Published in final edited form as:
Aphasiology. 2011 ; 25(6-7): 813–825. doi:10.1080/02687038.2010.542563.

Real-time production of unergative and unaccusative sentences in normal and agrammatic speakers: An eyetracking study

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Abstract

Background—Speakers with agrammatic aphasia have greater difficulty producing unaccusative (*float*) compared to unergative (*bark*) verbs (Kegl, 1995; Lee & Thompson, 2004; Thompson, 2003), putatively because the former involve movement of the theme to the subject position from the post-verbal position, and are therefore more complex than the latter (Burzio, 1986; Perlmutter, 1978). However, it is unclear if and how sentence production processes are affected by the linguistic distinction between these two types of verbs in normal and impaired speakers.

Aims—This study examined real-time production of sentences with unergative (*the black dog is barking*) vs unaccusative (*the black tube is floating*) verbs in healthy young speakers and individuals with agrammatic aphasia, using eyetracking.

Methods & Procedures—Participants' eye movements and speech were recorded while they produced a sentence using computer displayed written stimuli (e.g., *black, dog, is barking*).

Outcomes & Results—Both groups of speakers produced numerically fewer unaccusative sentences than unergative sentences. However, the eye movement data revealed significant differences in fixations between the adjective (*black*) vs the noun (*tube*) when producing unaccusatives, but not when producing unergatives for both groups. Interestingly, whereas healthy speakers showed this difference during speech, speakers with agrammatism showed this difference prior to speech onset.

Conclusions—These findings suggest that the human sentence production system differentially processes unaccusatives vs unergatives. This distinction is preserved in individuals with agrammatism; however, the time course of sentence planning appears to differ from healthy speakers (Lee & Thompson, 2010).

Keywords

Agrammatism; Unaccusative verbs; Eyetracking; Sentence production

The present study investigated real-time processes engaged during production of sentences with two linguistically distinct types of intransitive structures: unergatives (e.g., *bark*) vs unaccusatives (e.g., *float*) in healthy speakers and speakers with agrammatism. Although

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both verbs are associated with a single argument, they differ in terms of their underlying lexical-syntactic representations (Burizo, 1986; Levin & Rappaport Hovav, 1995; Perlmutter, 1978). The single argument of unergative verbs is agentive and base-generated at the pre-verbal position (1a). On the other hand, unaccusative verbs are associated with a theme argument, which is base-generated at the post-verbal position (1b). Therefore, in unaccusative sentences, the theme is moved to the subject position from the post-verbal position, while this is not the case for unergative sentences.

(1) **a.** The $\text{dog}_{\text{AGENT}}$ is barking. (unergative)

b. The $\text{tube}_{\text{THEMEi}}$ is floating t_i. (unaccusative)

This linguistic distinction has manifested in studies of sentence processing (Friedmann, Taranto, Shapiro, & Swinney, 2008) and language acquisition (e.g., Montrul, 1999) as well as in neuroimaging studies (e.g., Shetreet, Friedmann, & Harder, 2010; Meltzer-Asscher, Schuchard, den Ouden, & Thompson, 2010). For example, Friedmann et al. (2008), using a cross-modal lexical decision task, found that healthy listeners automatically re-activate the moved argument of an unaccusative verb upon hearing the verb, whereas this pattern was not shown with an unergative verb. Different neural correlates for processing unaccusatives vs unergatives were also reported. Shetreet et al. (2010), in a sentence comprehension task, found greater activation for unaccusatives than unergatives in the left inferior frontal gyrus (IFG) and left middle temporal gyrus (MTG), which were suggested to be responsible for syntactic and lexicalisation processes, respectively. Meltzer-Asscher et al. (2010), during a lexical decision task, found increased activation in the inferior parietal cortex for unaccusatives compared to unergatives, suggesting that unaccusatives are associated with greater argument structure complexity (Thompson, Bonakdarpour, et al., 2007).

