Published in final edited form as:

J Neurolinguistics. 2016 August 1; 39: 38–48. doi:10.1016/j.jneuroling.2016.01.001.

Structural Prediction in Aphasia: Evidence from *either*

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Abstract

Young neurotypical adults engage in prediction during language comprehension (e.g., Altmann & Kamide, 1999; Staub & Clifton, 2006; Yoshida, Dickey & Sturt, 2013). The role of prediction in aphasic comprehension is less clear. Some evidence suggests that lexical prediction may be spared in aphasia (Dickey et al., 2014; Love & Webb, 1977; cf. Mack et al, 2013), and there is even indication that structural prediction may be spared in some people with aphasia (PWA; e.g. Hanne, Burchert, De Bleser, & Vashishth, 2015). The current self-paced reading experiment manipulated the presence of *either* to examine structural prediction among PWA and a set of similar-aged neurotypical control participants. Consistent with intact structural prediction for both groups of participants, when *either* preceded a disjunction, reading times were faster on the *or* and second disjunct (cf. Staub & Clifton, 2006). For neurotypical controls, this effect of the presence vs. absence of *either* shrank reliably as more experimental items were encountered, whereas for PWA there was a non-significant trend for it to grow as more experimental items were encountered. These findings indicate that PWA and older neurotypical individuals can use a lexical cue to predict the structural form of upcoming material during comprehension, but that on-line adaptation to patterns in the local context may be different for the two groups.

Keywords

sentence processing; language comprehension; prediction; syntax; reading; aphasia; aging

Although the contribution of prediction to language comprehension in neurotypical populations was once debated (e.g. Hess, Foss & Carroll, 1995), the past fifteen years have seen growing evidence that prediction is vital to comprehension (e.g. Federmeier, 2007; Kuperberg & Jaeger, 2015; Pickering & Garrod, 2013). Reading studies show that highly predictable words are fixated for shorter amounts of time and are more likely to be skipped than less predictable words (e.g. Rayner, Ashby, Pollatsek, & Reichle, 2004). Event Related Potential (ERP) studies show that comprehenders predict semantic features and the phonological form of upcoming words (e.g., DeLong, Urbach, & Kutas, 2005; Lazlo & Federmeier, 2009; Wolotko & Federmeier, 2007). Visual world studies have shown that

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comprehenders anticipate probable upcoming referents based on verb information, world knowledge, shared context, case marking, etc. (e.g. Altmann & Kamide, 1999; Kamide, Scheepers, & Altmann, 2003).

This literature indicates that comprehenders routinely engage in lexical or referential prediction. But there is also evidence that neurotypical comprehenders make predictions about the form of upcoming sentence structure. The fact that syntactic surprisal is a good predictor of reading times (Levy, 2008; Hale, 2003) suggests that comprehenders keep track of which syntactic forms are most likely to appear next in a sentence. Research shows that comprehenders predict upcoming structure in sentences with parasitic gaps, ellipsis, and sluicing (Lau, Stroud, Plesch, & Phillips, 2006; Phillips, 2006; Yoshida, Dickey, & Sturt, 2013). Some of the most direct evidence of structural prediction comes from work investigating the processing consequences of the word *either*. Upon encountering the word *either*, comprehenders know that a disjunction is likely to follow. Staub and Clifton (2006) looked for processing consequences of this by comparing reading times for sentences with disjunctions that were or were not preceded by the word *either*. When *either* was present, reading times on the second disjunct were faster than when it was not. Reading times were also faster when the structure of the second disjunct matched the structure of the first disjunct (see Warren & Dickey, 2011 for production evidence of this expectation for parallelism). These findings suggest that neurotypical comprehenders use the presence of *either* to predict an upcoming disjunction and use the structure of the first disjunct to predict the structure of the second.

There is considerably less evidence regarding the role of prediction in aphasic comprehension. It has long been known that strongly predictive sentence contexts can facilitate lexical retrieval and production in aphasia (Love & Webb, 1977). Recent work shows that people with aphasia (PWA) read words more quickly in contexts that make them highly predictable (Dickey, Warren, Hayes & Milburn, 2014). This suggests that in strongly supportive contexts at least, predictive mechanisms may be maintained. However, in a 2013 paper testing verb-argument prediction in aphasia, Mack, Ji, and Thompson's participants with aphasia showed only limited (if any) prediction. Mack et al. measured the eye movements of PWA as they simultaneously heard a sentence and looked at a set of images. In the restrictive condition, the sentence's verb limited the set of possible direct objects to only one of the images, but in the unrestrictive condition, the verb could accept any of the images as its direct object. For example, participants might have heard "Sam will open the jar" or "Sam will break the jar" while looking at images of a jar, a pencil, a plate, and a stick. All of these objects are breakable, but only one of them is openable (the target object). In a similar experiment, Altmann and Kamide (1999) found that neurotypical college students began to gaze at the target in the restrictive but not the unrestrictive condition starting at the end of the verb or during the determiner *the*, even before the target was encountered in the speech stream. In Mack et al.'s study however, neither the participants with aphasia nor their age-matched controls (who were older than Altmann and Kamide's participants) showed anticipatory looks to the target before hearing it named. Nonetheless, both groups did look more to the target towards the end of the trial in the restrictive condition.

