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Effects of verb meaning on lexical integration in agrammatic aphasia: Evidence from eyetracking

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ABSTRACT

Relatively little is known about the time course of access to the lexical representations of verbs in agrammatic aphasia and its effects on the prediction and integration of the verb's arguments. The present study used visual-world eyetracking to test whether verb meaning can be used by agrammatic aphasic individuals to predict and facilitate the integration of a subsequent noun argument. Nine adults with agrammatic aphasia and ten age-matched controls participated in the study. In Experiment 1, participants viewed arrays of four objects (e.g., jar, plate, stick, pencil) while listening to sentences containing either a *restrictive* verb that was semantically compatible only with the target object or an *unrestrictive* verb compatible with all four objects (e.g., *Susan will open/break the jar*). For both participant groups, the restrictive condition elicited more fixations to the target object immediately after the verb. Experiment 2 differed from Experiment 1 in that the auditory sentences presented were incomplete (e.g., *Susan will open/break the*…). For controls, restrictive verbs elicited more target fixations immediately after the verb; however, the effects of verb type were noted downstream from the verb for the aphasic listeners. The results suggest that individuals with agrammatic aphasia have preserved ability to use verb information to facilitate integration of overt arguments, but prediction of upcoming arguments is impaired. Impaired lexical-semantic prediction processes may be caused by damage to the left inferior frontal gyrus, which has been argued to support higher-level lexical processes.

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1. Introduction

Agrammatic (Broca's) aphasia involves not only deficits in morphosyntactic processing, but also impaired lexical processing. At the level of single-word processing, priming effects have sometimes failed to emerge, or have emerged at a slowed time course, in adults with agrammatic aphasia relative to unimpaired adults (Milberg, Blumstein, & Dworetzky, 1988; Prather, Zurif, Love, & Brownell, 1997; Prather, Zurif, Stern, & Rosen, 1992; Utman, Blumstein, & Sullivan, 2001). Eye-tracking studies have also revealed deficits in single-word lexical processing, including generally slowed lexical access (Choy, 2011) and abnormal lexical competitor effects (Mirman, Yee, Blumstein, & Magnuson, 2011; Yee, Blumstein, & Sedivy, 2008). These findings have motivated several accounts of single-word processing deficits in agrammatic aphasia, including decreased levels of lexical activation (Janse, 2006; Milberg et al., 1988; Utman et al., 2001; Yee et al., 2008), slowed lexical activation (Prather et al., 1992, 1997), and impaired ability to select between competing lexical representations (Mirman et al., 2011).

Several studies have also investigated the role that lexical processing deficits play in sentence comprehension in agrammatic aphasia. Cross-modal priming studies of filler-gap structures, which involve displacement of a sentence constituent from its canonical position (e.g., *Who$_i$ did the boy kiss GAP$_i$ at school?*), found that participants with agrammatic aphasia showed delayed or absent reactivation of the filler at the gap site when sentences were presented at a normal speech rate (Burkhardt, Piñango, & Wong, 2003; Love, Swinney, Walenski, & Zurif, 2008; Swinney, Zurif, Prather, & Love, 1996; Zurif, Swinney, Prather, Solomon, & Bushel, 1993). On this basis, Love et al. (2008) argued that slowed lexical activation may underlie impaired comprehension of noncanonical sentences. Eyetracking studies have also lent support to the hypothesis that lexical processing deficits contribute to sentence comprehension impairments. Visual-world eyetracking experiments on gap-filling in agrammatic aphasia have reported intact and timely online processing, as reflected by increased looks to a picture of the filler at the gap site (Choy, 2011; Dickey, Choy, & Thompson, 2007; Dickey & Thompson, 2009). However, the participants in these studies also exhibited impaired comprehension of noncanonical sentences. A similar contrast between intact online processing and impaired offline processing was observed in an experiment investigating pronoun resolution (Thompson & Choy, 2009). One interpretation of these findings, proposed by Thompson and Choy (2009; cf. Choy, 2011) is that in agrammatic aphasia the syntactic processes supporting gap-filling and pronoun resolution are intact, resulting in timely reactivation of the antecedent, but lexical integration, i.e. the incorporation of the critical word into the unfolding representation of the sentence, is impaired. Further support for the lexical integration hypothesis comes from studies of lexical ambiguity resolution, which have revealed a deficit in timely selection of the appropriate meaning of ambiguous words in agrammatic aphasia (Hagoort, 1993; Swaab, Brown, & Hagoort, 1998).

Timely access to the lexical representations of verbs, including subcategorization (syntactic combinatory potential), argument structure (semantic combinatory potential), and selectional restrictions (the semantic restrictions that verbs place on their arguments), is essential to lexical and grammatical integration processes in unimpaired adults (e.g., Altmann & Kamide, 1999, 2007; Boland, 2005; Shapiro, Zurif, & Grimshaw, 1987, 1989; Trueswell, Tanenhaus, & Kello, 1993). It is well-documented that people with agrammatic aphasia often exhibit deficits in verb production, with greater impairment for verbs with complex lexical representations (e.g., Kim & Thompson, 2000; Thompson, 2003; Thompson & Lee, 2009; Zingeser & Berndt, 1990). However, relatively few studies have investigated verb access during on-line sentence comprehension in agrammatic aphasia. Studies investigating access to subcategorization and argument structure information have yielded mixed results. Cross-modal lexical decision studies (Shapiro & Levine, 1990; Shapiro, Gordon, Hack, & Killackey, 1993) provided evidence that people with agrammatic aphasia, like unimpaired controls, activate argument structure information immediately upon hearing the verb. However, a recent ERP study (Kielar, Meltzer-Asscher, & Thompson, 2012) reported abnormal electrophysiological responses to argument structure violations in individuals with agrammatic aphasia relative to control participants. Myers and Blumstein (2005) investigated the effects of a verb's selectional restrictions on the processing of a subsequent argument noun phrase in an auditory lexical decision paradigm using both single-word and sentence contexts. Participants made a lexical decision to a noun (e.g., *letter*) preceded by a (a) semantically associated and compatible verb (i.e., compatible with the verb's selectional restrictions) (e.g., *mail*), (b) semantically compatible but not associated verb (e.g., *find*), and (c) semantically incompatible verb (e.g., *persuade*). In the single-word experiment, the verb/noun pairs were presented in isolation, whereas in the sentence experiment, the pairs were embedded within grammatical (e.g., *The men mail/find/persuade the letter*) or ungrammatical environments (e.g., **The men mail/find/persuade over letter*). Across all contexts, unimpaired adults showed priming effects for nouns following semantically compatible/associated and semantically compatible/unassociated verbs relative to semantically incompatible verbs. Adults with agrammatic aphasia showed priming for semantically compatible/associated verbs across all contexts, but priming for semantically compatible/unassociated verbs emerged only in single-word and grammatical sentence contexts. Myers and Blumstein (2005) argue that these results suggest that access to selectional restriction information is vulnerable to disruption in agrammatic aphasia. Thus, some evidence suggests that impaired access to verb representations may affect lexical and grammatical integration processes in agrammatic aphasia.