The dissociation between unaccusatives vs unergatives also manifests in speech production of individuals with agrammatism. Kegl (1995) reported a speaker with agrammatic aphasia whose production of unaccusatives is impaired compared to unergatives. She proposed the syntactically enriched verb entry hypothesis (SEVEH), suggesting that any construction lacking an external argument and involving syntactic movement at s-structure induces production difficulty for speakers with aphasia. Thompson (2003) subsequently proposed the argument structure complexity hypothesis (ASCH). The ASCH suggests that as the verb's argument structure becomes more complex in terms of the number of arguments or there is a non-canonical mapping between d-structure and s-structure, production difficulty increases in speakers with agrammatic aphasia. These hypotheses have been supported empirically in many studies, using various tasks, including narrative production (Kegl, 1995; Thompson, 2003), action picture or video naming (Kim, 2005; Luzzatti et al., 2002; Thompson, 2003) as well as in sentence production using pictures (Bastiaanse & van Zonneveld, 2005; Lee & Thompson, 2004; see also McAllister, Bachrach, Waters, Michaud, & Caplan, 2009, for a parallel finding in fluent aphasic patients).

What still remains to be explored is how the linguistic distinction between unerga-tives and unaccusatives is reflected during on-line sentence production in healthy as well as impaired speakers and whether or not sentence production processes are different between the two groups. Psycholinguistic models of sentence production suggest that verbs and their argument structure properties play a critical role in the transformation a message into a sentence structure (e.g., Bock & Levelt, 1994). Based on a non-linguistic message formulated, a set of lexical items are retrieved. The lexical items consist of two representations, i.e., lemmas and lexemes. The lemma includes semantic and syntactic information of the word, whereas the lexeme represents the morpho-phonological form of the word. As for verbs, their argument structure information is stored in the verb's lemma. Hence, as the verb lemma is retrieved, its argument structure information is accessed and

guides subsequent sentence production processes, by specifying the number of arguments required and their structural arrangement in the sentence. Although the significant role of verb in sentence production is generally agreed, little is known about how and when verb argument structure knowledge is used during sentence production. Some studies with healthy young speakers suggest that sentence planning occurs in a radically incremental manner so that a verb's syntactic detail is not used during the initial planning of the utterance (e.g., Griffin, 2001; Schriefers, Teruel, & Meinshausen, 1999). Others suggest that language production is guided by a larger unit including at least some verb or predicate information as a part of initial sentence planning (e.g., Lindsey, 1975; Meyer, 1996). Investigating the real-time production of unaccusatives vs unergatives will facilitate understanding of the nature and time course of normal as well as impaired sentence production.

Lee and Thompson (2010), using eyetracking, examined the real-time planning of verb argument phrases (e.g., the mother is *apply*ing the lotion *to the baby*) and adjunct phrases (e.g., the mother is *choosing* the lotion *for the baby*) in English speakers with and without agrammatic aphasia. Participants produced a sentence using a set of computer-displayed written words. Participants' speech and fixations to each word were recorded and aligned together. While controls and speakers with aphasia did not show reliable differences in off-line measures, their eye movements revealed increased processing cost for adjuncts (reflected by greater looks to the verb and adjunct), as compared to goal arguments, indicating speakers' sensitivity to verb arguments vs adjuncts distinctions. Interestingly, speakers with aphasia showed this difference at an earlier stage of sentence planning than healthy speakers (before speech onset), suggesting that while their sensitivity to verb arguments vs adjuncts is preserved, they may use different planning strategies from healthy speakers.

The present study aimed to investigate the real-time production of unergative (e.g., *the black dog is barking*) and unaccusative sentences (e.g., *the black tube is floating*) in speakers with and without agrammatic aphasia, using an "eyetracking while speaking" paradigm. Specifically, the study explored whether and how production of the subject noun phrase (*the black tube*/*dog*) is realised differently in unaccusatives and unergatives. It was hypothesised that if on-line sentence production is sensitive to this linguistic distinction, speakers' eye movements will reveal different looking patterns when the subject noun involves a non-canonical syntactic derivation as in unaccusatives, compared to when it does not as in unergatives.