These findings provide no evidence of prediction, but they do suggest that integration of the target may have been facilitated by the verb's restrictions. However, the window for observing prediction in this study was very short: there was less than 150 milliseconds between the offset of the verb and the onset of the target noun. To allow more time for predictive processing to develop and be observed, in a second study Mack and colleagues truncated the sentences before the last noun, so the target was never encountered in the speech stream. With this modification, the control participants showed increased looks to the target in the restrictive condition quickly after the verb, and the participants with aphasia showed the same pattern considerably downstream from the verb. These results suggest that verb-argument prediction is slowed or impaired by aphasia. These findings, in combination with those from Love and Webb (1977) and Dickey et al. (2014), could be interpreted to suggest that: (1) PWA only make strongly supported predictions, and (2) those predictions may be slowed.

The research discussed above focuses on lexical and referential prediction in aphasia, rather than purely structural prediction. Given that aphasia often involves syntactic impairment (e.g. Goodglass, 1993) and syntactic computation may be important for structural prediction, one might expect PWA not to engage in structural prediction, at least not PWA with marked syntactic impairments (Goodglass, 1976; Kean, 1977; Menn & Obler, 1990). However, Hanne, Burchert, De Bleser, and Vashishth (2015) suggest that PWA might make structural predictions under certain conditions. Hanne et al. tracked the eyes of PWA (N=8) with sentence-comprehension deficits while they listened to reversible subject-verb-object (SVO) and object-verb-subject (OVS) sentences in German, in a sentence-picture matching task. Hanne et al. manipulated case and number marking to disambiguate the sentences' structure. Gazes to an OVS or SVO picture during the unfolding of a sentence were assumed to indicate prediction of the structure congruent with that picture. According to this measure, the PWA's structural prediction was impaired compared to controls, but they did successfully predict upcoming structure when morphosyntactic cues were strong and unambiguous. Hanne, Burchert, and Vashishth (2015) used the same paradigm to test PWA's processing of subject- and object-extracted wh-questions, and found similar evidence of slowed but extant prediction based on strong morphosyntactic cues. These findings are consistent with the picture emerging from aphasic lexical prediction above, according to which PWA only make strongly supported predictions.

These results are interesting and suggestive, but not conclusive. One issue is whether an increase in gazes to one of two pictures during the sentence necessarily reflects syntactic prediction or could possibly reflect some other comprehension process. For example, it is possible that participants assigned a structure only to the words they had already heard (e.g., assigning an agent role to the first NP after hearing an NP-V sequence) and then gazed at whichever picture was consistent with that assignment, without making any predictive commitments regarding upcoming material. Detailed evidence presented by Hanne et al (2015) regarding gazes at the different event participants in the images make this interpretation of their results less likely. However, converging evidence from other tasks would be helpful in strengthening the case that PWA engage in structural prediction.

A second possible issue is that the presence of visual representations of two potential interpretations for the sentences in these experiments could have supported the participants' language processing and thus boosted their prediction. The pictures provided participants with the set of referents and relations that were relevant to understanding, and could have facilitated processing. Converging evidence, from tasks and structures that provide fewer external supports to comprehension and fewer external constraints on the structures and interpretations that participants may assign during comprehension, would again be useful in establishing whether PWA predict upcoming structure.

The primary aim of the current experiment was to test whether PWA engage in structural prediction, using a more direct method of investigating the nature and time-course of structural prediction. Assuming that PWA may need high levels of support and extra time to generate predictions, Staub and Clifton's (2006) *either* manipulation is a good candidate for testing for structural predictions in this population. This is because *either* is an extremely reliable/strong cue for an upcoming disjunction. However, *either* is compatible with multiple possible structures: for example, it may introduce a distributed NP, as in "Emily dressed either child (though I'm not sure which one)." Since *either* most commonly appears immediately to the left of the first phrase in the upcoming disjunction with *or*, *either* may also serve as a cue that the upcoming material following *or* is structurally parallel to the phrase following *either*. However, due to flexibility in its syntactic position (Larson, 1985), *either* may also appear elsewhere in the sentence, as in "Emily either dressed a child or a pet." *Either* is thus a highly reliable but probabilistic cue regarding upcoming structure. Furthermore, the prediction-triggering *either* is separated from the disjunction-cueing *or* by the noun phrase that eventually serves as the first disjunct, allowing even slowed predictions the time to develop. Additionally, because the task is simply reading, it provides few external supports for, and places few external constraints on, the domain of prediction.

If the current experiment provides evidence of predictive behavior among PWA, analyses will be undertaken to begin to address two additional questions: (1) what capacities underlie this kind of structural prediction among PWA? and (2) how flexible or adaptable is this prediction system? With respect to the first of these questions, there are multiple candidate capacities that might underlie structural prediction ability. A number of recent proposals have suggested that the language production system is used for prediction during language comprehension (e.g. Federmeier, 2007; Pickering & Garrod, 2013). If this is the case, then participants with better language production abilities may show larger structural prediction effects. Another possibility is that syntactic computation could be vital for structural prediction. This might be the case if, for example, representing the current syntactic structure was important for calculating and updating predictions for upcoming structure. If syntactic computation is important for structural prediction, then participants with more intact sentence comprehension abilities may show larger structural prediction effects.