The present study investigates effects of access to verb meaning on subsequent lexical integration processes in aphasic and age-matched control listeners using a visual-world eyetracking paradigm, following Altmann and Kamide (1999). In that study, young adult participants made anticipatory fixations to a target object (e.g., a cake, within a scene also containing several non-edible objects) while processing a *restrictive* verb that was semantically compatible only with the cake (e.g., *The boy will eat the cake*) but not while processing an *unrestrictive* verb compatible with all objects in the scene (e.g., *The boy will move the cake*). In addition, the effects of verb type persisted into the noun itself, reflecting facilitated lexical integration in the restrictive condition. These findings indicate that healthy listeners use verb meaning to predict upcoming target nouns. Several other studies with young adult participants have replicated and extended these findings (e.g., Altmann & Kamide, 2007; Boland, 2005; Kamide, Scheepers, & Altmann, 2003), and such effects have also been found in 10- and 11-year old children (Nation, Marshall, & Altmann, 2003).

No previous research has investigated the eye movement patterns of healthy older adults or participants with aphasia using this paradigm. Two experiments were conducted. In Experiment 1, full sentences with restrictive and unrestrictive verbs (e.g., *Tomorrow Susan will open/break the window*) were presented in order to test the effects of verb meaning on the processing of a subsequent overt argument. As in previous experiments (e.g., Altmann & Kamide, 1999), this experiment investigates both prediction (anticipatory eye movements before the critical noun) and lexical integration (eye movements during the critical noun). In Experiment 2, the noun was omitted (e.g., *Tomorrow Susan will open/break the*…). This allowed us to investigate effects of verb meaning on the prediction of a subsequent argument, while providing a more generous time-window for prediction that is absent when the critical noun phrase immediately follows the verb. An additional motivation for including Experiment 2 is that prediction and integration of non-overt arguments are essential for comprehension of noncanonical sentences and have been argued to be impaired in agrammatic aphasia (e.g., Choy, 2011; Dickey, Choy, & Thompson, 2007; Dickey & Thompson, 2009).

Although we anticipate that older adults will perform similarly to younger listeners, event-related potential research suggests that predictive processes in sentence comprehension may be less robust in older compared to young adults (e.g., Delong, Groppe, Urbach, & Kutas, 2012; Federmeier & Kutas, 2005; Wlotko, Federmeier, & Kutas, 2012). If this is the case, verb-driven anticipatory eye movements (i.e., effects of verb type that emerge before noun onset) may be absent in the age-matched control listeners in Experiment 1. However, we expect to see effects of verb type on lexical integration following the verb (i.e., during processing of the noun in Experiment 1), as well as on prediction of a subsequent argument in Experiment 2, in which time constraints on prediction are eliminated. If the ability to access and use verb meaning to generate predictions and facilitate lexical integration is intact in agrammatic aphasia, then effects of verb type should emerge on the same time course as that observed for age-matched controls. However, if agrammatic aphasia involves impaired access to verb meaning or subsequent prediction and integration processes, then effects of verb meaning should be reduced, delayed, or absent relative to the control listeners.

2. Experiment 1

2.1. Participants

Nine adults with agrammatic aphasia (five male) and ten unimpaired adults (three male) participated in the study. All aphasic participants had sustained a left-hemisphere CVA at least two years previously. Detailed lesion information was available for six aphasic participants (all but A5, A6, and A9); see Table 1. For all six of these participants, the lesion included left inferior frontal cortex. The participant groups were matched for age (control *M* (SD) = 56.0 (10.8); aphasic *M* (SD) = 56.7 (14.5); $z = 0.04$, $p = 0.97$; Mann–Whitney *U* Test) and years of education (control *M* (SD) = 15.9 (1.5); aphasic *M* (SD) = 16.8 (2.3); $z = -1.1$; $p = .27$; Mann–Whitney *U* Test). All participants were (premorbidly) right-handed, with normal or corrected-to-normal vision and hearing and no history of psychiatric or developmental speech/language disorders. The study was approved by the Institutional Review Board at Northwestern University and all participants gave informed consent.

Table 1 presents demographic and language testing data for the participants with aphasia. Language testing included administration of the *Western Aphasia Battery-Revised* (WAB; Kertesz, 2006), the *Northwestern Assessment of Verbs and Sentences* (NAVS; Thompson, 2011), a narrative speech sample (Cinderella story), and for six participants, the Confrontation Naming subtest of the Northwestern Naming Battery (NNB; Thompson & Weintraub, experimental version). All participants presented with mild-to-moderate aphasia, as measured by Aphasia Quotient (AQ) derived from the WAB (*M* = 79.1; range = 67.5–87.8). The WAB Auditory Comprehension subtest revealed relatively intact word and sentence comprehension for all participants (*M* = 9.1; range = 7.45–10). All participants exhibited reduced fluency in a picture description task (WAB Fluency subtest; scores ≤6), and all except A5 also produced non-fluent speech in the narrative speech sample (mean words per minute (WPM) = 51.1; range = 22.6–120.0 control M from Thompson et al. (2012) = 132). The NAVS revealed grammatical deficits in both production and comprehension, with participants performing more accurately on canonical than noncanonical sentences (Sentence Production Priming Test, canonical *M* = 86%; noncanonical *M* = 47%, $p < 0.01$; paired *t*-test; Sentence Comprehension Test, canonical *M* = 84%; noncanonical *M* = 66%, $p < 0.05$, paired *t*-test). All participants except A9 also exhibited impaired verb argument structure production, as reflected by impaired production of sentences with three arguments as compared to sentences with one and two arguments on the Argument Structure Production Test (ASPT) of the NAVS. All participants also exhibited grammatical impairments in narrative speech, producing no more than 80% grammatically correct sentences (*M* = 53%, range = 0–80%; control *M* from Thompson et al. (2012): 93%). In addition, most participants (all but A5 and A8) exhibited reduced morphosyntactic complexity in narrative speech, as measured by the ratio of complex sentences (including sentences with embedding and/or noncanonical word order) to simple sentences (*M* = 0.45, range = 0–1.14, control *M* from 15 unimpaired older adults: 0.84). Finally, all participants who completed the NNB exhibited greater naming impairments for verbs than for nouns (*M* N:V ratio in naming accuracy: 1.26, range = 1.07–1.50). Thus, all participants in the present study exhibited several markers of agrammatic language production.

2.2. Stimuli

We constructed 40 sentence pairs with corresponding visual arrays, each of which contained four gray-scale clip-art pictures. The sentences were of the form *Tomorrow NP1 will V the NP2*, where NP1 was a proper name and NP2 was the target noun phrase. One member of each sentence pair contained a *restrictive verb*, which had the potential to combine semantically with only one of the objects in the array. For example, the verb *open* is restrictive given an array containing a jar, a plate, a pencil and a stick, because only jars can normally be opened. The other member of each sentence pair contained an *unrestrictive verb*, which could combine with any of the objects in the array. The verb *break* is unrestrictive in the context of this array, as jars, plates, pencils, and sticks can all be broken. The sentences were otherwise identical across conditions.