METHOD

Participants

A total of 12 young healthy speakers and 9 individuals with agrammatic aphasia participated in the study. Healthy speakers—7 females, 5 males, age: *M* (*SD*) =19 (1), range 19–21 years—were recruited from Northwestern University. The aphasic participants—1 female, 8 males; age *M* (*SD*) =54 (11), range 35–56 years; education *M* (*SD*) =16 (2.7), range 12–21 years; post-onset of stroke: *M* (*SD*) =7.2 (5.7), range 0.5–16 yrs—were recruited from the Aphasia and Neurolinguistics Research Laboratory at Northwestern University. To ensure all participants had normal or corrected-to-normal visual abilities, healthy speakers were asked to fill out a list of questionnaire. For individuals with aphasia, their case history was reviewed and they were asked if they had any visual discomfort prior to the experiment. None of the aphasic participants had visual deficits (e.g., visual neglect, hemianopia). All had normal and corrected-to-normal vision. No participant had a history of language or neurological disorders prior to the experiment or their stroke.

The diagnosis of agrammatic aphasia was made based on performance on the Western Aphasia Battery (Kertesz, 1982), the Northwestern Assessment of Verbs and Sentences (NAVS, Thompson, experimental version; see also Thompson, 2008), and neurolinguists' judgement of spontaneous speech and narrative speech samples (Cinderella story). The aphasic participants' language testing data are provided in Table 1. WAB aphasia quotients (AQs) ranged from 69.2 to 87.6, with auditory comprehension, while impaired, superior to verbal expressive ability. The results from the NAVS revealed greater deficits in verb naming than in verb comprehension. In the Argument Structure Production subtest, performance on sentences with one and two arguments was superior to that in sentences with three arguments. In the Sentence Priming Production subtest, all participants showed greater difficulty producing non-canonical sentences (passives, object relatives, and object wh-questions) compared to canonical sentences (actives, subject relatives, and subject wh-questions). In the Sentence Comprehension subtest, participants showed greater comprehension scores for non-canonical sentences compared to canonical sentences. For all participants, spontaneous speech was marked by reduced syntactic complexity and substitution and omission of grammatical morphology. In addition, the patients were able to read single words.

Linguistic stimuli

A total of 10 unergative and 10 unaccusative verbs were prepared and matched in terms of log frequency (1.78 vs 1.78; CELEX; Baayen, Pieenbrock, & van Rij, 1993) and length (1.1 vs 1.0 syllables; $p > .05$) between the conditions. The unaccusative verbs were selected from Perlmutter (1978) and Levin and Rappaport Hovav (1995). A set of adjectives and nouns was also selected and combined with the verbs, resulting in a set of 10 Adjective-Noun-Verb sentences per condition (2) (see Appendix for the list of sentence stimuli). The same adjectives were used between the conditions. The nouns were matched in their log frequency (1.67 vs 1.67) and length (1.9 vs 1.9 syllables) between the conditions.

(2) The black dog is barking (unergative condition)

The black tube is floating (unaccusative condition)

The stimuli were checked by a group of native speakers of English (n =5) prior to experiment and only the items that yielded target sentences at least with 80% accuracy were included in the study. To prevent participants from strategic use of one sentence structure, 40 filler sentences were prepared (e.g., *the man is donating money to the priest*). The fillers did not include any intransitive verbs or complex noun phrases.

Visual stimuli

A total of 60 visual panels (20 experimental and 40 filler items) were created using the written words. Because picture stimuli for intransitive actions depict only one image (either an agent doing an action or theme undergoing an action), written stimuli for the subject noun phrase (i.e., Adjective and Noun) were used such that clear eye movements from word to word could be recorded. The verb was displayed on the left side, while the adjective and noun were displayed on the right side of the panel (Figure 1). The verbs were presented in the present progressive form (*is barking*) to eliminate linguistic and processing differences between regular and irregular verbs. The positions of the adjectives and nouns were varied from trial to trial to avoid any visual bias due to repeated position. For filler items, three nouns were displayed on the right side of the panel.

