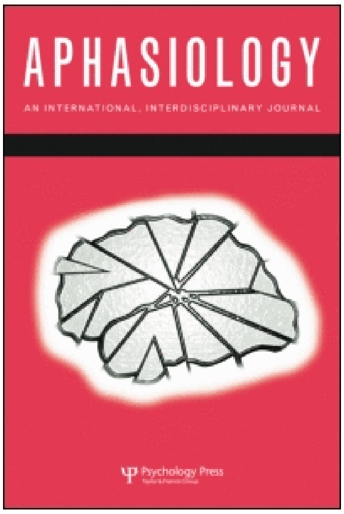

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Chance in agrammatic sentence comprehension: What does it really mean? Evidence from eye movements of German agrammatic aphasic patients

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Chance in agrammatic sentence comprehension: What does it really mean? Evidence from eye movements of German agrammatic aphasic patients

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Background: In addition to the canonical subject-verb-object (SVO) word order, German also allows for non-canonical order (OVS), and the case-marking system supports thematic role interpretation. Previous eye-tracking studies (Kamide et al., 2003; Knoeferle, 2007) have shown that unambiguous case information in non-canonical sentences is processed incrementally. For individuals with agrammatic aphasia, comprehension of non-canonical sentences is at chance level (Burchert et al., 2003). The trace deletion hypothesis (Grodzinsky 1995, 2000) claims that this is due to structural impairments in syntactic representations, which force the individual with aphasia (IWA) to apply a guessing strategy. However, recent studies investigating online sentence processing in aphasia (Caplan et al., 2007; Dickey et al., 2007) found that divergences exist in IWAs' sentence-processing routines depending on whether they comprehended non-canonical sentences correctly or not, pointing rather to a processing deficit explanation.

Aims: The aim of the current study was to investigate agrammatic IWAs' online and offline sentence comprehension simultaneously in order to reveal what online sentence-processing strategies they rely on and how these differ from controls' processing routines. We further asked whether IWAs' offline chance performance for non-canonical sentences does indeed result from guessing.

Methods & Procedures: We used the visual-world paradigm and measured eye movements (as an index of online sentence processing) of controls (N = 8) and individuals with aphasia (N = 7) during a sentence–picture matching task. Additional offline measures were accuracy and reaction times.

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Outcomes & Results: While the offline accuracy results corresponded to the pattern predicted by the TDH, IWAs' eye movements revealed systematic differences depending on the response accuracy.
Conclusions: These findings constitute evidence against attributing IWAs' chance performance for non-canonical structures to mere guessing. Instead, our results support processing deficit explanations and characterise the agrammatic parser as deterministic and inefficient: it is slowed down, affected by intermittent deficiencies in performing syntactic operations, and fails to compute reanalysis even when one is detected.

Keywords: Eye movements; Non-canonical sentences; Agrammatic aphasia; Broca's aphasia; Chance performance; Online and offline processing; Sentence comprehension disorders; German syntax.

INTRODUCTION

It has been well established for a long time that sentence comprehension in agrammatism is crucially determined by two factors: canonicity and reversibility (e.g., Grodzinsky, 1990). The common picture in agrammatism is that canonical structures, such as actives, subject relative clauses and subject clefts, are understood better than their non-canonical counterparts, namely passives, object relative clauses, object clefts, and object-topicalised sentences. However, this difference is additionally modulated by semantic reversibility, i.e., in contrast to irreversible sentences, reversible ones present problems for individuals with aphasia (IWAs) when they are in non-canonical word order (Burchert, De Bleser, & Sonntag, 2003; Caramazza & Zurif, 1976; Grodzinsky, Piñango, Zurif, & Drai, 1999).

Caramazza and Zurif's (1976) classic investigation made it clear that IWAs often perform at chance when they process semantically reversible non-canonical sentences. Since then it has become general practice to analyse the performance accuracy of IWAs in, for example, sentence–picture matching tasks by calculating percentage of correct responses in relation to chance level (e.g., 50% in a binary choice presentation where either the target or the foil can be chosen). This way of analysing data predicts three types of performance: above chance, below chance, and chance level. Usually above chance performance is taken to suggest a relatively preserved sentence comprehension, whereas below chance performance points to the application of an incorrect rule or strategy for sentence interpretation. Crucially, chance performance is seen as the result of guessing, i.e., a random choice between the two alternative interpretations of a reversible sentence (for example, Grodzinsky, 1990, 1995).

Two primary approaches have been proposed to explain IWAs' sentence comprehension deficit: the *impaired representation hypothesis* (Grodzinsky, 1986) and the *slowed processing account* (e.g., Burkhardt, Piñango, & Wong, 2003; Haarmann & Kolk, 1991; see also Dickey, Choy, & Thompson, 2007, for an overview). The impaired representation hypothesis assumes that the observed problems in comprehending non-canonical sentences are caused by damage to syntactic representations (e.g., Grodzinsky, 1995; Mauner, Fromkin, & Cornell, 1993). This damage causes IWAs to consistently construct qualitatively different syntactic representations compared to controls and to rely on processing heuristics to deal with non-canonical sentences.

The most prominent impaired representation account has been the *trace deletion hypothesis (TDH)* (Grodzinsky, 1986, 1990, 1995, 2000), which states that traces left behind after movement of a noun phrase (NP) in non-canonical sentences are deleted from the agrammatic sentence representation. This results in a thematic ambiguity of such structures because the Agent role is represented twice. For example, in non-canonical sentences with object-verb-subject order (OVS), one Agent would be assigned correctly to the subject position by grammar. However, the moved object in sentence-initial position cannot receive its correct thematic interpretation due to its trace being deleted. The parser therefore has to resort to a heuristic strategy that assigns the thematic role of Agent to the linearly first NP in the sentence resulting in a double-agent construction. The IWA then makes a guess about which of the two possible sentence interpretations is correct. The TDH thus predicts that agrammatic IWAs' comprehension of non-canonical reversible sentences should be at chance in contrast to canonical sentences, which should be interpreted correctly at above chance level.

Recently, these strong claims have been disputed from empirical, methodological, and linguistic viewpoints (for example, Berndt & Caramazza, 1999; Berndt, Mitchum, & Haendiges, 1996; Caplan 2001; Caramazza, Capasso, Capitani, & Miceli, 2005; Caramazza, Capitani, Rey, & Berndt, 2001; De Bleser, Schwarz, & Burchert, 2006). In a systematic review, Berndt et al. (1996) found that only a subset of the IWAs (33%) reported in the reviewed studies exhibited a comprehension pattern that was compatible with Grodzinsky and colleagues' assumptions. Overall, a high amount of variability was evident in IWAs' sentence comprehension abilities. De Bleser et al. (2006) emphasise that although different quantitative analyses have been presented to reconcile the apparent variability with the theoretical predictions, the variability problem remains unresolved. The authors make the case that the observed performance variability in sentence comprehension in aphasia should not be dismissed but rather explained theoretically.