We controlled several properties of the verb pairs across conditions (see Table 2 for a summary). First, we controlled for verb-argument structure. All of the verbs included in the study were transitive;

Table 1
Demographic data, language testing data, and etiology for the aphasic participants

	Age	Gender	Education	Years post-stroke	WAB			NAVS							Narrative speech				NNB
								SPPT		SCT		ASPT							
					AQ	AC	F	C	NC	C	NC	1-arg	2-arg	3-arg	WPM	MLU	%GS	S complex	N:V
A1	50	F	16	5.0	74.3	7.45	5	100%	27%	87%	53%	100%	100%	67%	26.6	6.2	74%	0.15	1.50
	Etiology: LH CVA affecting pars opercularis, premotor cortex, inferior precentral and postcentral gyri, extending to the anterior temporal lobe																		
A2	34	F	18	4.0	77.6	7.8	5	53%	20%	53%	67%	100%	100%	67%	33.1	6.1	79%	0.27	1.07
	Etiology: LH CVA affecting the inferior frontal and prefrontal gyri, extending to the anterior middle and superior temporal gyri																		
A3	51	F	12	7.0	67.5	8.45	4	93%	73%	80%	33%	100%	100%	67%	22.6	3.0	0%	0	1.18
	Etiology: LH CVA affecting the inferior frontal gyrus, middle superior frontal gyrus, premotor cortex, extending to the anterior superior temporal sulcus																		
A4	75	F	15	2.5	83	9.8	5	93%	67%	87%	73%	100%	100%	83%	55.7	5.9	55%	0.38	N/A
	Etiology: LH CVA affecting the insula and frontal white matter																		
A5	74	M	20	4.5	82.8	10	5	100%	47%	93%	53%	100%	100%	92%	120.0	9.9	79%	1.14	1.33
	Etiology: LH CVA affecting frontal cortex (no further details available)																		
A6	46	M	18	2.5	85.4	9.7	6	87%	60%	87%	67%	100%	93%	92%	50.2	8.2	71%	0.6	N/A
	Etiology: LH CVA (no further details available)																		
A7	55	M	18	10.5	87.8	9.6	6	100%	87%	100%	100%	100%	100%	92%	40.1	7.7	80%	0.33	N/A
	Etiology: LH CVA affecting pars opercularis, superior frontal cortex, including primary motor and premotor cortex																		
A8	51	M	16	7.0	69.7	9.25	4	80%	13%	67%	67%	100%	100%	83%	42.4	5.4	9%	0.83	1.40
	Etiology: LH CVA affecting pars opercularis, premotor cortex, posterior superior and middle temporal gyri, supramarginal gyrus, angular gyrus, superior parietal cortex, and extrastriate cortex																		
A9	74	M	18	14.0	84.1	9.45	6	67%	33%	100%	80%	100%	100%	100%	68.9	7.5	29%	0.35	1.07
	Etiology: LH CVA, affecting frontal, temporal, and parietal cortex (no further details available)																		
M	**56.7**		**16.8**	**6.3**	**79.1**	**9.1**	**5.1**	**86%**	**47%**	**84%**	**66%**	**100%**	**99.3%**	**82.4%**	**51.1**	**6.6**	**52.7%**	**0.45**	**1.26**
SD	*14.5*		*2.3*	*3.8*	*7.2*	*0.9*	*0.8*	*17%*	*26%*	*15%*	*19%*	*0%*	**2.2%**	12.8%	*29.6*	*2.0*	*31.8*	*0.35*	*0.18*

Note. WAB = Western Aphasia Battery; AQ = Aphasia Quotient; F = Fluency; AC = Auditory Comprehension; NAVS = Northwestern Assessment of Verbs and Sentences; SPPT = Sentence Production Priming Test; SCT = Sentence Comprehension Test; ASPT = Argument Structure Production Test; C = canonical sentences; NC = noncanonical sentences; 1-arg = one argument sentences; 2-arg = two argument sentences; 3-arg = three argument sentences; WPM = words per minute; MLU = mean length of utterance; %GS = % grammatical sentences; S complex = ratio of complex to simple sentences; NNB = Northwestern Naming Battery; N:V = ratio of correctly named nouns to correctly named verbs; LH = left hemisphere; CVA = cerebrovascular accident.

Table 2
Properties of verb pairs in Experiments 1 and 2.

Measure	Restrictive V Mean (SD)	Unrestrictive V Mean (SD)	Two-tailed t-test p-value
Argument structure			
Obligatorily transitive	$N = 13$	$N = 15$	*n/a*
Optionally transitive	$N = 14$	$N = 11$	
Alternating transitivity	$N = 11$	$N = 10$	
Other/multiple categories	$N = 2$	$N = 4$	
Raw frequency (*log*)	4.47 (0.53)	4.47 (.57)	$p = 0.99$
Contextual frequency (*log*)	3.46 (0.58)	3.52 (0.58)	$p = 0.64$
Length (*# syllables)*	1.28 (0.45)	1.20 (0.41)	$p = 0.44$
Length (*# phonemes*)	3.93 (1.05)	3.93 (1.02)	$p = 1$
Familiarity	561.3 (31.6)	556.6 (42.1)	$p = 0.66$
Imageability	468 (69.1)	461.9 (61.7)	$p = 0.74$

however, some permitted additional argument structure configurations. Some verbs, e.g. *locate*, were obligatorily transitive, requiring an agent and an overtly expressed theme: *Sam located the map* is a grammatical sentence, *Sam located* is not. Other verbs, such as *eat*, were optionally transitive, allowing the omission of the theme argument (e.g., *Sam ate the spaghetti* vs. *Sam ate*). Other verbs, such as *open*, exhibited alternating transitivity, allowing transitive agent-verb-theme structures (e.g., *Sam opened the door*) and intransitive theme-verb structures (e.g., *The door opened*). Two neurolinguists independently classified the 80 verbs included in the experiment into these three major categories, with initial 84% agreement. All cases of disagreement were discussed and resolved. As Table 2 shows, verbs in the restrictive and unrestrictive conditions were distributed approximately equally across the three major argument structure categories.[2]

In addition, we controlled for log frequency of occurrence, using data from the Corpus of Contemporary American English (COCA), a large (425+ million word) corpus of American English produced across a wide range of spoken and written genres over the last 20 years (Davies, 2008). To control for the fact that many of the verbs may appear in multiple syntactic frames, we also controlled for contextual frequency, i.e. the frequency of usage of verbs in the syntactic frame used in the experiment (verb, determiner, noun), also using the COCA. In addition, we controlled for the length (number of syllables and phonemes) of the two verbs across conditions. Finally, we used the MRC Psycholinguistic Database (Coltheart, 1981) to control familiarity and imageability for all verbs for which these measures were available ($n = 27$ in the restrictive condition, $n = 24$ in the unrestrictive condition). These measures are summarized in Table 2.

We also computed the lexical co-occurrence probability between the verb and target noun across conditions by dividing the co-occurrence frequency of the target noun and verb in the relevant syntactic frame (verb, determiner, noun) by the overall frequency of the verb in that frame (data from the COCA). There was no significant difference in verb–noun co-occurrence probability between the restrictive and unrestrictive conditions (restrictive M (SD) = 0.011 (0.015); unrestrictive M (SD) = 0.008 (0.014); $p = 0.37$). In addition, nouns referring to target and distractor objects had similar length, measured by number of syllables (target M (SD) = 1.58 (0.67); distractor M (SD) = 1.48 (0.72); $p = 0.48$) and log frequency (target M (SD) = 4.34 (0.48); distractor M (SD) = 4.20 (0.48); $p = 0.12$). In the unrestrictive condition, targets and distractors did not differ with respect to frequency of co-occurrence with the verb (target M (SD) = 008 (0.014); distractor M (SD) = 0.006 (0.017); $p = 0.49$). In the restrictive condition, co-occurrence frequency was near zero for distractors, consistent with the intention that the verb and distractors be semantically incompatible. Finally, to avoid phonological competition, target nouns never shared an initial segment with any of the distractors.