Procedures

After obtaining informed consent, participants were seated in front of the stimulus display computer monitor, located approximately 24 inches from participants' eyes. For head

stabilisation, participants rested their chins on a chinrest. The eyetracking system was calibrated to each participant's eyes at the beginning of the experiment, using a set of nine points equally distributed across the screen. Additional calibrations were done following every 15 trials during the experiment.

Task instructions, recorded by an English-speaking female, were presented over a loudspeaker. Participants were asked to make a sentence "using the verb and all the words presented on the screen". Prior to each trial, participants also heard the target verb via instruction (e.g., "the next verb is *bark*. Make a sentence using *is barking*."). Each trial began with a blank white screen, which appeared for 1500 milliseconds. This was replaced by a black fixation cross which appeared on the screen for 200 milliseconds. A beep lasting 100 milliseconds followed. At the onset of the beep, the stimulus panel appeared. Participants proceeded through the trials at their own pace by pressing the spacebar on the keyboard to advance to the next trial. The presentation of experimental and filler items was randomised. The stimuli were presented using Superlab 4.0 (Cedrus). Praat software was used to record participants' speech. Their eye movements were recorded using ASL eyelink 6000 remote eyetracking camera, controlled by Eye-link system software. The remote video camera sampled the position and direction of the participants' corneal and pupil reflection at the sample rate of 60 Hz. A fixation was defined as the participant's gazing at one position for 100 ms with a tolerance for change in position within 1.5 degree vertically and horizontally. A threshold of 100ms has been shown to effectively differentiate fixations from other ocular movements (Manor & Gordon, 2003).

Prior to the experiment, speakers with aphasia were screened for their comprehension and ability to orally read word stimuli (20 verbs, 20 nouns, and 10 adjectives) as singletons. For verbs they were presented with a set of four action pictures and a written verb. The patients were asked to read the verb aloud (oral reading) and point to the corresponding picture (comprehension). For nouns and adjectives, due to difficulty depicting adjectives and some nouns, a set of four written words was presented. The examiner read one word each time and the participants were asked to point to the corresponding word (comprehension). Then they were asked to read the word aloud on their own (oral reading). Only patients who had at least 90% accuracy for both comprehension and oral reading for each of the verbs, nouns, and adjectives were included in the study.

Data analysis

Participants' responses were transcribed and scored. The correct (target) responses included Adjective-Noun-Verb structures with all three target words included (e.g., *the black tube is floating*). Within-word disfluencies (e.g., *b-black*) and omission of articles were accepted. All other types of responses, including addition of words, were scored as "incorrect". When more than one attempt was made, only the first attempt (including at least a noun and auxiliary verb production) was scored.

Speech onsets of each content word (i.e., Adjective, Noun, and Verb) were measured using NU aligner software (Chun, unpublished). Three aphasic patients' data were hand-timed, due to their frequent disfluencies. Within-word disfluencies were measured from the onset of the first-attempted content word. For example, in the case of "ba-, barking", the onset of the verb (V) was measured from the onset of the first "ba-". All the onset times measured by NU aligner were hand-checked for reliability by the experimenter and two additional persons. Following previous eyetracking sentence production studies (Griffin, 2001; Thompson, Dickey, Cho, Lee, & Griffin, 2007), three speech regions were identified: the Pre-Adj region (from the onset of stimulus to the speech onset of the adjective), the Adj-N region (after the onset of the adjective to the onset of the noun), and the N-V region (after the onset of the noun to the onset of the verb).

Participants' fixations occurring during each trial were computed using Eyenal 6.0 analysis software. To define areas of interests (AOIs), three squares were drawn surrounding the position of each word (Adjective, Subject, and Verb), with approximately two degrees of visual angle. Fixations that fell inside these AOIs were counted as fixations to the word covered by the AOI. The fixation data were aligned with the speech regions mentioned above.

RESULTS

Two of our aphasic speakers (A8, A9) produced no target sentences in either the unergative or the unaccusative condition. Thus these two participants were excluded from the data analysis.