Slowed processing accounts provide an alternative explanation of comprehension deficits in aphasia. This class of theory assumes a causal relationship between limitations in IWAs' processing capacities and sentence comprehension deficits. They argue that IWAs' syntactic representations and their structural knowledge are unimpaired, and hence do not differ qualitatively from those of comprehenders without history of neurological impairment. Instead, the processing system is assumed to be affected by a pathological slowdown (e.g., Haarmann & Kolk, 1991), which might be due to reduced buffer size, slow activation, or a too-fast decay of structural information. Other authors assume a slow-down in the reactivation of lexical items (Swinney & Zurif, 1995), slowed online assembly of phrase structure (Burkhardt et al., 2003), or a delay in the formation of a fast-acting syntactic representation due to which purely semantic mechanisms for sentence comprehension emerge (Piñango 2000a, 2000b). Caplan and colleagues (Caplan, Waters, DeDe, Michaud, & Reddy, 2007) describe a processing deficit that involves limitations in available working memory resources, which in turn do not allow IWAs to deal with several syntactic operations simultaneously.

The overwhelming majority of studies investigating sentence comprehension in aphasia have traditionally used common offline tasks (e.g., sentence–picture matching, sentence–picture verification, acting-out). However, performance patterns derived from offline data ". . . can mask the nature of underlying online processing deficits" (Wassenaar & Hagoort, 2007, p. 739). Caplan et al. (2007) point out that aphasic offline performance only discloses the end-product of sentence comprehension, and one can assume that both residual online processing abilities and compensation have a share in the comprehension process. Thompson and colleagues (Dickey et al., 2007; Dickey & Thompson, 2009; Thompson & Choy, 2009) argue convincingly in favour of a simultaneous investigation of online and offline sentence processing in aphasia because it provides new insights into the nature of the underlying comprehension deficit. They investigated IWAs' online processing of non-canonical sentences in English using the *visual-world paradigm* (initially Cooper, 1974; see also Trueswell & Tanenhaus, 2004). In these studies eye movements of IWAs were monitored while they looked at visual displays depicting different objects, some of which were mentioned in auditory sentences. The authors found that, compared to control participants, qualitative deviations in IWAs' eye-movement patterns were only evident for trials eliciting incorrect responses and emerged only towards the end of a sentence.[1] In contrast, no deviation was seen for correct responses. Furthermore, no evidence for a delay in applying automatic processing routines was found. Caplan et al. (2007), using a self-paced listening task, also found that IWAs' online syntactic processing resembled normal processing whenever their offline response was correct. In contrast, online routines resulting in incorrect offline responses were marked by significant task effects and abnormal patterns in listening times. Caplan et al. argue that these findings point to deviant underlying processing mechanisms and intermittent disruptions in parsing for IWAs.

Dickey et al. (2007) suggest that it is neither a pathological slowdown in processing at the syntactic level nor impaired representations that is responsible for sentence comprehension difficulties in aphasia. Instead, based on Avrutin (2006), they argue for a *weakened syntax* approach on sentence comprehension disorders under which "the effect of damage to cortical tissue involved in building syntactic structure is not to fundamentally change the kinds of syntactic computations that are carried out, but instead to weaken the output of those computations" (Dickey et al., 2007, p. 17). This results in a high vulnerability for influence from intervening competitor interpretations.

The findings from these recent online studies on sentence comprehension disorders in aphasia challenge the central claim of the TDH, i.e., that agrammatic IWAs resort to guessing when processing non-canonical sentences, resulting in chance performance. Specifically, the TDH cannot explain why IWAs can ever apply normal-like sentence-processing routines to interpret non-canonical sentences correctly and why deviant fixation patterns are found for incorrect responses whereas non-deviant patterns accompany correct responses. If IWAs were uniformly applying a "guessing-as-last-resort strategy" in deriving the meaning of a non-canonical sentence, reaction times (cf. the study by Caplan et al., 2007) and eye-movement patterns (Dickey et al., 2007; Dickey & Thompson, 2009) would not have revealed such systematic differences. Thus, as Caplan and Waters (2003) put it, the chance-level performance could better be understood as ". . . correct interpretations of some sentences and incorrect interpretations of others" (p. 246), whereby incorrect responses are assumed to be due to disruptions in parsing that happen only occasionally. In this article we apply this idea to investigate online processing of a special type of non-canonical sentences in German agrammatic aphasia, and argue that such online investigation is critical in evaluating theories of sentence comprehension deficits in aphasia to reveal the true meaning of chance performance.

[1]By qualitative deviations we refer to differences in eye movements between controls and IWA that do not merely reflect a delay in an otherwise similar fixation pattern (which would be a quantitative difference) but which constitute a structurally different pattern of fixations to the objects or depicted events presented (cf. also Dickey et al., 2007).

Healthy and impaired processing of non-canonical sentences with object-verb-subject order in German

German canonical word order is subject-verb-object (SVO) in main clauses (1a) but the object NP can also be moved out of the verb phrase to the sentence-initial position (the Specifier position of CP) to derive a non-canonical object-verb-subject (OVS) order (1b).

(1)	a.	Der Sohn	küsst	den Vater.
		the_{NOM} son	is kissing	the_{ACC} father
	b.	Den Vater	küsst	der Sohn.
		the_{ACC} father	is kissing	the_{NOM} son
		"The son is kissing the father."		

The relatively rich German case-marking system interacts with the free word order and, at least in case of masculine NPs, allows for correct thematic role interpretation. The accusative case marker on *den Vater* "the_{ACC} father" in (1b) unambiguously signals that it is a moved object in a non-canonical OVS sentence. The nominative case marker on the NP *der Sohn* "the_{NOM} son" in (1a) signals that it is the grammatical subject of the sentence; however, its thematic role may remain temporarily ambiguous because the sentence could still be passive (*Der Sohn . . . wird vom Vater geküsst*. – "The son is kissed by the father."). This temporary thematic ambiguity is resolved as soon as the verb appears (*küsst* versus *wird*).