[2] The 6 verbs classified as other/multiple categories either permitted three-argument structures (e.g., *return* as in *Sam returned the book to the library*) and/or satisfied the requirements of two major categories (e.g., *cook*, which is both optionally transitive (e.g., *Sam cooked* vs. *Sam cooked the potatoes*) and exhibits alternating transitivity (e.g., *The potatoes cooked*).

The linguistic stimuli were recorded by a female native speaker of English, at a normal speech rate (4.49 syllables/second; Love et al., 2008). The length of the verbs and nouns (in ms) was the same across conditions (restrictive verb M (SD) = 374 (76); unrestrictive verb M (SD) = 402 (80); $p = 0.11$; restrictive noun M (SD) = 541 (142); unrestrictive noun M (SD) = 571 (130); $p = 0.33$).

The visual arrays consisted of four gray-scale clip art images, arranged around a central fixation cross. No image appeared in the experiment more than once. The positions of the target and distractor objects within the array were counterbalanced across items, using a latin-square design. The arrays were controlled for animacy: all arrays either contained four inanimate objects (35 arrays), four animate objects (one array), or two of each (four arrays). We also conducted two norming studies to test whether all visual images were easily identifiable and roughly equal in visual prominence. In the identification study, five native English speakers viewed each of the images and named them one by one. If more than one participant failed to produce the intended name for the object (or a synonym), the image was replaced and re-normed in the same way. In addition, five participants viewed each of the critical experimental arrays and were asked to indicate whether any of the objects stood out visually from the others and why. Arrays that were identified by more than one person to be unequal with regard to visual prominence were revised to address the observed concerns.

Twenty filler sentences were interspersed with the critical sentences. In all filler sentences, the target noun did not appear in the visual array. The stimuli were presented to participants in a pseudorandom order, starting with a filler sentence. There were no more than two adjacent trials from the same condition.

2.3. Procedure

Participants were seated in front of a 16″-by-10″ computer monitor in a dimly lit room. The experimental stimuli were presented using Superlab (Cedrus). Participants' eye movements were monitored using an Applied Science Laboratory (ASL) model 6000 remote eyetracker, which recorded the location of the participants' gaze every 16.7 ms. Following initial calibration of the eyetracker, there was a four-item practice session. We checked and re-calibrated the eyetracker every 10 trials.

Each trial began with the presentation of a cross, which participants were instructed to click on. After they did so, the cross remained on the screen for 1500 ms. Then, the visual array appeared and 1000 ms later the sentence was presented auditorily. The visual array remained on the screen for 2000 ms after the end of the sentence. Then, there was a beep and a new screen appeared with boxes containing the words "yes" and "no." Participants were instructed to click on "yes" if they had seen a picture of the final word of the sentence and to click on "no" if they had not. They were given up to 5000 ms to enter their response. As soon as they did so, the next trial began. See Fig. 1 for a schematic representation of trials from Experiments 1 and 2.

Experiments 1 and 2 were conducted in a single session, with a short break between the two. The order of experiments was counterbalanced across participants. In all, the testing session lasted approximately 45 min.

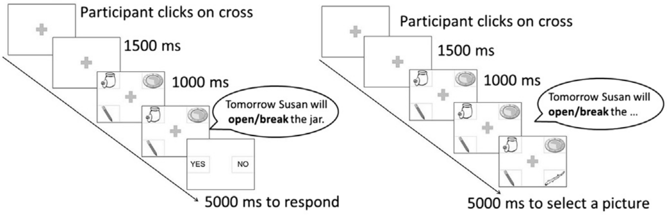

Fig. 1. Example trials from Experiments 1 and 2.

2.4. Data analysis

The offline task data were analyzed by calculating accuracy for each participant group in each condition. Preprocessing of the eye movement data was performed using Eyenal (Applied Science Laboratories). Following previous work (e.g., Dickey & Thompson, 2009), a fixation was defined as a look to the same position on the screen (within one degree of visual angle) that lasted at least 100 ms. The eye movement data were then analyzed further in two ways. For both analyses, we included only the trials in which the participant answered the yes/no probe correctly, indicating that they had recognized the target object. First, we calculated the proportion of fixations to the target object that started in each of five sentence regions: from picture onset to the onset of the verb (PreV), during the verb (V), during the noun phrase (NP), 0–500 ms from the offset of the noun (NOffset1), and 500–100 ms from the offset of the noun (NOffset2). The boundaries of each sentence region were measured using Audacity by two researchers working independently. We followed the standard practice of adding 200 ms to each time point for the purposes of analysis, in order to account for the time it takes to plan and execute a saccade (Matin, Shao, & Boff, 1993). Then, paired *t*-tests were performed on the proportion of target fixations between restrictive and unrestrictive conditions for each group and sentence region. A higher proportion of looks to the target in the restrictive compared to the non-restrictive condition indicated use of verb meaning to predict and/or facilitate integration of the target noun.

In addition, we performed a finer-grained analysis of eye movement patterns immediately after the verb using mixed-effects empirical logit regression (Barr, 2008). This analysis technique has several advantages for detecting subtle differences in eye movement patterns between groups, including treatment of time as a continuous variable, treatment of fixations to the target as a binary variable, and the presence of random terms in the model that account for variation across participants. Accounting for variation across participants was critical for the present study, as offline tasks revealed considerable heterogeneity within the aphasic group with respect to lexical processing ability. We performed this analysis on the eye movement data for the 500 ms time window starting from the offset of the verb (again shifted 200 ms downstream to account for eye movement planning and execution). This time window was chosen on empirical grounds. Inspection of the grand mean fixation data, collapsed across groups and conditions, showed that the proportion of fixations to the target object started to rise approximately at verb offset. This is thus the earliest point at which the linguistic stimuli drove fixations toward the target object.

To perform this analysis, the fixation data were first aggregated into 50 ms time bins by participant and condition. A separate by-item analysis was not performed due to a low number of observations per item. All fixations that overlapped with a particular time bin were included within that bin. Then, the data were entered into a linear model, using the lmer function from the languageR statistical package in R (Baayen, 2011). The dependent variable was the log odds of fixating the target picture. The independent variables, entered as fixed effects in the model, were time (treated as a continuous variable), group (control, aphasic), condition (restrictive, unrestrictive), and the interactions between these variables. To account for variability across participants and conditions, the model also included random intercepts and slopes for each participant and participant/condition pair. The two categorical variables (group, condition) were contrast-coded, so that their effects in the model are interpretable as main effects. All three predictor variables were also centered (i.e., mean-subtracted) in order to eliminate problematic levels of collinearity observed with non-centered variables. Due to centering of the time variable, the intercepts for group, condition, and their interaction reflect effects observed halfway through the time window, rather than anticipatory baseline effects (as in e.g., Barr, 2008, in which the time variable is not centered).