Production accuracy

Both groups produced only numerically fewer correct responses for unaccusatives than for unergatives. Healthy speakers produced 93% (*SD* =13) vs 95% (*SD* =9) for unaccusatives vs unergatives, respectively (Z =.756, p =.450, Wilcoxon). Speakers with aphasia showed 82% (*SD* =14) vs 85% (*SD* =19) for unaccusatives vs unergatives, respectively (Z =.819, p =.414, Wilcoxon). Performance for the aphasic speakers was numerically, but not reliably, lower than that of healthy speakers in both conditions (Unaccusatives: Z =1.169, p =.090; Unergatives: Z =1.174, p =.241, Mann-Whitney). Healthy speakers' errors were mainly addition of phrases or clauses (e.g., *the lazy governor is coughing as he hears complaints*). Errors produced by speakers with aphasia were not notably different between conditions. In both conditions their errors consisted of word order errors (e.g., *the dog is barking black*), semantic paraphasias, and other errors including production of fragmented utterances and sentences with multiple errors.

Speech onset latency data

Neither group showed a significant difference between the two conditions. Healthy speakers showed a mean (*SE*) of 1670 (109) vs 1586 (76) ms for the unaccusative vs unergative condition, respectively (Z =1.443, p =.151, Wilcoxon). Speakers with aphasia showed a mean (*SE*) of 3930 (308) vs 4230 (476) ms for the unaccusative vs unergative condition, respectively (Z =.845, p =.398, Wilcoxon). In addition, speakers with aphasia overall showed significantly longer speech onset latencies than healthy speakers (Unaccusatives: Z= 3.526, $p < .001$; Unergatives: Z =3.606, $p < .001$, Mann-Whitney).

Eye movement data

Figure 2 shows the proportion of fixation durations to each word by speech regions for young speakers (2a) and speakers with aphasia (2b). The statistical results, based on Wilcoxon signed ranks tests, are summarised in Table 2. Healthy speakers showed the following results: for the pre-Adj region, in both unergative and unaccusative conditions, they showed greater fixation durations to the Adjective and Noun than to the Verb. However, there was no difference in fixation durations between the Adjective and the Noun in both conditions. For the Adj-N region, none of the comparisons was significant in the unergative condition. Healthy speakers fixated to all three words equally. However, unlike the unergative condition, they showed greater fixation duration to the Noun than to the Adjective in the unaccusative condition. For the N-V region, in both conditions, healthy speakers showed greater fixation durations to the Verb than to the Adjective and Noun. Also, fixation durations were greater for the Noun than for the Adjective in both conditions.

Speakers with aphasia showed the following results: for the pre-Adj region, they showed differential patterns between the conditions. In the unergative condition the patients showed

greater fixation durations to the Adjective and Noun than to the Verb, although the difference did not reach to significance for the Noun. The difference in fixation durations between the Adjective and the Noun was not reliable. In the unaccusative condition, on the other hand, the patient showed significantly greater fixation durations to the Adjective than to the Noun and the Verb. For the Adj-N region, in both conditions, the patients showed greater fixation durations to the Adjective and Noun than to the Verb. No difference was found in fixation durations between the Adjective vs the Noun for both conditions. Lastly, for the N-V region, the patients showed greater fixation durations to the Noun and Verb than to the Adjective but showed equal fixation durations between the Noun and Verb in the unergative condition. In the unaccusative condition they showed greater fixation durations to the Verb than to the Noun and Adjective.

DISCUSSION

This study examined real-time planning processes engaged during production of unergative vs unaccusative sentences in speakers with and without agrammatism. In broader measures of production, including production accuracies and speech onset latencies, neither healthy speakers nor speakers with aphasia showed reliable differences between the two sentence types. Our speakers with agrammatic aphasia produced only numerically fewer correct unaccusatives than unergatives, unlike previous studies that showed greater deficits in unaccusatives compared to unergatives in agrammatism (e.g., Kim, 2005; Lee & Thompson, 2004; McAllister et al., 2009; Thompson, 2003). This inconsistency can be attributed to methodological differences between our study and previous ones. Whereas previous studies (e.g., Kim, 2005; Lee & Thompson, 2004; McAllister et al., 2009) used picture/video-based elicitation tasks, our patients produced a sentence given a set of written lexical items. Although speculative, use of written words might have reduced demands for accessing lemmas and boosted access to the phonological representation of target verbs (lexemes). This, in turn, might have eased the retrieval of verb argument structure properties stored in verb lemmas, facilitating sentence production in the speakers with aphasia. In addition, a relatively small number of items and participants were examined in our study, which may have inflated production ability.