Earlier behavioural studies of OVS order in simple German sentences (Gorrell, 2000; Hemforth, 1993) and object relative clauses (Schriefers, Friederici, & Kühn, 1995) found that adults take longer to process such sentences compared to canonical ones. Increased processing demands were also found with other experimental methods such as event-related potentials (Mecklinger, Schriefers, Steinhauer, & Friederici, 1995) and eye-tracking (Kamide, Scheepers, & Altmann, 2003; Knoeferle, 2007), although for eye-tracking studies the effect of word order and its interaction with case-marking is not uncontroversial. Thus both Kamide et al. and Knoeferle argue that unambiguous case-marking in German in both SVO and OVS sentences is processed in an incremental fashion and rapidly integrated into the sentence interpretation.

German IWAs have substantial difficulties when processing semantically reversible OVS sentences. Burchert et al. (2003) examined processing of SVO and OVS sentences in aphasia using a sentence–picture verification task. This study investigated whether it was possible to identify a subgroup of IWAs whose comprehension pattern fell within the predictions of the TDH even when unambiguous morphological cues are present. Unambiguous case markers in non-canonical sentences could potentially make a difference compared to English non-canonical sentences if German morphology circumvents the effects of deleted traces and overrides the application of a cognitive strategy to assign thematic roles (which would be assumed by the TDH).

The results indicated that enriched morphology did not generally make a difference in the error pattern. However, this was true for only one out of five IWAs. Other IWAs performed above chance on both case-marked canonical and non-canonical sentences, similar to the control group, and two IWAs were generally at chance for canonical and non-canonical sentences. Thus this study supported the conclusion from the literature that the TDH can explain only part of the data on agrammatic sentence comprehension but not the whole set of observed patterns.

Purpose of the study

We made use of the visual-world paradigm to investigate online processing of canonical and non-canonical declarative sentences in German agrammatic aphasia and compared it to that of adults without history of neurological impairments. We applied a sentence–picture matching task to examine online and offline processing simultaneously by measuring eye movements as well as accuracy and reaction times. We address three main questions. First, based on the contradictory findings from previous offline versus eye-tracking studies, we sought to shed new light on the time-course of processing German case-marked OVS sentences in adults. Does the case-marking on the first NP in OVS sentences direct listeners' eye movements to fixate the correct picture (the one that matches the sentence) already during the presentation of the verb and does this fixation preference for the target picture emerge at the same point in time as in SVO sentences?

Second, we aimed at extending Dickey et al.'s (2007) previous results for English IWAs' online processing of *Wh*-questions to German IWAs' online processing of canonical (SVO) and non-canonical (OVS) sentences. We expected to find that German IWAs would show eye-movement patterns qualitatively similar to controls in those trials where they interpret the sentence correctly. In addition, we investigated the online processing strategies IWAs rely on, and how they differ from those of control participants for the incorrectly interpreted SVO and OVS sentences.

Finally, our results contribute new evidence to the theoretical debate between the TDH, slowed processing, and weakened syntax accounts, and argue against the TDH, i.e., taking chance performance in sentence comprehension in aphasia as reflecting mere guessing.

METHOD

Participants

The participants were seven individuals with agrammatic Broca's aphasia and eight age-matched controls without history of neurological impairment. All were native speakers of German, and all but one (A1) were (pre-morbidly) right-handed. All control participants demonstrated normal or corrected-to-normal vision and hearing. For the IWAs, no obvious visual or hearing problems were evident given their performance on standardised aphasia tests involving visual and auditory stimuli. The IWAs were classified as Broca's using the ALLOC syndrome classification of the Aachen Aphasia Test (Huber, Poeck, Weniger, & Willmes, 1983). Their spontaneous speech was non-fluent and characterised by agrammatic symptoms. Sentence comprehension also exhibited the agrammatic pattern predicted by the TDH, with above-chance performance on canonical sentences and chance performance on non-canonical ones.[2] For the six right-handed IWAs, the lesion was localised in the left hemisphere,

[2]Chance performance was determined by carrying out a non-parametrical analysis of performance levels. The comprehension screening for canonical and non-canonical sentences (a sentence–picture matching task with two pictures) encompassed 20 items per condition. Hence, the chance value was at 50%, i.e., 10 correct responses. We calculated the chance range using the Fisher's exact test (one-sided) by comparing possible distributions of correct and incorrect responses against the 50% chance distribution (for example, comparing 10 correct and 10 incorrect responses against 12 correct and 8 incorrect answers). This procedure revealed that only a score that amounted to fewer than 4 incorrect answers (20%) or more than 15 correct responses (75%) was significantly different from chance. Therefore, scores that fell between 20% and 75% correct responses were considered as chance performance. This was true for each of the individuals with aphasia.

TABLE 1
Demographic data, all participants and neurological data, participants with aphasia

Participant	*Age*	*Gender*	*Education level (years)*	*Aphasia classification and severity*	*Aetiology and localisation*	*Years post-onset*
A1	54	M	High School (10)	Broca medium / mild	haemorrhagic, fronto-parietal right	14
A2	59	F	A-level (12)	Broca medium / mild	haemorrhagic, middle cerebral artery left	16
A3	70	M	High School (10)	Broca medium	ischaemic, left	19
A4	59	M	High School (10)	Broca medium	ischaemic, middle & posterior cerebral artery left	12
A5	35	F	High School (10)	Broca mild	ischaemic, middle cerebral artery left	9
A6	67	M	High School (10)	Broca medium / severe	ischaemic, middle cerebral artery left	11
A7	32	F	A-level (12)	Broca medium	haemorrhagic, middle cerebral artery left	5
C1	50	F	A-level (12)	n/a	n/a	n/a
C2	46	F	A-level (12)	n/a	n/a	n/a
C3	47	F	High School (10)	n/a	n/a	n/a
C4	63	M	A-level (12)	n/a	n/a	n/a
C5	47	F	High School (10)	n/a	n/a	n/a
C6	55	F	A-level (12)	n/a	n/a	n/a
C7	58	M	A-level (12)	n/a	n/a	n/a
C8	53	F	High School (10)	n/a	n/a	n/a

A = participants with aphasia; C = control participants; M = male; F = female; n/a = not applicable.

while the left-handed person had a lesion in the right hemisphere. They were between 32 and 70 years of age (M = 54) and post-onset time ranged between 5 and 15 years (M = 12). The control participants were between 46 and 63 years of age (M = 52). Demographic data for all participants and neurological data as well as syndrome classification and severity of aphasia for the IWAs are provided in Table 1. In order to control for possible confounds due to differences in age and education, the respective group data have been analysed statistically. There was no statistically significant difference between the two groups (factor age: $M_{IWA} = 53.71$, $M_{CONTR} = 52.29$, $U = 19$, $p = .535$, two-tailed; factor years of school: $M_{IWA} = 10.14$, $M_{CONTR} = 11.43$, $U = 13$, $p = .165$, 2-tailed). Hence both groups can be considered to be matched with regard to age and education.