2.5. Results

Table 3 summarizes the accuracy results. Though all participants performed well on the task, and five of nine aphasic participants performed within the control accuracy range (control $M = 96\%$, range = 92–100%; aphasic $M = 88\%$, range = 72–97%), the control group was significantly more accurate than the aphasic group overall ($p < 0.05$, two-sample *t*-test). This difference was driven by

Table 3
Accuracy results from Experiment 1. Mean (SD) percent correct is reported.

	Overall	Restrictive	Unrestrictive	Filler
Control group	96.0 (2.9)	98.0 (4.8)	96.5 (3.4)	93.5 (8.2)
Aphasic group	88.3 (9.4)	95.0 (4.3)	88.9 (13.9)	81.1 (16.4)

impaired performance on filler items ($p < 0.05$); accuracy did not differ between groups for either experimental condition (restrictive and unrestrictive condition p's > 0.1). To test for effects of verb meaning on accuracy, we performed paired t-tests on accuracy in the restrictive vs. unrestrictive conditions for each group; no significant differences were found (p's > 0.1).

The results of the sentence regions analysis of the eye data appear in Fig. 2, which represents the proportion of all fixations to the target picture within each sentence region. No differences between conditions were found for either group in the time before the verb was presented (PreV region) or during the presentation of the verb (V region) (p's > 0.1, paired t-test). Following the offset of the verb, during the presentation of the noun phrase (NP region), both the aphasic and control groups exhibited significant effects of condition, with a greater proportion of target fixations in the restrictive than in the unrestrictive condition (p's < 0.05). In the 500 ms immediately following the offset of the noun (NOffset1), a marginally significant effect of condition persisted in the aphasic group ($p = 0.054$) but no effects of condition were observed in the control group ($p > 0.1$). No significant effects for either group were found in the 500–1000 ms window following the verb (NOffset2).

Fig. 3 illustrates the proportion of target fixations across groups and conditions in 50 ms bins for the first 500 ms following verb offset. The mixed-effects empirical logit regression analysis confirmed that effects of verb meaning were evident in both groups soon after verb offset. Table 4 summarizes the parameters of the regression model. Positive coefficient values for the three predictor variables indicate increased fixations to the target picture over time, in the control group, and in the restrictive condition, respectively. A main effect of time was observed, with increased target fixations over time ($p < 0.001$). There was also a main effect of group, with control participants looking to the target picture more frequently than aphasic participants ($p < 0.05$), and a main effect of condition, with participants across groups exhibiting a greater likelihood of looking to the target picture following restrictive verbs relative to unrestrictive verbs ($p < 0.01$). This is consistent with the effects of condition found in both

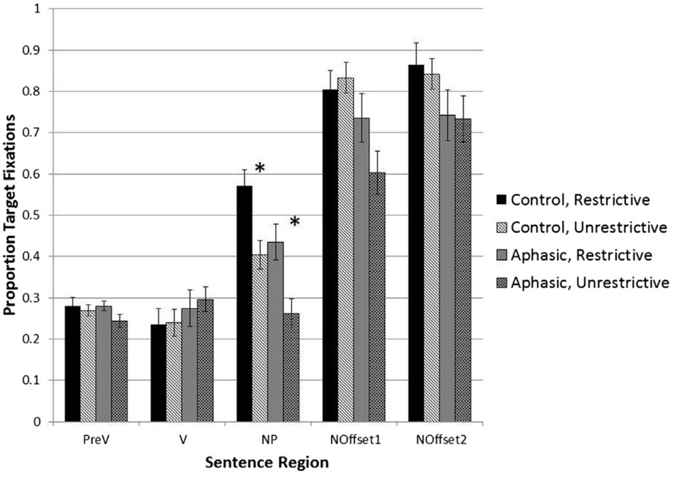

Fig. 2. Proportion of target fixations across sentence regions in Experiment 1. PreV = pre-verb; V = verb; NP = noun phrase; NOffset1 = 0–500 ms following offset of noun; NOffset2 = 500–1000 ms following offset of noun. Significant differences between restrictive and unrestrictive conditions are indicated (* = $p < 0.05$).

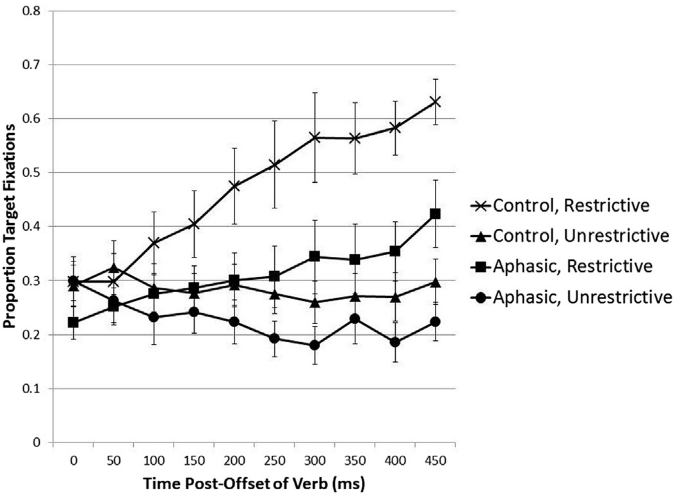

Fig. 3. Proportion of target fixations in first 500 ms following verb offset in Experiment 1 (50 ms time bins).

groups in the sentence regions analysis. In addition, there was a time x condition interaction, with looks to the target picture increasing more quickly over time in the restrictive condition than in the unrestrictive condition ($p < 0.001$). However, there were no significant interactions observed involving group (time × group; group × condition, time × group × condition; p's > 0.1), indicating that the two groups exhibited similar rates of increased fixations to the target picture over time and, critically, similar effects of verb meaning on the likelihood of fixating the target picture.

2.6. Discussion

The accuracy results revealed that some of the aphasic participants exhibited mild deficits in lexical processing. In addition, the aphasic participants fixated the target picture less frequently than the control participants in the first 500 ms following verb offset, reflecting generally slowed lexical access. This is consistent with previous research suggesting that lexical access is slowed in agrammatic aphasia (e.g., Choy, 2011; Love et al., 2008; Prather et al., 1992, 1997).

The eye movement patterns of both groups failed to reveal evidence of verb-driven anticipatory eye movements to the target picture. As illustrated by the sentence regions analysis, neither participant group exhibited increased looks to the target picture as a function of verb type during presentation of the verb. Thus, in contrast with the anticipatory eye movements displayed by young adults in previous studies (e.g., Altmann & Kamide, 1999, 2007; Boland, 2005; Kamide et al., 2003), the older adults in the

Table 4
Empirical logit analysis for Experiment 1: Model parameters and significance values.

