-global switch costs in RT gave rise to dissociative effects between the two groups. PWA exhibited deficient local processing skills or/and enhanced global biases compared to controls; global-to-local attention shifting costs were found to be significantly larger compared to costs stemming from shifting attention from the local to the global perceptual level. The greater global-to-local shifting costs constitute evidence of impaired attention switching operations in non-fluent/agrammatic aphasia, thus, connecting previous findings about impaired divided attention skills in aphasia (Erickson, Goldinger, & LaPointe, 1996; McNeil, Odell, & Tseng, 1991; Murray et al., 1997; Slanksy & McNeil, 1997) with explicit evidence on the level of attention shifting that was deficient in PWA. Interestingly, and contra initial expectations, incongruent trials were not performed worse than congruent trials by PWA (and controls); rather it was global-to-local attention shifting costs and probably maintenance of the task's shifting rule in working memory, that made the non-verbal attention shifting task more difficult to perform for the PWA.

Finally, the regression analyses between the global local task's switching costs and the groups' performance in the garden path sentences of the grammaticality judgment task demonstrate that language-unimpaired controls adopted distinct strategies for efficiently disambiguating the garden path effect relative to PWA. For controls, there was a relationship between the benefit of constraining Case morphological cues and garden path resolution efficiency; reading times on the Determiner of the DPs speeded up as local to-global attention shift costs increased. For PWA, on the other hand, greater global-to-local switch costs speeded up grammaticality judgments and raised accuracy in garden path trials.

These findings highlight the critical role of an attention shifting deficit in explaining garden path performance in PWA, and raise some interesting reflections about the correlation between PWA's ability to use local, fine-grained morphological cues signaling the appropriate syntactic parse in garden path sentences and their ability to dynamically shift their attention to selectively focus on local information in the non-verbal domain. One can claim that PWA's deficient global-to-local attention shifting skills may have contributed to attenuating the saliency of low-level morphological cues such as Case, thus, making it more difficult for the patients to quickly integrate the local disambiguating information as the garden path sentences unfolded in real time. The inhibitory (Novick et al., 2009; Vuong & Martin, 2015) and lexical integration deficit (Sheppard et al., 2017) accounts that have been proposed so far to explain the robustness of garden path effects in aphasia have been important in pinning down the mechanisms that may be deficient in PWA disallowing them from quickly recovering from the garden path effect. Yet, the specific accounts are insufficient to explain performance in sentences wherein garden path resolution can be attained through attending local morphological cues, such as Case, explicitly marking the syntactic role of the ambiguous region. Crucially, PWA's high rates of rejecting IO readings in the present study suggest that sensitivity to the verbs' subcategorization frame was preserved, while the lack of significant group differences in the incongruent trials of the global local task implies that PWA's ability to inhibit incongruent, interfering stimuli was comparable to that of controls. The global local task revealed that PWA exhibited exaggerated global-to-local attention shifting costs that may have driven most attention to the end-state of the ambiguous sentences, while local Case cues remained defocused. In

sum, our data extend the view that domain-general abilities and in particular attentional control affect garden path processing, and more generally speaking, sentence processing in PWA.

Conclusion

The present study sheds light on issues relating to the processing of garden path sentences in non-fluent/agrammatic aphasia, such as whether disambiguating Case morphology contributes to patients' parsing decisions, as well whether a deficit in PWA's attention shifting skills relates to their garden path resolution performance. The optional transitivity of the verbs proved to be a more robust index of PWA's parsing decisions than disambiguating Case morphology; post-verbal DPs in garden path sentences were treated as plausible themes of the optionally transitive verbs regardless of explicit Case morphological cues. The non-verbal global local task, on the other hand, revealed heightened attention switch costs for PWA that mainly stemmed from difficulty disengaging attention from global information to selectively focus on local information. Attention shifting effects on garden path processing were shown to be dissociable across the two groups; controls' ability to integrate the disambiguator in garden path sentences improved with enhanced local-to-global attention shift costs, while PWA's ability to resolve the garden path effect was mainly guided by global-to-local attention shift costs. The overall evidence raises the possibility that garden path resolution involves attention shifting skills which are impaired in Broca's aphasia and should be further investigated to assess how sentence comprehension and executive attention operations interact in aphasia.

Acknowledgements

We would like to thank our participants and referring physicians for their dedication and interest in our study. KT was supported by NIH (National Institute of Deafness and Communication Disorders) through award R01 DC014475.