Materials

Materials for this study consisted of single sentences presented simultaneously with pairs of pictures. There were 88 trials: 40 experimental, 40 filler, and 8 practice items.

Linguistic stimuli. We selected 22 German transitive verbs that described simple events. For each verb, four different semantically reversible sentences were constructed: canonical active (2a), non-canonical active (2b), low-complexity passive (2c), and high-complexity passive (2d). A total of 20 of each the canonical and non-canonical active sentences made up the experimental items, while high and low-complexity passives, also 20 of each, served as fillers. The practice items consisted of the four different sentences of two verbs so that for each sentence type two sample sentences were included in the practice set.

(2)	a.	Der Sohn	fängt	den Vater.		[canonical active]
		the_{NOM} son	is catching	the_{ACC} father		
		"The son is catching the father."				
	b.	Den Sohn	fängt	der Vater.		[non-canonical active]
		the_{ACC} son	is catching	the_{NOM} father		
		"The father is catching the son."				
	c.	Der Sohn	wird	gefangen.		[passive low]
		the_{NOM} son	is being	caught		
		"The son is being caught."				
	d.	Der Sohn	wird	vom Vater	gefangen.	[passive high]
		the_{NOM} son	is being	by the_{DAT} father	caught	
		"The son is being caught by the father."				

Canonical sentences (2a) had simple SVO word order, while non-canonical ones (2b) had OVS structure. In passives with high-complexity (2d) there was a *by*-phrase between the auxiliary and the verb participle, which was omitted in passives with low-complexity (2c).

The nouns were matched for frequency using the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). They were morphologically simple, animate, and of masculine gender. Each NP was overtly and unambiguously case-marked at the determiner. All verbs were of low frequency (determined using the CELEX database). (All the experimental and filler sentences are listed in Table A1 in the Appendix.)

Sentences were recorded by a female native speaker of German using a digital microphone (Hama HS-20). They were spoken with a neutral prosodic contour, which was kept constant across all sentence types and at a speech rate of 4.11 syllables per second for SVO sentences and 3.93 syllables per second for OVS sentences. These rates fall well into the range of 3–6 syllables per second considered to be normal speech rate (Levelt, 2001; Yorkston, Beukelman, Strand, & Bell, 1999). The recordings were subsequently normalised using Wavelab 4.0 software by Steinberg Media Technologies.

Visual stimuli. The visual stimuli depicted 22 semantically reversible events and were rendered as 44 black-and-white line drawings arranged in pairs. Figure 1 illustrates the pair of pictures that accompanied the sample example in (2). They were "scene sketches" in the terminology of Henderson and Ferreira (2004), which depict a limited number of different objects interacting in a semantically coherent and meaningful fashion. The two pictorial versions of each event differed with respect to the mapping of the thematic roles on the two participants of the event (Figure 1). In one version, one of the characters was the agent of the action (e.g., the son is catching the father in Figure 1B) while in the second version, the same person was depicted as the patient (the father is catching the son in Figure 1A).

All pictures were of comparable size and scene content. They were controlled for naming and comprehension agreement in a norming study in which 30 students from the University of Potsdam had participated. The direction of the action was balanced across all pictures; i.e., an equal number of pictures had their action being directed to the left compared to those in which the action direction was to the right. The importance of balancing the action directions when using depicted events in eye-tracking

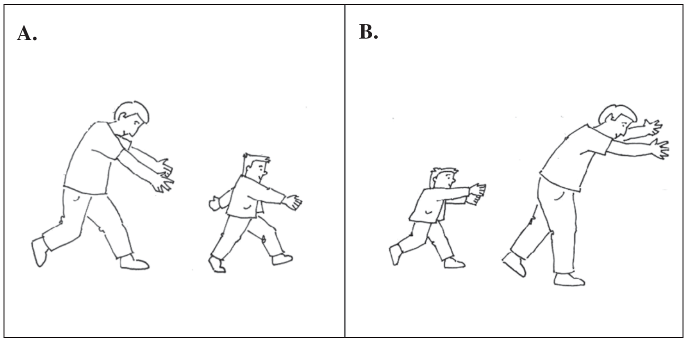

Figure 1. Sample visual display. Non-canonical (OVS) example: *Den Sohn fängt der Vater* "The father is catching the son". (A) Correct picture (target). (B) Wrong picture (foil).

studies was pointed out by Scheepers and Crocker (2004) because it helps to avoid preferred scanning preferences in terms of a simple from-left-to-right viewing strategy.

Procedure

A presentation list was constructed in which each experimental item was paired with a filler item. Half of the sentences from each of the two experimental conditions were randomly matched with fillers from the set of high-complexity passives. The other half formed a pair with one of the low-complexity passives, which again were chosen at random. Each participant received a randomised individual presentation of the list in which an experimental item always preceded or followed a filler item in such a way that two experimental items from the same condition were never adjacent. The experiment was conducted using DMDX software (Forster & Forster, 2003).

Participants performed a sentence–picture matching task. They listened to the sentence while viewing the pair of pictures, and then selected the picture that best matched the sentence. Control participants were run in a laboratory on campus while IWAs participated in the study at their homes. Participants' eye movements were monitored using an ISCAN ELT-500 remote portable eye-tracker (sampling rate: 60 Hz, error rate: less than 1 degree of visual angle). Participants were comfortably seated at approximately 60 cm from the stimuli laptop monitor (screen size: 17 inches, resolution: 1280 × 1024 pixels). At the set viewing distance, the characters depicted in the stimulus pictures (e.g., the father and the son in Figure 1) subtended 3–4° visual angle, which is within the resolution of the eye-tracker.

Two portable loudspeakers connected to the laptop delivered the sound. Prior to the experiment, a short calibration procedure was performed to assess eye position and visual acuity that required participants to fixate five calibration points on the laptop monitor. Additional calibration was performed during the study when necessary. All participants successfully completed the calibration procedure. Participants who used glasses or contact lenses wore them during the experiment.

Instructions were presented in written form as several opening screens of the experiment, immediately after the calibration procedure was complete. In addition, the second experimenter also read the instructions out loud to the IWAs. The instructions required the participants to view the picture pair, listen to the spoken sentence and use the keyboard to choose the picture that matched the sentence.[3] Participants were instructed to give their answers by pressing one of the two buttons on a keyboard using two fingers of the left hand.[4] All other buttons of the keyboard were covered with cardboard.