With respect to the second question, namely *how flexible is this predictive system?*, there is evidence that neurotypical participants sometimes adapt to experiment-internal statistics, causing effects to either grow or disappear over the course of an experiment (e.g., Fine, Jaeger, Farmer & Qian, 2013; Fine & Jaeger, 2013). Frequently encountering low-probability structures results in facilitation for those structures as they become more

predictable or expected within the context of the experiment. This adaptation to local structural probabilities is likely grounded in implicit learning mechanisms, which also underlie other adaptive behavior such as structural priming (Bock & Griffin, 2000; Chang, Dell & Bock, 2006; Dell & Chang, 2014; Kim, Carbary & Tanenhaus, 2014). It is unclear whether this sort of adaptation occurs among aphasic participants, though some recent evidence consistent with preserved implicit learning in PWA would suggest that it might. Schuchard and Thompson (2014) show evidence of implicit learning in PWA on an artificial grammar learning task, and there is evidence that PWA may show surprisingly large structural priming effects, even for sentence types for which they show significant impairments (e.g., Hartsuiker & Kolk, 1998; Saffran & Martin, 1997).

Method

Participants

The experiment was run with two groups of participants. The first group was 18 native English speaking PWA who were compensated \$10 per hour. All were pre-morbidly right-handed, and had chronic aphasia subsequent to left-hemisphere stroke. Their ages ranged from 50 to 82 (mean: 67.8) and their years of education ranged from 12 to 21 (mean: 15.9). The onset of their aphasia had occurred between 17 and 151 months previously. They were referred from the Western Pennsylvania Participant Registry, a registry of community-dwelling stroke survivors in the greater Pittsburgh area. See Table 1 for their demographic data.

The second group of participants was a set of 24 neurotypical community-dwelling adults (20 female) who reported no history of speech, language, neuropsychological or hearing disorders. They were referred from the University of Pittsburgh's Clinical and Translational Science Institute's Research Participant Registry. These participants were in a similar age range as the PWA (range: 50-73, $M = 61$) and their ultimate level of educational attainment ranged from a high school diploma to masters degrees. They were paid \$10 per hour for their participation.

Materials

Twenty items, each with two conditions, were run in this experiment. The two conditions were identical, except that one included the word *either* between the verb and post-verbal NP and the other did not (see (1) below).

- 1a) Emily painted either | a lovely still life | or a beautiful portrait | of her mother. (Either)
- 1b) Emily painted | a lovely still life | or a beautiful portrait | of her mother. (No Either)

Presentations regions for self-paced reading are marked with a pipe (|). All experimental sentences contained disjoined NPs, with a determiner (*a* or *the*), a modifier (usually adjectival, but sometimes post-nominal), and a head noun. The critical region was the word *or* and the following three words, and was followed by a sentence-final segment. For most of the items, the head noun of the second disjunct fell in the critical region, but for a few it did not (e.g. Martin baked either | a large cake | or two pans of | chocolate muffins yesterday.) The full set of items appears in Appendix A.

Procedure

Participants with Aphasia—PWA were tested in two three-hour sessions, separated by one to two weeks. They were tested either in a laboratory at the University of Pittsburgh or in their homes, if they preferred. In the first testing session, participants completed hearing screening and standardized language and cognitive testing. The full set of language and cognitive scores are included in Table 2. Participants completed the Comprehensive Aphasia Test (CAT; Swinburn, Porter & Howard, 2004) to characterize their language impairments. The CAT provides a measure of overall aphasia severity (the Modality Mean T-Score), as well as sub-scores that measure comprehension and production performance at different levels of language (word, sentence, discourse). The CAT Written Sentence Comprehension T-Score provides a measure of participants' sentence-level reading comprehension impairments. Scores on this portion of the CAT are based on PWAs' ability to comprehend simple and syntactically complex sentences, including passives and sentences with center-embedded relative clauses. The raw scores for only the complex sentences from this set were recorded as CAT Written Complex Sentence Comprehension Raw Scores. As measures of participants' sentence-level listening comprehension impairments, we also gathered CAT Spoken Sentence Comprehension T-Scores and administered the Sentence Comprehension Test of the Northwestern Assessment of Verbs and Sentences (NAVS; Cho-Reyes & Thompson, 2012). This NAVS subtest measures performance on both canonical and non-canonical sentences (including object clefts and object relative clauses). These scores provide an additional measure of these PWAs' ability to compute syntactic structure and use it to constrain sentence comprehension. One final comprehension measure was the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA; Kay, Lesser, & Coltheart, 2009) subtest 48: written picture-word matching. To provide measures of these PWAs' language-production abilities at the word and sentence level, we also gathered CAT Object Naming, Action Naming, Word Fluency, and Sentence Repetition T-scores. CAT Spoken Picture Description T-scores provide a measure of higher-level language production, in the context of a connected speech task.

In addition to the CAT and the NAVS and PALPA subtests, participants completed two measures of conceptual-semantic processing: Pyramids and Palm Trees, three-picture version (PPT; Howard & Patterson, 1992), and the Kissing and Dancing Test (KDT; Bak & Hodges, 2003). These two picture-based tests measure participants' access to object-related (PPT) and action-related (KDT) conceptual-semantic knowledge.