Appendices

Appendix A.

Diagnoses of agrammatic comprehension were based on the convergence of clinical consensus and the results of standardized aphasia examinations, including the Short Form of the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1972; adaptation in Greek: Tsapkini, Vlahou, & Potagas, 2010), the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983; adaptation in Greek: Patricacou et al., 2007), and syntactic comprehension measures from the Bilingual Aphasia Test (Paradis & Kehayia, 1987; Peristeri & Tsapkini, 2011). As revealed by the scores in the BAT subtests, the patients were able to process the semantics of words without difficulty and their comprehension skills in structurally simple sentences, such as active transitives (mean score: 96.3%; range: 88%–100%), non-reversible passives (mean score: 95.0%; range: 75%–100%), and subject relative clauses (mean score: 83.9%; range: 58%–100%) were relatively preserved; yet, they faced difficulty with processing sentences resulting from syntactic movement, such as reversible passives (mean score: 31.7%; range: 0%–50%), object relatives (mean score: 57%; range: 50%–65%) and

focused sentences (mean score: 40%; range: 17%–58%). Regarding their reading skills, the patients had intact single-word decoding skills as demonstrated by their performance in a list of 53 Greek words having a range of one to eight syllables (Padeliadou & Sideridis, 2000). Table 2 lists demographic and clinical information for the participants with Broca's aphasia.

Appendix B.

DISSOCS tests (*p*-values) (Crawford & Garthwaite, 2002) on each patient's RT and accuracy scores in the TO and TS trials of the self-paced reading garden path task and on the global-to-local and local-to-global switch costs (in RT) of the global local attention switch task.

Patient	Self-paced reading garden path task TO vs. TO trials		Global local task Global-to-local vs. Local-to-global switch costs
	RT	Accuracy	RT
P#1	>.05	.003	.001
P#2	.49	.001	.011
P#3	<.05	.02	.002
P#4	>.05	>.05	.001
P#5	.04	.64	.65
P#6	.47	.11	.11
P#7	>.05	>.05	.95
P#8	.03	.004	.002
P#9	.85	.001	.30
P#10	.58	.016	.002
P#11	<.05	.001	.003
P#12	>.05	.001	>.05
P#13	.39	.001	.001
P#14	<.05	.001	.52
P#15	<.05	.001	.04

Note:

P = patient; TO = transitive verb, Object reading; TS = transitive verb, Subject reading

Appendix C.

Mean RT and accuracy (%) in the global-to-global non-switch, local-to-local non-switch, local-to-global switch, and global-to-local switch trials of the global local attention switch task separately for the congruent and incongruent condition.

Group	Measure	Global-to-global non-switch		Local-to-local non-switch		Local to global switch		Global to local switch	
		C	I	C	I	C	I	C	I
Broca (N=15)	RT (SD)	1773 (399)	1828 (346)	1325 (300)	1429 (331)	2150 (326)	2358 (348)	2535 (394)	2816 (348)
	Accuracy (SD)	98.0 (2.9)	93.9 (6.9)	91.4 (8.2)	90.3 (9.4)	87.6 (9.9)	76.4 (10.4)	46.8 (10.3)	44.1 (10.3)
Controls (N=15)	RT (SD)	1254 (277)	1468 (361)	1247 (392)	1312 (387)	2052 (301)	2116 (334)	1964 (376)	2305 (394)
	Accuracy (SD)	99.2 (2.1)	94.9 (6.2)	97.9 (6.5)	93.5 (5.7)	97.8 (4.5)	88.4 (11.8)	71.6 (11.7)	69.6 (11.7)

Note:

C = congruent trials; I = Incongruent trials

References

- Bates E, & Wulfeck B (1989). Comparative aphasiology: A cross-linguistic approach to language breakdown. *Aphasiology*, 3, 111–142.
- Bates E, Wulfeck B, & MacWhinney B (1991). Crosslinguistic research in aphasia: An overview. *Brain and Language*, 41, 123–148. [PubMed: 1933255]
- Crawford JR & Garthwaite PH (2002). Investigation of a single case in neuropsychology. Confidence limits on the abnormality of test scores and test score differences. *Neuropsychologia*, 40, 1196–1208. [PubMed: 11931923]
- Dapretto M, & Bookheimer SY (1999). Form and content: Dissociating syntax and semantics in sentence comprehension. *Neuron*, 24 (2), 427–432. [PubMed: 10571235]
- Devescovi A, Bates E, D'Amico S, Hernandez A, Marangolo P, Pizzamiglio L, & Razzano C (1997). Grammaticality judgments in patients with and without expressive agrammatism. *Aphasiology*, 11, 543–579.
- Erickson RJ, Goldinger SD, & LaPointe LL (1996). Auditory Vigilance in Aphasic Individuals: Detecting Nonlinguistic Stimuli with Full or Divided Attention. *Brain and Cognition*, 30 (2), 244–253. [PubMed: 8812002]
- Frazier L (1987). Processing syntactic structure: Evidences from Dutch. *Natural Languages and Linguistic Theory*, 5, 519–559.
- Frazier L, & Fodor JD (1978). The sausage machine: A new two-stage parsing model. *Cognition*, 6, 291–32.
- Goodglass H, & Kaplan E (1972). *The assessment of aphasia and related disorders*. Philadelphia, PA: Lea & Febiger.
- Hanne S, Burchert F, & Vasisht S (2015). On the nature of the subject–object asymmetry in wh-question comprehension in aphasia: evidence from eye tracking. *Aphasiology*, 30 (4), 435–462.
- Huck A, Thompson RL, Cruice M & Marshall J (2017). The influence of sense-contingent argument structure frequencies on ambiguity resolution in aphasia. *Neuropsychologia*, 100, 171–194. [PubMed: 28392303]
- Hula WD, & McNeil MR (2008). Models of attention and dual-task performance as explanatory constructs in aphasia. *Seminars in Speech and Language*, 29, 169–187. [PubMed: 18720315]
- Kaplan E, Goodglass H, & Weintraub S (1983). *Boston naming test*. Philadelphia, PA: Lea & Febiger.
- Kim M, & Thompson CK (2000). Patterns of comprehension and production of nouns and verbs in agrammatism: Implications for lexical organization. *Brain and Language*, 74, 1–25. [PubMed: 10924214]
- Korda RJ, & Douglas JM (1997). Attention deficits in stroke patients with aphasia. *Journal of Clinical and Experimental Neuropsychology*, 19, 525–542. [PubMed: 9342688]

- Marinis T (2003). Psycholinguistic techniques in second language acquisition research. *Second Language Research*, 19 (2), 144–161.
- Martin RC, & He T (2004). Semantic short-term memory and its role in sentence processing: A replication. *Brain and Language*, 89, 76–82. [PubMed: 15010239]
- McNeil MR, Odell K, & Tseng CH (1991). Toward the integration of resource allocation into a general theory of aphasia. *Clinical Aphasiology*, 20, 21–39.
- Meng M, & Bader M (2000). Mode of disambiguation and garden path strength: An investigation of subject-object ambiguities in German. *Language and Speech*, 43, 43–74.
- Murray LL (1999). Attention and aphasia: Theory, research and clinical implications. *Aphasiology*, 13, 91–112.
- Murray LL (2000). The effects of varying attentional demands on the word-retrieval skills of adults with aphasia, right-hemisphere brain damage or no brain-damage. *Brain and Language*, 72, 40–72. [PubMed: 10716874]
- Murray LL, Holland AL, & Beeson PM (1997). Auditory processing in individuals with mild aphasia: A study of resource allocation. *Journal of Speech, Language, and Hearing Research*, 40, 792–809.
- Murray LL, Keeton RJ, & Karcher L (2006). Treating attention in mild aphasia: Evaluation of attention process training-II. *Journal of Communication Disorders*, 39, 37–61. [PubMed: 16039661]
- Murray LL, Salis C, Martin N, & Dralle J (2018). The use of standardised short-term and working memory tests in aphasia research: A systematic review. *Neuropsychological Rehabilitation*, 28 (3), 309–351. [PubMed: 27143500]
- Navon D (1977). Forest Before Trees: The Precedence of Global Features in Visual Perception. *Cognitive Psychology*, 9, 353–383.
- Novick JM, Kan IP, Trueswell JC, & Thompson-Schill SL (2009). A case for conflict across multiple domains: Memory and language impairments follow damage to ventrolateral prefrontal cortex. *Cognitive Neuropsychology*, 26(6), 527–567. [PubMed: 20183014]
- Padeliadu S, & Sideridis G, (2000). Discriminant validation of the Test of Reading Performance (TORP) for Identifying Children at Risk of Reading Difficulties. *European Journal of Psychological Assessment*, 16 (2), 139–146.
- Papadopoulou D (2006). *Cross-linguistic variation in sentence processing*. Amsterdam: Kluwer.
- Papadopoulou D & Tsimpli IM (2005). Morphological Cues in Children's Processing of Ambiguous Sentences: A Study of Subject/Object Ambiguities in Greek In Brugos A, Clark-Cotton MR & Ha S (Eds.), *BUCLD 29: Proceedings of the 29th annual Boston University Conference on Language Development* (pp. 471–481). Boston: Cascadia Press.
- Paradis M, & Kehayia E (1987). *Exetasi diglossias gia afasikous* (Greek version) [Bilingual aphasia test]. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Patricacou A, Psallida E, Pring T, & Dipper L (2007). The Boston naming test in Greek: Normative data and the effects of age and education on naming. *Aphasiology*, 21, 1157–1170.
- Peristeri E, & Tsapkini K (2011). A comparison of the BAT and BDAE-SF batteries in determining the linguistic ability in Greek-speaking patients with Broca's aphasia. *Clinical Linguistics and Phonetics*, 25, 464–479. [PubMed: 21453043]
- Peristeri E, Tsimpli IM, & Tsapkini K (2013). The on-line processing of unaccusativity in Greek agrammatism. *Applied Psycholinguistics*, 34 (2), 233–276.
- Roussou A, & Tsimpli IM (2006). On Greek VSO again! *Journal of Linguistics*, 42, 317–354.
- Schneider W, Eschmann A, & Zuccolotto A (2002). *E-prime reference guide*. Pittsburgh, PA: Psychology Software Tools.
- Shapiro LP, Nagel N, & Levine B (1993). Preferences for a verb's complements and their use in sentence processing. *Journal of Memory and Language*, 32, 96–114.
- Sheppard SM, Love T, Midgley KJ, Holcomb PJ, Shapiro LP (2017). Electrophysiology of prosodic and lexical-semantic processing during sentence comprehension in aphasia. *Neuropsychologia*, 107, 9–24. [PubMed: 29061490]
- Shneiderman B (1998). *Designing the user interface Strategies for effective human-computer interaction*. (3rd ed). MA: Addison-Wesley Longman.