Each trial started with the 700-ms presentation of a blinking smiley face in the middle of a white screen. This was designed to attract participants' attention and direct their eye gaze to the centre of the screen. Then the picture pair (i.e., target and foil picture), shown next to each other separated by a black vertical line (see Figure 1), appeared simultaneously with the spoken sentence. The position of the target picture was counterbalanced across trials, with no more than three consecutive trials on the same side of the screen.

After the practice phase, the participant was given the opportunity to ask questions to make sure that the task was clear. In addition to eye movements, we collected response accuracy and reaction times, the latter being measured from the beginning of the trial. Reaction times exceeding 15 s were considered time-outs and were recorded as "no response". For control participants the entire experiment lasted approximately 20–30 minutes (test phase 8–10 minutes). For the IWAs the experiment took between 30 and 60 minutes (test phase 15–30 minutes).

Data analysis

For the 40 experimental sentences, we defined four *regions of interest* (ROIs)[5] based on the sentence constituent structure, as shown in Table 2. The pre-verbal NP region was the first NP consisting of the determiner and head noun, the second region was the verb, the post-verbal NP region included the second determiner and head noun, and the final region was the post-offset region (not shown in Table 2), i.e., the period of silence after the presentation of the spoken sentence until the participant's response (the button push) that indicated the trial's end.

ROI durations were calculated for each experimental item separately using Wavelab 4.0 software. For the analysis of eye movements, we used individual ROI durations per item, while for statistical comparisons of mean region durations we used averages. For items in the canonical condition, mean duration of the entire sentence was slightly shorter compared to non-canonical sentences, 1463 ms vs 1532 ms, but the difference was not significant ($t(37) = -1.124$, $p = .268$). Additional t-tests showed that the mean durations of ROIs did not differ across the two conditions: pre-verbal

[3]It must be noted that no screening of motor responsiveness was done with the individuals with aphasia and of course motor ability plays an important role in the design we used. However, the ability to give motor responses to the task was observed and judged by the two experimenters during the practice phase of the experiment. In addition, we had determined a maximum response time of 15000 ms and answers exceeding this time span were considered time-outs. Hence, if any participant had striking deficits in motor responsiveness, we would have expected many time-outs. However, this was not the case for neither of the participants.

[4]For patient A1, who had a lesion in the right hemisphere and was pre-morbidly left-handed, the left hand was hemiparetic. Therefore two mirror buttons on the right side of the keyboard were used, and he was instructed to use two fingers of his right hand.

[5]We use the term ROI to refer to a specific part of the auditory sentence presented together with the two pictures. In using this term that way (and not for a specific area of the visual display), we oriented ourselves towards visual-world studies by for example Knoeferle and colleagues (Knoeferle, 2007; Knoeferle, Crocker, Scheepers, & Pickering, 2005) and Altmann and colleagues (Altmann & Kamide, 1999, 2004; Kamide et al., 2003).

TABLE 2
Regions of interest (ROI) and their mean duration, ms

Condition	*Pre-verbal NP M (SD)*	*Verb M (SD)*	*Post-verbal NP M (SD)*	*Translation*
Canonical	Subject-NP		Object_NP	
	Der Sohn	*fängt*	*den Vater.*	the$_{NOM}$ son is catching the$_{ACC}$ father
	569 (98)	372 (104)	678 (74)	"The son is catching the father."
Non-canonical	Object-NP		Subject-NP	
	Den Sohn	*fängt*	*der Vater.*	the$_{ACC}$ son is catching the$_{NOM}$ father
	644 (91)	400 (113)	661 (105)	"The father is catching the son."

NP: $t(37) = -2.581$, $p = .141$; verb: $t(37) = -1.075$, $p = .289$; post-verbal NP: $t(37) = 1.116$, $p = .271$. Therefore, both experimental conditions were matched in terms of ROI durations.

For analysis of eye movements, a fixation was defined whenever the eyes were in a stable position in one spot and remained there still for least three frames (= 100 ms).

Predictions

For controls, we expected accuracy to be at ceiling in both experimental conditions. Based on the literature reviewed above, non-canonical sentences were expected to impose higher processing demands on the language comprehension system. Therefore we predicted longer reaction times for OVS compared to SVO sentences.

In IWAs, we expected accuracy to be consistent with the pattern found in previous aphasia studies, i.e., a severe impairment for non-canonical sentences, with canonical structures being significantly less impaired. We also expected their reaction times to be longer than controls'. In addition, similar to controls, IWAs' RTs for non-canonical sentences should be longer compared to canonical ones. Finally, if non-canonical sentences impose a disproportionately higher processing load on the impaired sentence comprehension system, it should manifest itself as an interaction between Sentence Type and Participant Group, resulting in a more pronounced canonicity effect in IWAs compared to controls. Following Dickey et al.'s (2007) suggestion, we also expected to observe an effect of response accuracy on reaction times in the IWAs; i.e., RTs should be substantially longer for incorrectly answered sentences compared to correctly answered trials.

In terms of control participants' online sentence processing, we expected to find very similar eye-movement patterns for both sentence types if the overt unambiguous case-marking in OVS sentences is being processed incrementally. In this case, controls should show significantly more fixations on the correct picture already in the verb region. However, if the higher processing load associated with the non-canonical word order is present regardless of overt case-marking, then a fixation preference for the target picture should emerge only later.

As far as IWAs were concerned, a central issue in our study was to evaluate a crucial assumption of the TDH, in particular that chance performance reflects the agrammatic individuals' guessing when trying to identify the correct meaning of a non-canonical sentence, with their "seemingly" correct answers resulting from a "guessing-as-last-resort-strategy". If this is correct, we should find qualitatively different online processing of non-canonical sentences in IWAs compared to controls regardless of whether IWAs' sentence comprehension was successful or not. Thus, TDH would lead us to expect qualitative deviations in IWAs' fixation patterns relative to controls *regardless of whether they identified the picture correctly or not.*

RESULTS

Statistical data analysis: Linear mixed models

We used linear mixed models (LMMs) to analyse the results. LMMs have several advantages over repeated measures ANOVA, one of them being that they allow by-item and by-participant variance to be taken into account simultaneously, making separate analyses, or *min-F'* estimates, (Clark, 1973; Raaijmakers, Schrijnemakers, & Gremmen, 1999) redundant. (See also Baayen, 2008, and the 2008 special issue on emerging data analysis in the *Journal of Memory and Language, 59*(4), for further discussion of this issue.) Another important property of generalised linear mixed models is that extreme values (outliers) are prevented from introducing biases in the estimation of model parameters (so-called shrinkage); this property of LMMs is particularly relevant in the present research, where the participant sample size is of necessity relatively small. Although ordinary parametric methods could be unreliable in such data, LMMs are robust to outliers. Details about shrinkage are discussed in Gelman and Hill (2007, pp. 252–259).