Control participants—Control participants were tested in a single three-hour session in a laboratory at the University of Pittsburgh. They first completed a hearing screening as well as questionnaires regarding their demographic and medical history. They then completed two tests intended to screen for frank memory or non-language cognitive disorders: the Mini-Mental State Exam (MMSE; Folstein, Folstein & McHugh, 1975) and Raven's Colored Progressive Matrices (RCPM; Raven, 1965). Only participants who scored at least 27 out of 30 on the MMSE, and at least 30 out of 36 on the RCPM were included in our final sample of 24 participants.

After the testing described above, participants completed the current experiment as well as an unrelated self-paced reading experiment, a sentence-picture matching experiment, and a pair of visual-world studies. These tasks were completed in the same three-hour session for controls, and in a second session for PWA. The experimental task took between 25 and 45 minutes to complete. It was run on a laptop computer using E-Prime v.2 software (Schneider, Eschmann, & Zuccolotto, 2002). The experiment started with a set of self-paced reading instructions, which the experimenter also reviewed verbally. Then participants completed 3 practice items, some with yes/no comprehension questions. After the experimenter verified that they understood the task, participants began the main experiment.

Sentences were presented in non-cumulative moving-window self-paced reading (Just, Carpenter, & Wooley, 1982). Participants pressed the 1 or 0 number keys to advance through the sentence, one word or phrase at a time. The time between presses was recorded as reading time. Participants used their pre-morbidly non-dominant hand to press the 1 or 0 keys. To encourage participants to read for comprehension, approximately 20% of trials across the entire session were followed by a yes/no comprehension question, which could be answered by pressing 1 for yes and 0 for no. Eight of the 20 sentences from the current experiment were followed by such comprehension questions. An example is “Did Emily make a sculpture?” for the item “Emily painted (either) a lovely still life or a beautiful portrait of her mother.”

The 20 experimental items were divided into two presentation lists in a Latin Square design for counterbalancing purposes, with each list including one condition from each item and an equal number of each condition. The sentences from these lists were combined with 62 sentences from two other experiments for a total of 82 trials in the experimental session. One of the two other experiments that served as filler items investigated semantic anomalies, so each counter-balanced list contained 10 semantically normal and 20 semantically anomalous sentences (e.g. Corey’s hamster explored/lifted/entertained a nearby backpack and filled it with sawdust). Comprehension questions were never asked following anomalous sentences. The other filler experiment used 32 items of various syntactic forms adapted from Rayner et al. (2004), which implemented a 2x2 word frequency by predictability manipulation (e.g. Before warming the milk, the babysitter took the infant’s bottle/diaper out of the travel bag. and To prevent a mess, the caregiver checked the baby’s diaper/bottle before leaving.). This meant that each counter-balanced list included eight sentences with a highly predictable word that was high frequency, eight sentences with a highly predictable word that was low frequency, and 16 sentences in which a predictable word was replaced by a plausible high frequency (eight sentences) or low frequency (eight sentences) word. None of the sentences from these other two experiments had any disjunctions. The presentation order of the sentences was randomized for each participant, with no constraints on the randomization. Participants were encouraged to take breaks between trials whenever necessary.

Results

Inspection of reading-time data from the experimental task revealed that one participant with aphasia had extreme reading-time values. This participant’s mean RTs at each segment of

the *either-or* sentences were more than two standard deviations above the across-condition means for the remaining participants with aphasia. As a result, this participant's data were excluded from further analysis. The results for PWA reported below are from the remaining seventeen PWA in the sample.

Language and cognitive testing

The results of standardized language and conceptual-semantic processing testing for the PWA are presented in Table 2. All T-scores are on a scale that in principle goes from 0-100, but given that the mean is 50 and standard deviation is 10, the vast majority of scores fall between 30-80 (within 3 SDs of the mean). The PWA's overall language impairments were mild to moderate, yet variable, with Mean Modality T-Scores ranging from 41.8 to 66.1 (M: 55.3). Note that a mean modality T-score of 68.2 is the cutoff for the presence of aphasia on the CAT (Swinburn et al., 2004). They also varied in their written sentence comprehension impairments, with CAT Written Sentence Comprehension T-Scores ranging from 41 to 72 (M: 56.9). Their raw scores for CAT Written Complex Sentence Comprehension spanned the entire possible range, from 0 to 10 (M: 4.8). Scores on PALPA 48, Written Picture-Word Matching, were considerably less variable, but ranged from 19 to 40 (M: 36.6; possible range is 0-40). There was more variability in spoken comprehension measures. CAT Spoken Sentence Comprehension T-Scores ranged from 43 to 72 (M: 55.9). Scores on both NAVS subtests spanned the entire possible range from 0 to 15, with a mean of 8.27 for canonical sentences and a mean of 5.4 for non-canonical sentences.