Despite the lack of differences observed in global measures, the eye movement data revealed qualitatively different patterns between the unaccusative and unergative conditions. Two patterns were notable: (1) differences were apparent in fixations to the Adjective and the Noun in both groups, and (2) the two groups of speakers differed with regard to sentence regions where processing differences between the two sentence types were apparent. Healthy speakers showed greater fixation durations to the Noun (e.g., tube) than to the Adjective (e.g., black) before producing the noun (the Adj-N region) in the unaccusative condition; however, they showed equal durations of fixation to the Adjective (e.g., black) and the Noun (e.g., dog) in the unergative condition. Similarly, speakers with aphasia showed significantly greater fixation duration to the Adjective (e.g., black) than to the Noun (e.g., tube) in the unaccusative condition before producing the adjective (the pre-Adj region); however, they showed equal durations of fixation to the Adjective (e.g., black) and Noun (e.g, dog) in the unergative condition. In addition, speakers with aphasia showed significantly greater fixation durations to the Verb than to the Noun before producing the verb (the N-V region) in the unaccusative condition, but showed no difference in fixation durations between the Noun and the Verb in the unergative condition.

Although preliminary, we interpret these findings in terms of differential integration processes of lexical items and phrase structure building between the two conditions. When the subject noun is the agent without involving a non-canonical derivation, lexical items may be integrated simultaneously into the utterance structure. Both groups of speakers'

equal fixation durations to the Adjective and the Noun during production of unergative NP may suggest that speakers integrated the adjective (e.g., black) and noun (e.g., dog) into the complex NP (e.g., black dog) concurrently. On the other hand, when the subject noun is the theme of the verb (unaccusative condition), involving syntactic movement, the process of integrating lexical items into the utterance may proceed in a more serial fashion, resulting in increased fixation to the element that is about to be produced. Healthy speakers' increased fixation for the theme Noun compared to the Adjective prior to articulation of the noun and aphasic speakers' increased fixation for the Adjective over the theme noun prior to speech onset may reflect this serial process of lexical-syntactic integration (see discussion below for the speech region differences between the groups). In addition, speakers with aphasia appear to utilise these different planning strategies during the N-V region as well, as reflected by increased fixation to the unaccusative Verb over the Noun before producing the verb in the unaccusative condition, but not in the unergative condition.

Based on the current findings, it is difficult to say whether or not the different fixation patterns noted between conditions are due to increased processing demands associated with unaccusatives. According to the ASCH (Thompson, 2003) and the SEVCH (Kegl, 1995), unaccusative structures engender increased processing costs compared to unergatives, hence one might interpret our findings as such. However, given that both hypotheses were formulated using off-line measures and considering the preliminary nature of the present findings, this interpretation is only speculative at this point. Nonetheless, our data clearly show that the linguistic distinction between unaccusatives and unergatives is realised during on-line sentence production, with distinct eye movement patterns associated with each form, paralleling previous findings derived from sentence processing experiments (Friedmann et al., 2008) and neuroimaging studies (Meltzer-Asscher et al., 2010; Shetreet et al., 2009). Further, these findings provide the first empirical evidence showing that the unaccusative–unergative distinction is realised during on-line sentence planning in agrammatism. This finding suggests that even when individuals with agrammatism produce unaccusatives and unergatives equally well, they show distinctions in processing between the two constructions as do healthy speakers, adding to the results of previous off-line studies (Kegl, 1995; Lee & Thompson, 2004; McAllister et al., 2009; Thompson, 2003). More research is needed to understand how on-line processes are affected when speakers with agrammatism fail to produce unaccusatives and the relation between on-line planning processes and the different levels of complexity of verb argument structures.