Unless stated otherwise, we present coefficient estimates, their standard errors, and *t*- or *z*-scores (depending on the dependent measure). An absolute *t*-score of 2 or greater indicates significance at the alpha level of .05. Note also that the *t*-score is not accompanied by degrees of freedom or *p*-values. This is because in linear mixed models degrees of freedom can only be approximated (Baayen, 2008; Gelman & Hill, 2007). The statistical analyses on reaction times were carried out on log-transformed values. We report the log-transformed analyses because linear models based on untransformed reaction times generally do not meet the assumptions of additivity and linearity (Gelman & Hill, pp. 59–65).

For comprehension accuracy and reaction times, when we use ordinary parametric methods such as *t*-tests, we also report results of conventional statistical comparisons using non-parametrical tests. In general, these analyses confirm the results we obtained using LMMs. We do not report non-parametric statistics for the eye-movement data because LMMs are robust to outliers, as discussed above.

Comprehension accuracy

We fitted a generalised linear model using a binomial link function, with Sentence Type and Participant Group as fixed factors, and items as a random factor. The analysis showed that IWAs (coded as 1) performed worse on average in accuracy compared to controls (coded as –1) (coefficient = –1.22955, *SE* = 0.17531, *z*-score = –7.014, $p < .01$). Table 3 shows that comprehension accuracy for non-canonical sentences was lower than for canonical ones (coefficient = –0.83465, *SE* = 0.17531, *z*-score = –4.761, $p < .01$) in IWAs. It must be noted that one control participant (HN) only matched 13 out of the 20 non-canonical sentences correctly to the corresponding picture. If this participant is included in the analysis, controls' mean comprehension accuracy

TABLE 3
Comprehension accuracy as a function of Sentence Type and Participant Group, means and standard errors, %

	Participant Group	
Sentence Type	*Controls*	*IWAs*
Canonical	98.12 (1.07)	80.29 (3.14)
Non-canonical	93.52 (2.09)	46.37 (4.26)

in the non-canonical condition is 89.93 % (*SE* = 2.39). However, although results of statistical comparisons do not change, we excluded this participant from the analysis, because such a high error rate is very uncommon for German adults without any history of neurological impairment if one compares it to the usual mean of adults' correct responses in psycholinguistic studies using such sentence structures; see for example the studies by Knoeferle and colleagues or Mecklinger and colleagues cited above.

Analysing the unaggregated accuracy data using logistic regression with a binominal link function, we found no interaction between Sentence Type and Participant Group ($z < 1$). However, visual inspection of the data pattern indicated that an interaction exists, and we hypothesised that using aggregated data for analysis might show this effect. Comparing the two differences in proportions of correct answers using an unpaired *t*-test confirmed that an interaction exists between Sentence Type and Participant Group, $t(8) = 5.19$, $p < .001$, two-tailed.

Non-parametrical statistical analyses also revealed that IWAs performed worse than controls in both conditions (canonical: Mann-Whitney, $U = 0$, $z = -3.32$, $p < .001$; non-canonical: Mann Whitney, $U = 0$, $z = -3.12$, $p < .001$). Likewise, non-parametrical tests also confirmed that there is an effect of Sentence Type on IWAs' performance (Wilcoxon signed-rank, $T = 0$, $p = .018$) but not on controls' accuracy (Wilcoxon signed-rank, $T = 2$, $p > .05$), pointing to the interaction between Sentence Type and Participant Group.

Reaction time data

Figure 2 shows reaction time data, i.e., the time it took the participants to determine which picture is correct measured from the moment the picture pair appeared on the screen until the button push. Treating Sentence Type, Participant Group, and Response

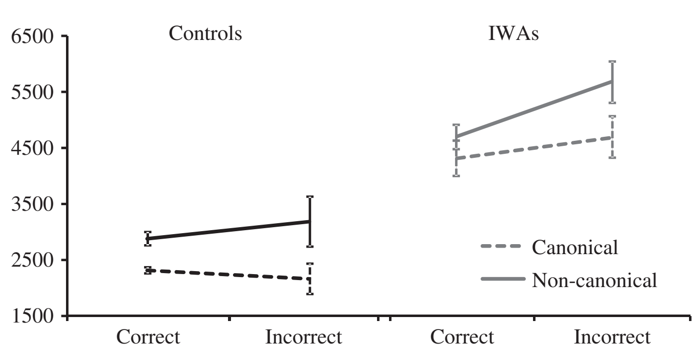

Figure 2. RTs as a function of Sentence Type, Participant Group, and Response, ms.

(*correct*, coded as 1, and *incorrect*, coded as 0) as fixed factors, and items as a random factor, IWAs' RTs were found to be significantly longer than controls' (coefficient = 0.26496, $SE = 0.017$, $t = 15.22$). In addition, the non-canonical sentences elicited longer RTs than the canonical ones (coefficient = 0.07155, $SE = 0.016$, $t = 4.30$). No interaction was found between Sentence Type and Participant Group ($t < 1$). Finally, IWAs' correct responses were faster than their incorrect responses (coefficient = –0.116, $SE = 0.046$, $t = -2.54$).

The effect of Participant Group on RTs was also found when we used non-parametrical statistical comparisons; IWAs were slower than controls in both conditions (canonical: Mann-Whitney, $U = 0$, $z = -3.24$, $p < .001$; non-canonical: Mann Whitney, $U = 6$, $z = -2.36$, $p < .01$). Likewise, non-parametrical analyses confirmed the effect of Sentence Type on RTs for controls (Wilcoxon signed-rank, $T = 0$, $p = .018$). For IWAs, non-parametrical comparisons did not show the effect of answer type (correct or incorrect) on reaction times (canonical sentences: Wilcoxon signed-rank, $T = 12$, $p = .37$; non-canonical: Wilcoxon signed-rank, $T = 10$, $p = .25$).