These PWA varied in their degree of language-production impairments, as well. This was true at the word level, with Object Naming T-Scores ranging from 37 to 74 (M: 58.7) and Action-Naming T-scores ranging from 39 to 69 (M: 57.8). Their ability to retrieve words based on phonological or semantic cues also varied widely, with Word Fluency T-Scores ranging from 43 to 71 (M: 55.5). These PWA also varied in their sentence-repetition and connected-speech performance, with Sentence Repetition T-Scores ranging from 39 to 63 (M: 54.6) and Spoken Picture Description T-scores ranging from 34 to 75 (M: 56.7). Even though these measures involved different levels of language production (word, sentence, connected speech) and had different task demands (confrontation naming, picture description, repetition), they were all strongly correlated in this sample of PWA (all $r > .65$).

Finally, these PWA also exhibited a range of performance on the conceptual-semantic processing measures. Scores on KDT ranged from .60 to .96 (M=.84), and scores on PPT ranged from .65 to .98 (mean=.88).

Experimental task

Comprehension question accuracy rates indicated that participants were reading and comprehending the sentences reasonably well. Mean accuracy across all comprehension questions in the session was 73% (range 54%-96%) for the PWA and 93% (range 83%-100%) for the control participants. Accuracy rates for the subset of questions that were based on items in the current experiment were very similar.

We used the lme4 package (Bates, Maechler, & Bolker, 2013; ver. .999999-2) in R (R Development Core Team, 2013; ver 3.0.1) to build linear mixed effect models with participants and items as crossed random factors (Baayen, 2008). Random effects structure was maximal, following Barr, Levy, Scheepers, and Tily (2013). In the few cases in which maximal models did not converge, the random slopes accounting for the least variance were incrementally dropped until the model converged. Analyses were done over $\log_2$ transformed reading times to make the reading time distributions more normal. Condition (Either vs. No Either) was deviation coded, and all fixed factors were centered. As discussed in Baayen (2008), an absolute value of two or greater for the t statistic was taken to indicate significance at the $p < .05$ level.

Control Results

Figure 1 shows grand mean untransformed reading times for the control participants at the pre-critical, critical, and post-critical regions. On the pre-critical region, a model with a fixed factor of condition showed a reliable effect ($\beta = -.08$, $SE = .03$, $t = -2.88$), such that reading times were faster when the region was not preceded by *either*. On the critical region (the *or* and three following words), a model that included condition and the order of exposure to the experimental items (e.g. was this the first or twelfth experimental item the participant encountered?) as fixed factors indicated two reliable main effects and a reliable interaction¹. Control participants read the critical region faster when it was preceded by an *either* ($\beta = .13$, $SE = .03$, $t = 4.10$), sped up as they encountered more experimental items ($\beta = -.012$, $SE = .003$, $t = -4.02$), and showed a reduced effect of *either* as they encountered more experimental items ($\beta = -.011$, $SE = .005$, $t = -2.05$). To provide a visualization of the form of this interaction in the raw data, in Figure 2 we present condition means for controls for the first versus second half of the experimental trials they encountered. On the post-critical region, a model testing the fixed factor of condition showed it had no reliable effect.

The fact that there was a reverse *either* effect on the pre-critical region in this participant group raises the possibility that the *either* effect on the critical region may have resulted because *either* spurred a differential distribution of processing effort rather than prediction. However, the change in the *either* effect as more experimental sentences were encountered may itself be evidence of learning a new prediction, as will be argued in the Discussion below.

PWA Results

Figure 3 shows grand mean untransformed reading times for the PWA at the pre-critical, critical, and post-critical regions. Models run on the pre-critical region and post-critical regions indicated no reliable effects of condition ($ts < 1$).

At the critical region, a model that included condition and the order of encounter of the experimental items as fixed factors showed a reliable effect of condition ($\beta = .11$, $SE = .05$, $t = 2.11$), such that reading times were faster when *either* preceded the disjunction. This was

¹To see whether the presence of a head noun in the critical region affected this pattern, we ran this analysis and the parallel analysis with PWA separately on items with and without a head noun in the critical region. The presence versus absence of a head noun had no influence on the direction of effects in either case.

the only reliable effect, although there was a trend towards a positive interaction between condition and order of encounter ($\beta = .014$, $SE = .008$, $t = 1.82$), such that the effect of having an *either* was larger for later trials than for earlier trials. This trend is worth noting because it is in the opposite direction from the reliable interaction shown by the control participants. To provide a visualization of the form of this trend in the raw data, in Figure 4 we present condition means for PWA for the first versus second half of the experimental trials they encountered. These means show that as they encountered more experimental sentences, PWA had shorter reading times on the critical region in the conditions with *either* and slightly longer reading times on the critical region in conditions without an *either*. This is different from the pattern in the controls, who with more exposure, showed the greatest reductions in reading times for the No Either condition.

To begin to investigate what capacities underlie this structural prediction in PWA, we ran similar models to those above, each including fixed factors of condition and an individual difference measure. In a few cases individual difference measures were missing for two participants; in these cases models were run over data from the 15 participants for whom we had the measures. All models showed reliable main effects of condition, with faster reading times when an *either* was present. None of the following measures of overall language processing ability or syntactic ability, namely CAT Mean Modality T-score, Written Complex Sentence Comprehension raw score, Written Sentence Comprehension T-score, Spoken Sentence Comprehension T-score, or NAVS Non-Canonical Sentences, resulted in any main effects or interactions with condition. NAVS Canonical Sentences was a marginally reliable predictor of reading times at the critical region ($\beta = .03$, $SE = .015$, $t = 1.98$), but did not interact with condition. Additionally, none of Sentence Repetition T-Scores, Action Naming T-Scores, Word Fluency T-Scores, PALPA 48 Written Picture Word Matching, or Spoken Picture Description T-Score showed any main effects or interactions with condition. However, one measure of language production ability, Object Naming T-Score, interacted with condition ($\beta = .01$, $SE = .005$, $t = 2.00$), such that participants who were better at retrieving and producing names for pictured objects were more affected by the presence or absence of *either*. To provide a visualization of this effect in the raw data, Figure 5 shows mean reading times on the critical region given a median split based on object-naming ability.