- Slansky BL, & McNeil MR (1997). Resource allocation in auditory processing of emphatically stressed stimuli in aphasia. *Aphasiology*, 11, 461–472.
- Tsapkini K, Vlahou C, & Potagas C (2010). Adaptation and validation of standardized aphasia tests in different languages: Lessons from the Boston diagnostic aphasia examination-short form in Greek. *Behavioural Neurology*, 22, 111–119. [PubMed: 20595743]
- Tyler LK, Marslen-Wilson WD, Randall B, Wright P, Devereux BJ, Zhuang J, Papoutsis M, & Stamatakis EA (2011). Left inferior frontal cortex and syntax: function, structure and behaviour in patients with left hemisphere damage. *Brain*, 134, 415–431. [PubMed: 21278407]
- Vuong LC, & Martin RC (2015). The role of LIFG-based executive control in sentence comprehension. *Cognitive Neuropsychology*, 32, 243–265. [PubMed: 26216232]
- Weinberg A (2001). A Minimalist Theory of Human Sentence Processing In Epstein SD & Hornstein N (Eds.), *Working Minimalist* (pp. 283–314). Cambridge, MA: MIT Press.
- Wulfeck B, Bates E, & Capasso R (1991). A crosslinguistic study of grammaticality judgments in Broca's aphasia. *Brain and Language*, 41, 311–336. [PubMed: 1933262]

Figure 1.

The set of shapes used in the global local switching task. The scale from global to local was 10:1. The circled shapes belong to the congruent trials of the task.

Figure 2.

PWA and Controls' mean RTs (in msecs) on grammaticality judgments in the online grammaticality judgment task.

Figure 3.
PWA and controls' mean accuracy (%) on grammaticality judgments in the online grammaticality judgment task.

Figure 4. PWA and controls' mean reading times (in msec) on the Determiner segment of TS and TO sentences of the online grammaticality judgment task.

Figure 5. PWA and controls' mean reading times (in msec) on the Noun segment of TS and TO sentences of the online grammaticality judgment task.

Figure 6.

RTs (in msecs) reflecting local-to-global and global-to-local switch costs in the congruent and incongruent trials of the global local task for each group (C=Congruent; I=Incongruent).

Figure 7.

Accuracy (%) reflecting local-to-global and global-to-local switch costs in the congruent and incongruent trials of the global local task for each group (C=Congruent; I=Incongruent).