Eye movements

For eye-movement analyses, we operationalised the dependent variable as the proportions of fixations to the two pictures (correct vs wrong). In order to compute these, the fixation proportions to each character in a picture (Agent and Theme) were analysed by participant, so that for each participant one data point corresponded to each character in the picture. Following this, we compared proportions of fixations to the correct versus wrong picture, i.e., we took the sum of fixations to the Agent and Theme character in the correct picture and compared it to the sum of fixations to the characters in the wrong picture. In all figures, asterisks indicate a statistically significant difference between these two sums. Controls' data consisted of their correct responses in the sentence–picture matching task, and because they generally performed at ceiling, this constitutes most of their data. IWAs' data were partitioned into correct and incorrect trials and these two datasets were compared with the controls'. Each ROI (see Table 2) was analysed separately. A simple linear model was fitted in each analysis (instead of a mixed model) because participant variance was quite low.

We first present the comparison between both participant groups' fixation proportions when only IWAs' correct trials are considered (Figure 3A–D). As can be seen in Figure 3A, in canonical word order, control participants started to reliably fixate the correct picture at the onset of the Object-NP. The IWAs took longer (Figure 3B): they showed a significantly greater proportion of fixations to the correct picture starting at the post-offset region. In non-canonical order (Figure 3C and D), IWAs' fixations resembled controls' in that both groups had a significantly greater proportion of fixations to the correct picture from the onset of the Verb, i.e., from relatively early on.

Consider now those trials in which the IWAs made an incorrect response (Figure 3E and F). Here their fixation pattern is quite different from that of controls. In both canonical and non-canonical sentences, the IWAs tend to fixate the wrong picture more than the correct one. Inspection of the dynamics of eye movements for the canonical sentences (Figure 3E) reveals a U-shaped pattern: during the Subject-NP region, IWAs start with fixating the wrong picture, then at the Verb, fixations on the wrong picture decrease but in the post-offset region proportions of fixations to the wrong picture go up again. This brief decrease of fixations to the wrong picture during

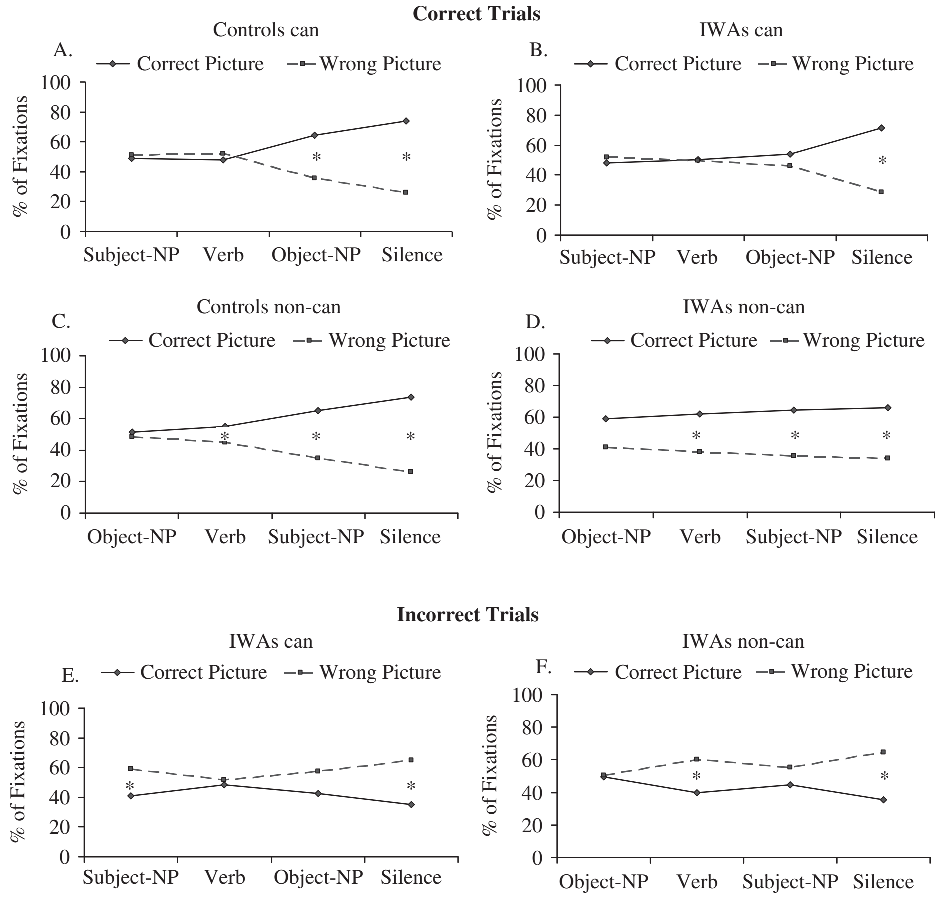

Figure 3. Fixation proportions to correct vs wrong picture as a function of Sentence Type, Participant Group, and Response (for IWAs only). (A) Controls, canonical sentences. (B) IWAs, correct trials, canonical sentences (80.29% of trials). (C) Controls, non-canonical sentences. (D) IWAs, correct trials, non-canonical sentences (46.37% of trials). (E) IWAs, incorrect trials, canonical sentences (19.71% of trials). (F) IWAs, incorrect trials, non-canonical sentences (53.63% of trials).

the Verb region could be indicative of increasing uncertainty although it did not result in a reanalysis that often follows such uncertainty. The IWAs thus did not show any signs of revision of the incorrect structure that they were constructing.

A similar pattern was also found for the non-canonical sentences for which the IWAs made incorrect responses (Figure 3F). Although there was no preference to fixate the wrong picture during the Subject-NP region, the fixation proportions to the wrong picture increased significantly during the Verb region and remained high during the post-offset region as well. (Table A2 in the Appendix lists coefficients, standard errors and *t*-values for analyses of eye movements.)

Summary of results

To summarise the findings: As expected, controls were almost at ceiling in choosing the correct picture in both conditions while the IWAs had some difficulties with canonical sentences and were at chance level in the non-canonical condition. The response latencies, on the other hand, showed that both participant groups were slower in processing non-canonical order compared to canonical order, but the IWAs were overall slower than controls. Absence of interaction between Sentence Type and Participant Group for reaction time measures is indicative of the idea that the effect of non-canonical word order on reaction times was not more pronounced in IWAs than in the control group. Finally, eye-movement patterns showed that when the IWAs processed the sentences correctly, their eye movements were quite similar to those of the controls but (at least for canonical sentences) they took longer in settling on the correct picture. It is only in the incorrectly answered sentences that we see the fixation patterns of the IWAs diverge from those of the controls.