Discussion and Conclusions

The findings of the current experiment provide novel evidence that PWA and older neurotypical adults can use a lexical cue to predict the structural form of upcoming material during comprehension. Just as it did for neurotypical young adults in Staub and Clifton's (2006) experiment, the presence of *either* spurred participants in the current study to expect an upcoming disjunction and facilitated its processing. There was evidence that the control participants learned across the experiment, and a hint that PWA may have as well, though in different ways as will be discussed below.

The findings of the current study provide important evidence for prediction during comprehension in PWA, using a different method and different structures from previous work. The current results extend the findings of both Hanne et al. papers from 2015 in

showing that PWA are sensitive to and base predictions on function words, not only on unambiguous case markers. The current findings are also consistent with Hanne, Burchert, De Bleser and Vashishth's (2015) suggestion that PWA are more likely to show prediction when the cue to prediction is more reliable and more salient. Although the current experiment did not manipulate cue strength, it used a cue, *either*, that is both highly salient, as it is easy to perceive, and a highly reliable cue to an upcoming disjunction. Additionally, the design of the current experiment allowed predictions time to develop, which may be important for detecting them in PWA and older neurotypical adults (e.g. Mack et al, 2013).

These factors, which contributed to the ease of prediction in the current experiment, may also have supported the finding of prediction in the older neurotypical controls. There is a growing body of evidence that in general, older adults rely less on predictive mechanisms during comprehension than younger adults, although this varies considerably across individuals (Wlotko, Lee, & Federmeier, 2010). The strong effects of *either* observed in the current sample of older adults suggests that when prediction is spurred by strong cues and has time to develop, older adults do engage in prediction.

An important question to consider is exactly what participants are predicting in this experiment. We have framed the current findings as specifically reflecting syntactic prediction. The reason for this is that the literature on *either* in neurotypical sentence processing makes a good case that these kinds of facilitation effects reflect syntactic prediction, as the syntactic form of the first disjunct influences the expected syntactic form of the second disjunct following *either* (Staub & Clifton, 2006). However, the current findings do not rule out the possibility that other kinds of prediction may have played a role in the effect. One possibility is that participants attend to the contingency between *either* and *or*, and simply make a lexical prediction for an upcoming *or*. We think this is unlikely because facilitation of a single two-letter word is unlikely to lead to 300-400 ms reading time differences across a four-word region. It also seems unlikely that any particular lexical items in the second disjunct are being predicted, as across items the words in the second disjunct are plausible but likely to have low cloze probabilities. Semantic prediction may be a more viable candidate; namely it is possible that upon reading *name verbed either...* participants began to predict *verb*-able objects, and during the course of the first disjunct they honed those predictions for the second disjunct to have similar semantic features to the first disjunct. Under this account, comprehenders would gain access to the same prediction-inducing information in the No Either condition only upon encountering the *or*, which may be too late for it to have an effect. The viability of this account depends on how related the semantics of the two disjuncts are in the current experiment, and perusal of the items suggests that this is variable. Future studies will be necessary to disentangle these mechanisms in PWA and older neurotypical adults.

An alternative mechanism that could have influenced the current findings is the fact that encountering an *either* provides the comprehender with a cue that the upcoming linguistic material has a special status or structure. Within Discourse Representation Theory (Kamp & Reyle, 1993), disjunctions require a complex structure in which each disjunction is separately represented in a subordinate discourse representation structure. Within a more psycholinguistically-oriented mental models account, the propositions formed by each

disjunct have special status in that they are only possibly true of the world. Either of these accounts could easily be extended to processing, and both predict that participants will have difficulty at the second disjunct in the absence of an *either*. To illustrate within the mental models account, upon reading “Emily painted a lovely still life”, a comprehender will likely enter that proposition into his or her mental model as fact, but then upon encountering “or a beautiful portrait” be forced to downgrade [painted (Emily, still-life)] from a fact to a possibility. The presence of *either* allows the comprehender to anticipate the uncertainty of what comes next, and thus avoid any cost of revising his or her mental model. Alternatively or additionally, the presence of *either* might serve to disambiguate a structural garden path, in that it signals that there will likely be an upcoming complex conjoined DP structure.