	Coefficient estimate	Standard error	*Z* value	*P* value
(Intercept)	−0.649	0.037	−17.619	<0.001
Time	0.321	0.140	2.293	0.0022
Group	0.183	0.074	2.483	0.013
Condition	0.196	0.069	2.824	0.005
Time × group	0.177	0.281	0.631	0.528
Time × condition	1.002	0.192	5.227	<0.001
Group × condition	0.074	0.139	0.536	0.592
Time × group × condition	0.091	0.384	0.238	0.812

present study did not use verb meaning to predict the upcoming noun phrase prior to its onset. However, both aphasic and control participants exhibited facilitated integration of the target noun immediately following the presentation of a restrictive verb. In both groups, these effects reached significance in the first 500 ms following verb offset. In addition, the two groups exhibited similar rates of increased fixations to the target picture over time across conditions. These results thus indicate that agrammatic listeners, like healthy age-matched controls, can use verb information to facilitate the integration of a subsequent argument. This suggests that agrammatic aphasic listeners have intact and timely access to the semantic representations of verbs, as well as a preserved ability to use verb meaning to facilitate the integration of an overt argument. Experiment 2 tests whether the ability to use verb meaning to generate predictions is also preserved.

3. Experiment 2

3.1. Participants

The participants were the same as in Experiment 1.

3.2. Stimuli

There were 40 critical sentence pairs, each with a corresponding visual array of four objects. The form of the sentences was the same as in Experiment 1, except that the sentences were lacking a target noun (e.g. *Tomorrow NP will V the*…). Each sentence pair contained one restrictive and one unrestrictive verb. We used the same verb pairs as in Experiment 1 (see Table 2 for a summary of their properties), but with different noun phrases and visual arrays to avoid repetition effects across experiments. For example, in Experiment 1 the verb pair *open/break* was associated with an array containing a jar (target), a plate, a pencil, and a stick (distractors). In Experiment 2, the same verb pair was associated with an array containing a window (target), a lamp, a string, and an egg (distractors). We counterbalanced the stimulus lists so that participants did not hear a critical verb more than once across experiments (e.g., if they heard *close* in Experiment 1, they heard *break* in Experiment 2, and vice versa). A female native speaker of English recorded the experimental sentences, speaking at a normal rate (4.44 syllables/s). The acoustic length of the verbs (in ms) was controlled across conditions (restrictive M (SD) = 367 (80); unrestrictive M (SD) = 386 (66), $p = 0.27$).

As in Experiment 1, we controlled the co-occurrence frequency between the verb and target noun across conditions, using the COCA (Davies, 2008). There was no significant difference across conditions (restrictive M (SD) = 0.0075 (0.010); unrestrictive mean (SD) = 0.0044 (.009); $p = 0.14$). We also controlled the length, frequency, and co-occurrence frequency of the target nouns and distractors, again using the COCA. Target nouns and distractors were approximately equal in length in syllables (target M (SD) = 1.55 (0.71); distractor M (SD) = 1.48 (0.66); $p = 0.59$). There was no significant difference in the log frequency of nouns associated with target objects and distractor objects (target M (SD) = 4.28 (0.41); distractor mean (SD) = 4.22 (0.51); $p = 0.46$). In the unrestrictive condition, where the verb was intended to be compatible with all four objects, the mean co-occurrence probability between the verb and the target and distractor nouns did not differ significantly (target M (SD) = 0.0044 (0.009); distractor M (SD) = 0.0044 (0.010); $p = 0.99$). In the restrictive condition, the mean co-occurrence frequency between the verb and the distractors was near zero. There was no phonological overlap between the target and distractor nouns.

The visual stimuli were arrays of four clip-art objects arranged around a fixation cross, which were controlled, normed and counterbalanced in the same way as Experiment 1. Thirty-seven arrays contained four inanimate objects, one contained four animate objects and two contained two of each. No image appeared in the experiment more than once, though some images appeared once each in Experiments 1 and 2. When images were repeated across experiments, they always appeared in different arrays and were associated with different verb pairs.

Participants heard one version of each sentence pair, counterbalanced so that each participant saw 20 items per condition. In addition, 20 filler sentences were included. In the filler sentences, we varied the restrictiveness of the verb such that in 10 sentences each, the verb could combine with two or three objects in the array. The filler and experimental sentences were presented in pseudorandom order, beginning with a filler sentence and containing no more than two consecutive trials of the same condition.

3.3. Procedure

Participants listened to incomplete sentences while viewing visual arrays of four objects. They were instructed to listen carefully to the sentences and click on the picture that best completed the sentence. In the restrictive condition, the correct response was the target object; in the unrestrictive condition, all four objects were acceptable responses.

The eyetracking procedures were the same as in Experiment 1. Following the initial calibration, we familiarized the participants with the task with a 4-item practice session. See Fig. 1 for a schematic representation of a sample trial. Each experimental trial began with the presentation of a cross in the middle of the screen. Participants were instructed to click on the cross. After they did so, the cross remained on the screen for an additional 1500 ms, and then a visual array of four objects was presented. After 1000 ms, the sentence fragment was presented auditorily. At the end of the sentence fragment, the participants were given up to 5000 ms to click on the best-fitting picture. After they did so, the program proceeded to the next trial.

3.4. Data analysis

To analyze the participants' performance on the offline task, we calculated the percent of responses in which the participant clicked on the target object. In the restrictive condition, this was the only correct response, and thus we expected the unimpaired participants to select the target nearly all of the time. In the unrestrictive condition, all four objects were acceptable responses, and thus we expected at-chance ($\sim$25%) performance. Using two-sample *t*-tests, we compared the proportion of target responses across groups for each condition.

The preprocessing of the eye movement data was similar to that of Experiment 1. However, in contrast with Experiment 1, all trials were included in the analysis because in only the restrictive condition were responses classifiable as correct or incorrect. We calculated the proportion of fixations to the target that started within each of several sentence regions: from picture onset to the onset of the verb (PreV), during the verb (V), 0–500 ms following the offset of the verb (VOffset1), 500–1000 ms after verb offset (VOffset2), and 1000–1500 ms after verb offset (VOffset3). For each group and sentence region, we compared the proportion of target fixations between the restrictive and unrestrictive conditions. We also performed a mixed-effects empirical logit regression analysis, using the same procedures and model structure as that of Experiment 1. As in Experiment 1, the time window entered into the analysis was the first 500 ms from the offset of the verb.

3.5. Results

The participants' accuracy is summarized in Table 5. In the restrictive condition, where the target picture was the only correct response, the control participants selected the target picture more frequently than the aphasic participants (control $M = 95\%$, range = 90–100%; aphasic $M = 78\%$, range = 55–95%; $p < 0.01$), though four aphasic participants performed within the accuracy range for controls. This shows that some of the aphasic participants experienced difficulty in using verb meaning to select the target picture. In the unrestrictive condition, where all pictures were compatible with the sentence, participants selected the target picture with similar frequency across groups (control $M = 35\%$, range: 25–45%; aphasic $M = 31\%$, range = 15–45%; $p > 0.1$).