Table 1.

Sentence types (grammatical and agrammatical) and examples in the online reading/grammaticality judgment task. Abbreviations: PAST.IMPERF.3SG = past imperfective tense, 3rd person singular; NOM.PL = Nominative case, plural number; PAST.PERF.3PL = past perfective tense, 3rd person plural; INTR = intransitive; TR = transitive; ACC.PL = Accusative case, plural number

Sentence type	Example
Optionally transitive verb; Subject reading (TS) – grammatical	Kaθos/ erave/ i/ skufi/ jlistrisan/ apo/ tin/ karekla while sew _{PAST.IMPERF.3SG.INTR} the _{NOM.PL} hat _{NOM.PL} slip _{PAST.PERF.3PL} from the chair “While s/he was sewing the hats slipped from the chair.”
Optionally transitive verb; Object reading (TO) – grammatical	Kaθos/ erave/ tus/ skufus/ jlistrisan/ apo/ tin/ karekla while sew _{PAST.IMPERF.3SG.TR} the _{ACC.PL} hat _{ACC.PL} slip _{PAST.PERF.3PL} from the chair “While s/he was sewing the hats (they) slipped from the chair.”
Intransitive verb; Subject reading (IS) - grammatical	Kaθos/ horeve/ i/ pinakes/ epesan/ kato/ sto/ jراسي while dance _{PAST.IMPERF.3SG.INTR} the _{NOM.PL} painting _{NOM.PL} fall _{PAST.PERF.3PL} down the grass “While s/he was dancing the paintings fell on the grass.”
Intransitive verb; Object reading (IO) – ungrammatical	*Kaθos/ horeve/ tus/ pinakes/ epesan/ kato/ sto/ jراسي while dance _{PAST.IMPERF.3SG.INTR} the _{ACC.PL} painting _{ACC.PL} fall _{PAST.PERF.3PL} down the grass “While s/he was dancing the paintings fell on the grass.”

Table 2.

Demographic and clinical information for the PWA that have participated in the study.

Patient	Age	Education (years)	Years (post stroke)	Syntactic comprehension (%) (BAT subtest)	Single word decoding (Reading Performance Test; Sideridis & Padelidou, 2000) (max. score: 53)	Lesion Site
P#1	58	12	2	52.86	48	L IFG
P#2	47	13	6	42.86	51	L IFG
P#3	66	14	10	62.86	52	L frontal, MFG
P#4	68	9	7	60.00	51	L STG, insular
P#5	73	9	10	71.43	52	L MTG
P#6	74	13	12	52.86	52	L IFG, MFG
P#7	42	12	2	68.57	48	L IFG
P#8	55	13	5	71.43	50	L IFG
P#9	65	12	5	70.00	50	L STG
P#10	66	14	12	52.86	52	L IFG, MFG
P#11	62	13	20	60.00	53	L MTG
P#12	61	12	3	62.86	50	L frontal, MFG
P#13	59	12	3	55.71	48	L IFG
P#14	62	12	3	55.71	49	L STG, insular
P#15	62	9	2	57.14	50	L IFG

Note:

P = person with aphasia; BAT = Bilingual aphasia test; L = left; IFG = inferior frontal gyrus; MFG = middle frontal gyrus; STG = superior temporal gyrus; MTG = middle temporal gyrus

Table 3.

Between- and within-group effects in the RTs of the grammaticality judgment task. Main effects of group, transitivity, syntactic function and their interactions in the Broca and control group.

Type of analysis	Group	Transitivity	Syntactic function	Transitivity*Syntactic function	Transitivity*Group	Transitivity*Syntactic function*Group
Between-group	$F(1, 28) = 16.953, p < .001, \eta^2 = .38$	$F(1, 28) = .128, p = .723, \eta^2 = .005$	$F(1, 28) = .683, p = .415, \eta^2 = .02$	$F(1, 28) = 442, p = .512, \eta^2 = .02$	$F(1, 28) = 31.950, p < .001, \eta^2 = .53$	$F(1, 28) = 8.385, p = .007, \eta^2 = .23$
Within-group						
Broca		$F(1, 14) = 26.549, p < .001, \eta^2 = .65$	$F(1, 14) = 2.098, p = .169, \eta^2 = .13$	$F(1, 14) = 18.950, p = .001, \eta^2 = .58$		
Controls		$F(1, 14) = 12.271, p = .004, \eta^2 = .47$	$F(1, 14) = .047, p = .831, \eta^2 = .01$	$F(1, 14) = 1.494, p = .242, \eta^2 = .09$		

Table 4.