Another notable finding of the current study is that while healthy speakers showed the differences during speech, i.e., after they began articulating the adjective of the complex NP, speakers with aphasia showed the differences from the earliest stage of sentence production, i.e., the pre-Adj region. Similar findings were shown in Lee and Thompson (2010), which examined real-time planning of verb arguments (entities specified by a verb's lexical representation) and adjuncts (entities that are not specified by a verb) in speakers with and without agrammatic aphasia. Our healthy speakers' data can be accounted for within theories of "rapid" incremental production, which holds that syntactic information of a verb is not used during initial planning of utterances (e.g., De Smedt, 1996; Griffin, 2001; Schriefers et al., 1999). On this model, speakers begin utterances based on the first activated word (the adjective, in our case) and the remainder of the utterance is planned during speech, thus the verb information is used most actively after the utterance is initiated. Our young speakers appear to be most sensitive to the verb argument structure distinction between unaccusatives and unergatives when they are about to produce the noun. On the other hand, in speakers with aphasia, the unaccusative–unergative distinction appears to play a significant role during initial planning stage, resulting in differential looks to the Adjective and the Noun between the conditions from the Pre-Adj region, before articulation of the adjective. This pattern is consistent with theories of language production, which hold that at

least some verb information is used during initial planning of utterances (e.g., Lindsley, 1975; Meyer, 1996).

Why did our speakers with agrammatic aphasia show different time course compared to young healthy speakers? Does the use of verb information in an earlier stage of sentence planning benefit speakers with agrammatic aphasia, perhaps providing a syntactic frame for an upcoming utterance, compensating for otherwise impaired syntactic processes? Alternatively, was the finding attributed to generally reduced cognitive resources due to ageing? Definitive answers to these questions cannot be gleaned from the present data. Further research is needed examining how various factors affect on-line sentence production, investigating normal and impaired sentence planning under differential processing conditions, including ageing (in particular, because we did not examine age-matched healthy speakers), non-native speakers, and under increased cognitive demands. The effects of different levels of deficits in aphasia (e.g., lexical semantic vs syntactic) and severity on aphasic sentence production, and the effects of different types of utterances (e.g., utterances with verb predication vs linear string of words) and tasks also requires additional investigation (see Spieler & Griffin, 2006, for evidence of differential production processes in young and older speakers during the production of multiple words with a copula verb).

To conclude, the present study provides novel findings that the linguistic distinction between unaccusatives and unergatives is associated with differential real-time sentence production processes by utilising the temporal links between eye movements and speech production. Both healthy speakers and speakers with agrammatic aphasia showed more pronounced differences in fixation times between the adjective and the noun when the integration of words into utterances involves a non-canonical syntactic derivation. Interestingly, speakers with agrammatic aphasia showed a different time course from young speakers, suggesting that while the unergative–unaccusative distinction is preserved in agrammatism, verb argument structure properties may play a role at an earlier stage of sentence planning in agrammatic compared to normal sentence production.

Acknowledgments

The authors acknowledge two anonymous reviewers for their comments. Special thanks go to the individuals with aphasia who participated in this study. This research was supported by NIH ROI- DC01948-16 (C. K. Thompson).

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Figure 1.
A set of sample visual stimuli for the unergative (left) and unaccusative (right) condition.

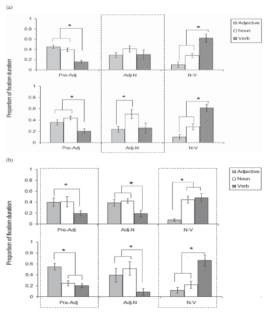

Figure 2.
Proportion of fixation durations to each word by speech region (squared regions indicate where speakers showed different fixation patterns in the unaccusative condition compared to the unergative condition). (a) Young control speakers, unergatives (top) vs unaccusatives (bottom). (b) Aphasic speakers, unergatives (top) vs unaccusatives (bottom).