Turning to the eye movement data, Fig. 4 illustrates the proportion of fixations to the target picture within each sentence region. No differences between conditions were found for either group in the regions before and during the verb (PreV and V regions). In the first 500 ms following verb offset (VOffset1), the control group exhibited a significant effect of condition, with a greater proportion of target fixations in the restrictive condition ($p < 0.001$). This persisted into the following two regions, VOffset2 (500–1000 ms from verb offset; $p < 0.01$) and VOffset3 (1000–1500 ms from verb offset,

Table 5
Behavioral results from Experiment 2. Mean (*SD*) percent selection of the target picture is reported

	Restrictive	Unrestrictive
Control group	95.0 (3.3)	35.0 (6.7)
Aphasic group	78.3 (15.0)	31.7 (10.0)

$p < 0.05$). In contrast, the aphasic group did not exhibit any effects of condition in VOffset1 or VOffset2 (p's > 0.1). A significant effect of condition emerged during VOffset3 ($p < 0.01$), with more fixations to the target object in the restrictive than in the unrestrictive condition.

Fig. 5 presents the eye movement data in 50 ms bins for the 500 ms starting with the offset of the verb. The parameters of the regression model are summarized in Table 6; interpretation of coefficients is the same as in Experiment 1. The analysis revealed main effects of time (more fixations to the target picture as the time window progressed; $p < 0.05$) and condition (more target fixations in the restrictive than unrestrictive condition; $p < 0.001$) but no main effect of group ($p > 0.1$). Critically, an interaction was observed between group and condition ($p < 0.01$). To investigate the source of this interaction, we obtained simple effects of condition for each group using model comparison with treatment-coded regression models. These analyses revealed an effect of condition (restrictive > unrestrictive) for the control group ($p < 0.001$) but not for the aphasic group ($p > 0.1$). These results converge with those of the sentence regions analysis, indicating immediate effects of verb meaning in controls but not aphasic participants. There was also an interaction between time and condition ($p < 0.05$), reflecting a greater increase in target fixations over time in the restrictive condition. No significant interactions were observed between time and group or between time, condition, and group.

3.6. Discussion

As in Experiment 1, the eye movement data revealed no effects of condition for either group during the processing of the verb. However, the age-matched control listeners exhibited increased fixations to the target picture following restrictive verbs in the first 500 ms following verb offset. The effects of verb meaning thus emerged in the same time window across experiments for the control listeners. In Experiment 1, this time window coincided with presentation of the noun; however, the same time

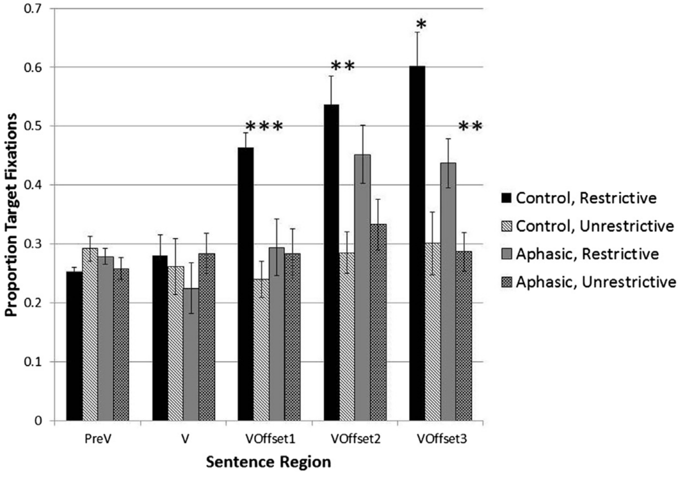

Fig. 4. Proportion of target fixations across sentence regions in Experiment 2. PreV = pre-verb; V = verb; VOffset1 = 0–500 ms following offset of verb; VOffset2 = 500–1000 ms following offset of verb; VOffset3 = 1000–1500 ms following offset of verb. Significant differences between restrictive and unrestrictive conditions are indicated (*** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$).

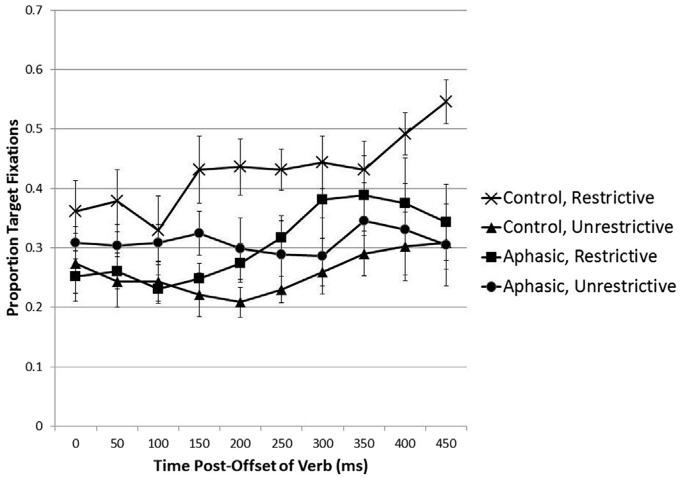

Fig. 5. Proportion of target fixations in first 500 ms following verb offset in Experiment 2 (50 ms time bins).

window in Experiment 2 did not contain a noun and therefore the observed effects of verb meaning can be interpreted as predictive. Thus, the results of Experiment 2 suggest that older adults are able to use verb meaning predictively, though these predictive processes are not sufficiently rapid to emerge during the verb, as has been reported for young adults (Altmann & Kamide, 1999, 2007; Boland, 2005; Kamide et al., 2003).

In contrast with Experiment 1, the aphasic listeners did not exhibit an effect of verb meaning in the 500 ms time window immediately following the verb, nor in the following 500 ms window. In this group, an effect of verb meaning emerged only following a substantial delay (1000–1500 ms following verb offset). The presence of an effect of verb type at this late time window indicates that aphasic listeners, like age-matched listeners, were able to use verb meaning predictively, though only with a significant delay. In addition, the data from the offline task indicated that aphasic participants were less accurate than control participants in selecting the target picture in the restrictive condition. Taken together, these results suggest that agrammatic aphasia may involve a deficit in the ability to use verb meaning to predict upcoming arguments both on- and offline.

4. General discussion

The present study used the visual-world eyetracking paradigm to investigate the time course of access to verb meaning and its effects on lexical integration in agrammatic aphasic and age-matched control listeners. The study included two experiments that investigated the effects of verb meaning on processing of subsequent overt (Experiment 1) and non-overt (Experiment 2) arguments. The eye

Table 6
Empirical logit analysis for Experiment 2: model parameters and significance values.

	Coefficient estimate	Standard error	*Z* value	*P* value
(Intercept)	−0.620	0.031	−19.899	<0.001
Time	0.360	0.177	2.027	0.043
Group	0.042	0.062	0.673	0.501
Condition	0.163	0.036	4.481	<0.001
Time × group	0.440	0.355	1.240	0.215
Time × condition	0.656	0.321	2.046	0.041
Group × condition	0.225	0.073	3.097	0.002
Time × group × condition	−0.037	0.642	−0.058	0.954

movement data were analyzed using mixed-effects empirical logit regression (e.g., Barr, 2008), in addition to the more standard analysis of fixation proportions by sentence region. In addition to providing a finer-grained picture of eye movement patterns over time, this analysis also accounted for participant-specific variability in eye movement patterns. This was especially important given the heterogeneity in performance observed within the aphasic group for the offline tasks.