The change in prediction over the course of the experiment, and the fact that this change is different across the two groups of participants, raises interesting questions about what aspects of the prediction are changing. First we will consider the adaptation in the controls. Control participants showed a reduction in reading times on the critical region as the experiment progressed, but a reliable interaction indicated that this reduction was greater in the No Either condition than in the Either condition, resulting in a reduction of the *either* effect across the experiment. A likely explanation of this adaptation to the absence of *either* is based on the account above; perhaps the older neurotypical participants adjusted to the unusually high likelihood (compared to normal experience) of encountering disjunctions following the frame ‘name-verb-indefinite description’ within the experiment and began to anticipate disjunctions in the No Either condition as the experiment progressed. This pattern is reminiscent of the experiment-internal adaptation to low-frequency structures reported by Fine et al. (2013) and Fine & Jaeger (2013). As discussed above, this emerging prediction could have led participants to expect and prepare for the more complex discourse structure, syntactic structure, or mental models required by disjunctions.

Although the interaction between the presence or absence of *either* and the order of encounter was only a non-significant trend for the PWA, it did have a very different form from the significant interaction present in the controls. For PWA, reading times on the critical region became faster in the Either condition and slower in No Either condition as they encountered more experimental materials. This suggests that unlike the controls, PWA did not begin to anticipate disjunctions in the No Either condition. The pattern in the means could indicate that PWA’s predictions of disjunctions following an *either* improved in strength or precision with more experience, but given that the interaction is not reliable, this is only speculation.

The current experiment also represented a preliminary foray into determining what capacities underlie structural prediction in aphasia. The sole individual difference measure that interacted with the structural predictability effect in the current experiment was performance on an object-naming task. Participants with more intact object-naming ability showed a greater *either* effect. This is in principle compatible with recent models that assume the language production system plays a major role in prediction during comprehension (e.g. Federmeier, 2007; Pickering & Garrod, 2013). However, although it is clear why the ability to quickly and accurately access and produce a label for an object might be associated with the ability to predict a particular word, it is less clear why this

might be associated with predicting a disjunction. It seems unlikely that the critical capacity underlying this effect is lexical processing ability or fluency, because if it were, PALPA Written Picture-Word Matching scores should also have interacted with condition.

Additionally, the form of the interaction is somewhat surprising, because the larger effect of *either* in the better object-namers came about primarily because of slow reading times on the No Either condition. This raises the possibility that perhaps a separate factor that happens to be correlated with Object Naming T-scores may be behind the apparent effects of language-production ability on structural prediction. One seemingly likely possibility given the trend evident in Figure 5, namely that participants with higher Object Naming T-scores had slower reading times, is that slower or more careful reading may have driven this effect. As a preliminary test of this possibility, we re-ran some analyses including comprehension question performance as an individual difference measure. Comprehension question performance produced no reliable main effects and did not interact with the *either* effect nor the *either*/Object-Naming interaction. The interaction of the *either* effect with Object Naming thus remains puzzling, and the possibility remains that it could simply be a spurious effect.

It is worth considering why no measures of comprehension ability were associated with the size of the structural prediction effect in the current experiment. It is possible that Written Complex Sentence raw score, Written Sentence Comprehension T-score, Spoken Sentence Comprehension T-score, and NAVS non-canonical sentence score fail to predict the size of the *either* effect because they index the capacity to build and maintain complex and infrequent structures like passives, which simply may not be drawn upon in making structural predictions under the conditions in this experiment. After all, the disjunctive structures used in the current experiment are comparatively simple and have canonical word order. Consistent with this, NAVS canonical sentence score did marginally predict reading times in the current experiment; however, like the other measures, it did not interact with the *either* effect. Future work with a larger sample and more individual difference measures will be necessary to disentangle the contribution of particular capacities to structural prediction.

The current experiment provides evidence that PWA and older neurotypical adults can and do engage in structural prediction during language comprehension, and that older neurotypical adults have preserved implicit learning abilities that underlie the adaptation of these predictions across the course of an experiment.

Acknowledgments

This research was supported by NIH grant R01DC011520 to the first and second authors and by grant number UL1TR000005 to the Clinical and Translational Science Institute of the University of Pittsburgh. It is the result of work supported with resources and the use of facilities at the VA Pittsburgh Healthcare System. We thank Mandy Simons for helpful discussion and for her work helping develop the original set of stimuli from which the ones in the current study were adapted; Rebecca Hayes, Michelle Holcomb, Evelyn Milburn, and Teljer Liburd for help running participants; and Dominique Walker for help with language testing.

Appendix A

Items used in the experiment. Asterisks denote presentation regions.

- 1) Jay used (either)* a long rake*or a spade with*a rounded end to dig up the weeds.

- 2) Katy bought (either)* a new TV*or a fancy pair*of speakers with her paycheck.
- 3) Martin baked (either)* a large cake*or two pans of*chocolate muffins yesterday.
- 4) Emily painted (either)* a lovely still life*or a beautiful portrait*of her mother.
- 5) John built (either)* a toothpick bridge*or a model of*a neuron for school.
- 6) Louise wore (either)* a long pearl necklace*or a diamond pin*that was very old.
- 7) Paul picked out (either)* a toy truck*or a child-sized easel*for his present.
- 8) Alyssa wrote (either)* a silly book of poems*or a serious novel*about civil war.
- 9) Brian composed (either)* a classical aria*or a rock opera*in the style of The Who.
- 10) June donated (either)* a box of books*or a load of*clothes to the local shelter.
- 11) David found (either)* a serious error*or a few sloppy*calculations in the paper.
- 12) Elizabeth broke (either)* a valuable vase*or a mirror that*was an antique.
- 13) Frank invented (either)* a better souffle*or a new procedure*for making fondant.
- 14) Gail owns (either)* a fancy Mazda*or some kind of*German sports car.
- 15) Henry planted (either)* a cherry tree*or a Japanese maple*in his front yard.
- 16) Finn invited (either)* a Palestinian activist*or an Israeli politician*to the event.
- 17) Joshua ordered (either)* a large pizza*or a calzone with*broccoli and spinach.
- 18) Karen deciphered (either)* a Mayan carving*or an Egyptian hieroglyphic*engraving.
- 19) Laura designed (either)* a new website*or an interesting layout*for the magazine.
- 20) The agency funded (either)* a sociology study*or a project to*improve math skills.