TABLE 1

Aphasic participants' language testing scores

Language testing	**A2**	**A3**	**A4**	**A5**	**A6**	**A1**	**A7**	**A8**	**A9**	**Mean**
WAB										
AQ	82.4	71.2	74.5	74.4	81.9	81.4	87.6	69.2	78.5	77.7
Fluency	5	4	4	4	6	6	4	5	4	4.7
Comprehension	9.8	8.7	9	8.6	9.2	7.8	10	7.4	9.9	8.9
Repetition	10	7.6	9.6	7.2	6.8	9.2	9.7	6.3	6.4	8
Naming	9.3	7.3	6.7	8.4	10	9	9.1	7.9	9.5	8.5
NAVS										
Verb Naming	91	85	85	76	38	86	88	56	91	76
Verb Comprehension	100	100	97	100	100	100	100	100	100	100
Argument Structure Production										
1-place (intransitive) verbs	100	100	100	100	88	100	100	100	100	97
2-place (transitive) verbs	95	100	100	100	79	94	100	75	100	97
3-place (dative) verbs	88	83	89	83	78	93	94	85	67	81
Sentence Priming Production										
Canonical sentences	100	93	80	53	100	100	100	87	100	90
Non-canonical sentences	86	60	53	0	67	66	53	33	40	51
Sentence Comprehension										
Canonical sentences	100	80	87	93	87	100	100	67	87	89
Non-canonical sentences	93	80	73	40	67	40	93	33	67	65

TABLE 2

Statistical results for eye movement data

	Pre-Adj region		Adj-N region		N-V region	
	Z	**p-value**	**Z**	**p-value**	**Z**	**p-value**
Healthy speakers, Unergative Condition						
Adjective vs Noun	0.863	0.388	1.255	0.209	2.223	0.026*
Adjective vs Verb	2.903	0.004*	0.000	1.000	2.667	0.008*
Noun vs Verb	2.903	0.004*	1.020	0.308	2.275	0.023*
Healthy speakers, Unaccusative Condition						
Adjective vs Noun	1.098	0.272	2.312	0.021*	2.353	0.019*
Adjective vs Verb	2.040	0.041*	0.089	0.927	3.059	0.002*
Noun vs Verb	2.432	0.015*	1.530	0.129	2.353	0.019*
Speakers with aphasia, Unergative Condition						
Adjective vs Noun	0.507	0.612	0.845	0.398	2.360	0.018*
Adjective vs Verb	2.197	0.028*	1.690	0.091	2.360	0.018*
Noun vs Verb	1.859	0.063	2.028	0.043*	0.338	0.735
Speakers with aphasia, Unaccusative Condition						
Adjective vs Noun	2.197	0.028*	0.507	0.612	1.572	0.116
Adjective vs Verb	2.197	0.028*	1.690	0.091	2.316	0.018*
Noun vs Verb	0.338	0.735	1.992	0.046*	2.028	0.043*

*$p < .05$.

APPENDIX

List of target sentences

Unergative condition (n =10)	Unaccusative condition (n =10)
The black dog is barking.	The black tube is floating.
The small rabbit is running.	The small egg is breaking.
The dirty cat is sleeping.	The dirty water is leaking.
The angry librarian is crying.	The angry visitor is coming.
The little mouse is jumping.	The little bottle is rolling.
The tall director is laughing.	The tall officer is stumbling.
The pretty model is walking.	The pretty plate is dropping.
The large lion is crawling.	The large boat is sinking.
The ugly writer is sneezing.	The ugly snowman is melting.
The lazy governor is coughing.	The lazy janitor is falling.

Although some of our unaccusative verbs have an accusative counterpart (e.g., *break*, *melt*), we classified all verbs whose single argument is assigned the theme role as unaccusatives, based on Levin and Rappaport-Hovav (1995) and Perlmutter (1978). Comparison of eye movement patterns between the alternating (e.g., *break*, *melt*) and non-alternating unaccusative verbs (e.g., *float*, *fall*) did not reveal significant differences (all *p*s > 1.0 for both control and aphasic group, Wilcoxon tests).