Previous studies with healthy young adult participants have found that verb meaning is used to predict and facilitate integration of subsequent arguments, as reflected by increased fixations to the target object during and following restrictive relative to unrestrictive verbs (Altmann & Kamide, 1999, 2007; Boland, 2005; Kamide et al., 2003). For the older listeners in the present study, effects of verb meaning emerged in the first 500 ms following presentation of the verb for both overt and non-overt arguments. In Experiment 1, this time window coincided with the presentation of the noun phrase; thus, the results indicate that unimpaired listeners used verb information rapidly to facilitate lexical integration. In Experiment 2, no noun was presented, and therefore these effects reflect the use of verb meaning to predict upcoming arguments. In sum, the healthy participants made rapid use of verb meaning to predict upcoming lexical items and facilitate lexical integration. However, in contrast with previous studies with young adult participants, there were no effects of verb type observed during the verb in either experiment, suggesting that lexical-semantic prediction processes may be slowed during healthy aging. This finding is consistent with research suggesting that linguistic prediction processes may be less rapid and robust in older adults than in young adults (e.g., Delong, Groppe, Urbach, & Kutas, 2012; Federmeier & Kutas, 2005; Wlotko, Federmeier, & Kutas, 2012).

Eye movement patterns revealed that the aphasic listeners exhibited online lexical processing deficits in both experiments. In Experiment 1, the aphasic participants made fewer fixations to the target picture than the control participants in the first 500 ms following verb offset, which coincided with presentation of the target noun phrase. This indicates that access to the lexical representations of nouns was slowed for the aphasic listeners, consistent with several previous studies (e.g., Choy, 2011; Love et al., 2008; Prather et al., 1992, 1997). In addition, the aphasic participants differed from the control group with respect to the effects of verb meaning on eye movement patterns. In Experiment 1, aphasic listeners exhibited early effects of verb type that had a similar time course to that of the control group; restrictive verbs conferred a processing advantage in the first 500 ms following verb offset. These results suggest that access to the semantic representations of verbs is intact in agrammatic aphasia, and that aphasic listeners were able to use verb meaning to facilitate integration of a subsequent overt argument. However, the results of Experiment 2 revealed significantly delayed effects of verb type in the aphasic listeners relative to control participants. In the aphasic group, significant effects of verb type emerged only 1000–1500 ms after verb offset, in contrast with 0-500 ms post-offset for the control group. These results indicate that, despite intact access to verb meaning, the aphasic listeners were not able to generate timely predictions about upcoming arguments.

Thus, the results of Experiment 1 suggest that online access to verb meanings, as well as integration of verbs with their (overtly expressed) arguments, is largely intact in agrammatic aphasia. With respect to the time course of verb access, these findings are consistent with previous cross-modal interference studies that reported immediate access to verb-argument structure representations in participants with Broca's aphasia but not in participants with Wernicke's aphasia (Shapiro et al., 1993; Shapiro & Levine, 1990). The present results also converge with the finding that individuals with Broca's aphasia show online sensitivity to selectional restrictions, at least in some contexts (Myers & Blumstein, 2005). These aspects of sentence processing may be largely intact in Broca's aphasia because they are supported by posterior perisylvian brain regions, such as the posterior superior temporal gyrus and angular gyrus, which are typically spared in Broca's aphasia but damaged in Wernicke's aphasia. Of the six participants in the present study for whom detailed lesion information was available, all had lesions that included Broca's area, whereas the lesion of only one participant (A8) extended into posterior temporal and inferior parietal cortex. Neuroimaging studies support the view that posterior perisylvian regions are critical for accessing the representations of verbs, including selectional restrictions and argument structure representations, and these regions have also been implicated in the integration of verbs with their arguments (see e.g., Friederici, 2011; Thompson & Meltzer-Asscher, in press, for discussion). Converging evidence comes from a voxel-based lesion symptom mapping (VLSM) study, which found that impaired comprehension of semantically reversible sentences was correlated with damage to left temporo-parietal cortex, but not with lesions in Broca's area (Thothathiri, Kimberg, & Schwartz, 2012). As posterior perisylvian regions were undamaged in the majority of our participants, these regions likely supported timely access and use of verb meaning to facilitate lexical integration in Experiment 1.

However, the results of Experiment 2 indicate that, despite timely access to verb representations, the aphasic listeners were not able to generate timely predictions about upcoming arguments. A previous eyetracking study (Meyer, Mack, & Thompson, 2012) also reported a lack of predictive eye movements in listeners with agrammatic aphasia, namely the absence of an 'agent-first' processing bias in the comprehension of semantically reversible passive sentences. These results also converge with those of Myers and Blumstein (2005) in that access to selectional restrictions, though intact in some contexts, was vulnerable to disruption in others. This deficit may stem from damage to the left inferior gyrus (IFG), which has been argued to control higher-level lexical processes (e.g., Bedny, McGill, & Thompson-Schill, 2008; Heim et al., 2009; Righi, Blumstein, Mertus, & Worden, 2010). In the aphasia literature, some researchers have also argued that damage to the left IFG results in impaired higher-level lexical processes. Love et al. (2008) argue that the left IFG may support a lexical rise-time parameter that is critical for lexical reactivation processes in noncanonical sentences. In addition, Mirman et al. (2011) used eyetracking and computational modeling to investigate lexical competitor effects (i.e., the time course of fixations to objects phonologically related to a target word) in participants with Broca's and Wernicke's aphasia, who exhibited abnormal and distinct eye movement patterns. The authors argue for a model in which the locus of these deficits is *response sensitivity*, i.e., the extent to which differences in lexical activation drive behavioral responses (in this case, eye movements). According to this model, response sensitivity is decreased in Broca's but increased in Wernicke's aphasia. The authors suggest that response sensitivity is affected by the relationship between the left IFG and posterior perisylvian regions, such that damage to the left IFG decreases response selectivity whereas damage to posterior regions increases it. Decreased response sensitivity might also be expected to slow predictive eye movements, which are driven by relatively subtle differences in activation between the target and competitors. If this is the case, then decreased response selectivity may underlie the impaired prediction processes observed for the aphasic participants in the present study.

Returning to the question of whether lexical integration is impaired in agrammatic aphasia, the results of the present study suggest that some processes involved in lexical integration (i.e., the prediction of upcoming arguments) are impaired whereas others (i.e., the integration of the verb with its overt arguments) are intact. This is perhaps unsurprising given that simple, canonical sentence comprehension in agrammatic aphasia is largely preserved, with comprehension deficits observed mainly in noncanonical filler-gap structures, in which overt arguments are displaced. Future research is needed to test whether impaired prediction processes contribute to impaired comprehension of noncanonical sentences, consistent with the general lexical integration accounts proposed in previous work (Choy, 2011; Thompson & Choy, 2009). This seems plausible given that studies of noncanonical sentence processing in unimpaired adults have shown that prediction is a critical component of the processing of filler-gap structures (e.g., Phillips, Kazanina, & Abada, 2005).

5. Conclusion

The results of the present study provide new insights into the nature of lexical processing deficits in agrammatic aphasia and their effects on sentence comprehension. Participants with agrammatic aphasia demonstrated intact access to and use of verb meaning to integrate the verb with subsequent overt arguments. However, the ability to use verb meaning to predict upcoming arguments was impaired. Additional research is necessary to better understand how impaired lexical-semantic prediction processes may impact sentence comprehension in agrammatic aphasia.

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