Between- and within-group effects in the accuracy measure of the grammaticality judgment task. Main effects of group, transitivity, syntactic function and their interactions in the Broca and control group.

Type of analysis	Group	Transitivity	Syntactic function	Transitivity*Syntactic function	Transitivity*Group	Transitivity*Syntactic function*Group
Between-group	$F(1, 28) = 44.440, p < .001, \eta^2 = .61$	$F(1, 28) = 3.879, p < .05, \eta^2 = .12$	$F(1, 28) = 12.898, p = .001, \eta^2 = .32$	$F(1, 28) = 19.485, p < .001, \eta^2 = .41$	$F(1, 28) = 3.674, p = .06, \eta^2 = .10$	$F(1, 28) = 6.281, p = .018, \eta^2 = .18$
Within-group						
Broca		$F(1, 14) = 8.688, p = .011, \eta^2 = .38$	$F(1, 14) = 30.812, p < .001, \eta^2 = .69$	$F(1, 14) = 74.993, p < .001, \eta^2 = .84$		
Controls		$F(1, 14) = .000, p = .987, \eta^2 = .00$	$F(1, 14) = .100, p = .757, \eta^2 = .01$	$F(1, 14) = 1.083, p = .316, \eta^2 = .07$		

Table 5.

Between- and within-group effects in the RTs of the global local task.

Type of analysis	Group	Transitivity	Syntactic function	Transitivity*Syntactic function	Transitivity*Group	Transitivity*Syntactic function*Group
Between-group	$F(1, 28) = 44.440, p < .001, \eta^2 = .61$	$F(1, 28) = 3.879, p < .05, \eta^2 = .12$	$F(1, 28) = 12.898, p = .001, \eta^2 = .32$	$F(1, 28) = 19.485, p < .001, \eta^2 = .41$	$F(1, 28) = 3.674, p = .06, \eta^2 = .10$	$F(1, 28) = 6.281, p = .018, \eta^2 = .18$
Within-group						
Group						
PWAs		$F(1, 14) = 8.688, p = .011, \eta^2 = .38$	$F(1, 14) = 30.812, p < .001, \eta^2 = .69$	$F(1, 14) = 74.993, p < .001, \eta^2 = .84$		
Controls		$F(1, 14) = .000, p = .987, \eta^2 = .00$	$F(1, 14) = .100, p = .757, \eta^2 = .01$	$F(1, 14) = 1.083, p = .316, \eta^2 = .07$		

Table 6.

Between- and within-group effects in the accuracy measure of the global local task.

Type of analysis	Group	Switch level	Within-shape congruency	Switch level* Within-shape congruency	Switch level*Group	Within-shape congruency*Group	Switch level*Within-shape congruency*Group
Between-group	$F(1, 28) = 5.774, p = .023, \eta^2 = .17$	$F(1, 28) = 25.865, p < .001, \eta^2 = .48$	$F(1, 28) = 2.693, p = .112, \eta^2 = .09$	$F(1, 28) = 3.076, p = .09, \eta^2 = .10$	$F(1, 28) = .983, p = .330, \eta^2 = .03$	$F(1, 28) = .755, p = .392, \eta^2 = .02$	$F(1, 28) = .074, p = .778, \eta^2 = .003$

Table 7.

Results of the stepwise regression analysis on the TS trials of the grammaticality judgment task.

Group	TS sentences	Standardized coefficients- beta weights	% Variance explained	ANOVA
Broca (<i>N</i> = 15)	Dependent: Grammaticality judgment/RT			
	Predictor: Global-to-local switch cost/RT incongruent	$\beta = -.574, p = .025$	33.0%	$F = 6.402, p = .025^*$
	Dependent: Grammaticality judgment/Accuracy			
	Predictor: Global-to-local switch cost/ACC incongruent	$\beta = .479, p = .036$	42.4%	$F = 6.158, p = .004^{**}$
Controls (<i>N</i> = 15)	Dependent: Reading times on Determiner			
	Predictor: Local-to-global switch cost/ACC incongruent	$\beta = -.548, p = .034$	30.0%	$F = 5.577, p = .034^*$

Note:

* $p < 0.05$,

** $p < 0.005$

N = number, RT: reaction time, ACC: accuracy, TS: transitive verb; subject reading