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Highlights

- Structural prediction among people with aphasia (PWA) was examined
- PWAs' reading of *or* and an NP disjunct was speeded by *either*, showing prediction
- Effect of *either* decreased across the experiment for older controls
- Findings provide novel evidence of lexically-cued structural prediction in aphasia
- Controls and PWA may adapt on-line to likelihood of structures in the local context

Figure 1. Grand means by condition for raw reading times in milliseconds at the pre-critical, critical, and post-critical regions for control participants. Error bars are standard errors of the mean.

Figure 2. Grand means by condition for raw reading times in milliseconds on the critical region for the first versus second half of experimental items encountered for control participants. Error bars are standard errors of the mean.

Figure 3.

Grand means by condition for raw reading times in milliseconds at the pre-critical, critical, and post-critical regions for PWA. Error bars are standard errors of the mean.

Figure 4.

Grand means by condition for raw reading times in milliseconds on the critical region for the first versus second half of experimental items encountered for PWA. Error bars are standard errors of the mean.

Figure 5. Grand means by condition for raw reading times in milliseconds on the critical region for PWA, given a median split by object-naming ability. Error bars are standard errors of the mean.

Table 1

Demographic information, participants with aphasia (PWA)

Participant	Sex	Age at Testing	Months post-onset	Occupation	Education
201	F	71	39	Manufacturing worker	High school
202	F	70	63	Manager - grocery store	High school
203	M	62	68	Electronic engineer/computer programmer	BS in Computer Science
204	F	68	69	Medical assistant	Associate's degree
205	F	54	71	Teacher	Masters of Education
206	F	50	94	Case worker	Bachelor's degree
207	F	64	30	Housewife	High School GED
209	M	65	70	Realtor	20 years
211	M	74	19	Institutional researcher	PhD
212	M	78	120	Professor	PhD in English
213	M	62	58	Grocery warehouse worker	Associate's degree in criminology
214	M	80	136	Retired	PhD
216	M	67	52	Engineer	BS
217	M	67	151	Sheet metal worker	14 years
219	M	82	23	Metallurgical engineer	College plus some graduate work
220	M	67	35	Engineer	High school
221	M	71	17	Private contractor	Bachelor's degree, plus some graduate work
<i>Mean</i>		67.8	65.6		

Table 2

Language and conceptual-semantic testing data, participants with aphasia (PWA)

Participant	CAT Mean Modality T score	CAT Written Sentence Comp. T score	CAT Written Sentence Comp. raw score	CAT Spoken Sentence Comp. T score	Object Naming T score	Action Naming T score	Word Fluency	Spoken Picture Desc. T Score	Sentence Repet.	PALPA 48: Written Word- Pict. Match	NAVS Canon- ical Sent.	NAVS Non- Canon. Sent.	KDT	PPT
201	45.8	51	5	49	49	39	43	34	48	40	0	0	0.92	.92
202	56.9	57	5	58	61	56	59	52	56	N/A	N/A	N/A	0.88	.96
203	56.6	51	3	50	64	63	60	73	60	39	12	1	0.96	.83
204	59.6	64	8	61	62	69	61	70	63	40	15	7	0.92	.96
205	63.6	67	8	65	64	59	61	68	63	39	15	13	0.96	.87
206	50.1	64	8	49	51	54	48	36	48	39	0	0	0.73	.88
207	66.1	72	10	72	66	69	71	75	63	40	15	15	0.92	.98
209	62.0	64	6	61	64	69	60	60	63	40	13	14	0.87	.85
211	45.6	41	0	57	47	52	45	39	45	29	2	0	0.6	.85
212	62.1	61	5	58	64	56	60	75	53	40	11	5	0.96	.98
213	44.4	44	0	50	50	56	45	46	48	19	7	1	0.63	.79
214	62.4	60	5	61	70	63	68	75	53	40	11	5	0.83	.98
216	47.9	46	0	52	54	59	47	39	53	N/A	N/A	N/A	0.85	.87
217	53.1	51	0	57	59	63	56	50	48	38	3	3	0.79	.92
219	60.1	68	9	58	62	54	51	58	63	39	12	15	0.88	.94
220	41.8	51	6	43	37	39	43	N/A	39	32	0	0	0.75	.65
221	61.7	55	4	49	74	63	66	N/A	63	35	8	2	0.85	.81
Mean	55.3	56.9	4.8	55.9	58.7	57.8	55.5	56.7	54.7	36.6	8.27	5.4	0.84	.88