DISCUSSION

The aim of this study was to test the assumptions set up by the trace deletion hypothesis concerning online sentence processing in agrammatic aphasia. Applying the visual-world paradigm allowed us to assess the basic claim of the TDH, namely that IWAs rely on a guessing strategy when trying to identify the correct meaning of non-canonical reversible sentences, resulting in their chance performance for these structures. We employed a sentence–picture matching task with simultaneous offline (accuracy and reaction times) and online (eye movements) measures to examine impaired as well as unimpaired sentence processing of German OVS and SVO structures. We compared offline and online measures within and across sentence types as well as across participant groups.

The results contribute to three issues concerning the processing of non-canonical sentences. The first is the role and time-course of processing of unambiguous case-marking information in controls. The second is a number of similarities and differences in online processing between the controls and the IWAs that calls for a direct comparison of our findings with those of Dickey et al.'s (2007) for English-speaking IWAs. Finally, our results constitute novel evidence against the trace deletion hypothesis (Grodzinsky, 1995) and in favour of processing accounts of sentence comprehension disorders in aphasia (Caplan et al., 2007; Dickey et al., 2007). We argue further that chance performance in comprehending non-canonical sentences in Broca's aphasia is not due to guessing.

Controls' data are discussed first because impaired sentence processing can only be evaluated against the background of well-understood healthy processing routines. Several previous offline studies found that adults do not always take into consideration the accusative case marker in German non-canonical OVS sentences (e.g., Gorrell, 2000; Konieczny, 1996). In contrast, recent eye-tracking studies showed that case-marking information in these sentences can be used rapidly and incrementally to anticipate referents for upcoming sentence constituents (Kamide et al., 2003; Knoeferle, 2007). While our results support the view that case-marking information in OVS sentences is rapidly integrated, we also found evidence that the interpretation process as a whole is not immediate. Controls' eye movements do indicate that for OVS sentences the preference for the correct picture arose already during the verb region and this is earlier than in canonical sentences where such a fixation preference was only seen from the post-verbal NP region onwards. We speculate that the early fixation of the correct picture in OVS sentences is due to the fact that the first accusative-case-marked NP is sufficient to allow participants to predict the sentence's thematic interpretation; hence the fixation preference arises at the verb. In contrast, in SVO sentences, the pre-verbal NP does not deliver sufficient information to reveal the theta-role relations because the structure is also compatible with a passive sentence that we also used in our experiment. Thus the disambiguating information becomes available later and it is only at the verb that enough information is available to identify the thematic relations resulting in the correct picture being fixated reliably more often only from the post-verbal Object-NP onwards.

However, analysis of reaction times revealed that controls need more processing time to facilitate correct offline sentence comprehension of OVS sentences compared to canonical ones. Hence, although automatic online processing of overt case-marking information at the Object-NP in German OVS structures proceeds in an incremental fashion, the processing mechanism takes longer to determine the sentence's global grammatical and semantic relations and to use these for identifying the correct picture in a sentence–picture matching task.

The second issue is similarities and differences in processing of canonical and non-canonical sentences between the control participants and the IWAs. Comparing IWAs' offline processing of non-canonical sentences with that of controls showed, as predicted, that their comprehension of non-canonical sentences was severely impaired. At first sight this is exactly what the TDH predicts, i.e., chance performance for the non-canonical sentences and a significantly better score for canonical sentences, which lies well above chance. However, the analyses of IWAs' online processing revealed that explaining chance performance on non-canonical structures in aphasia simply as a result of a guessing strategy is not sufficient. Analysing IWAs' eye-movement patterns separately for correct and incorrect trials (following Dickey et al., 2007) allowed us to evaluate whether IWAs do indeed guess when trying to identify the correct agent of a non-canonical sentence. If this were the case the ambiguity in theta-roles, which is assumed by the TDH, should be reflected in equally distributed fixations to the correct and wrong picture during the entire span of the non-canonical sentence regardless of whether it was interpreted correctly or incorrectly at the end. The assumptions of the TDH do not lead us to expect early fixation preferences for the correct picture, neither in correctly nor in incorrectly answered trials. The present results, however, indicate that IWAs' preference to fixate one of the two pictures differentiated depending on the response accuracy of the trial, i.e., we observed a striking difference in the IWAs' online processing depending on whether the offline response was correct or incorrect. For the correctly interpreted OVS sentences, IWAs displayed an early and stable preference to fixate the correct picture, and their eye-movement patterns did not exhibit any qualitative differences from controls. In contrast, for the incorrectly interpreted OVS sentences, eye movements of IWAs were clearly qualitatively deviant from those of controls. Although initially their fixation pattern was similar to controls' (reflecting fixations equally distributed between both pictures), the arising preference to fixate the correct picture, exhibited by the control participants at the verb, was not observed. Instead, the IWAs preferred to fixate the wrong (foil) picture, although during the Subject-NP region there was an increase in fixations on the correct picture. This increase in uncertainty of eye movements might be seen as reflecting an unsuccessful attempt to reanalyse the structure. This idea is compatible with the explanation proposed in the eye-tracking literature on development of processing in children (Trueswell et al., 1999) where such eye-movement patterns reflect inability to revise initial parsing commitments. The finding of divergent eye-movement patterns as a factor of the response accuracy is surprising if one assumes that IWAs' chance performance on non-canonical sentences results from guessing behaviour. Crucially, it provides evidence that a performance at chance level must not necessarily be due to the IWA choosing randomly between possible answer types but should better be understood as resulting from distinct underlying processing routines. One of these routines seems to correspond to normal-like processing and thus results in a correct response. In cases where these normal processing mechanisms are not available to the impaired processing system, online routines diverge from healthy processing and result in an incorrect offline response.

Finally, the present results provide evidence consistent with the slowed processing account on agrammatism. First, IWAs' reaction times for non-canonical as well as canonical sentences were longer than controls' latencies. In addition, IWAs' eye movements for correctly answered canonical sentences reflected a clear delay in their online processing but again, just like for correctly answered non-canonical items, we found no evidence for a qualitative deviation compared to controls. The slowed processing hypothesis is further supported by the fact that IWAs' reaction times for incorrectly answered OVS sentences were significantly longer than those for correct answers. While Dickey et al. (2007) found this only for structures containing *wh*-movement, we suggest that the general idea of an interaction between processing time and response accuracy can be extended to sentence processing in aphasia in general. And this is exactly what we found: The effect of accuracy on reaction times was significant for both conditions, with IWAs' incorrect responses being slower compared to their correct answers. Thus, in general, the results of this study point to a processing deficit explanation of syntactic comprehension disorders in aphasia.

However, reducing the deficit merely to a delay in syntactic analysis may not be sufficient. A more comprehensive explanation of the deficit may lie in additional factors that need to be systematically explored. For canonical as well as non-canonical sentences, we observed that whenever IWA's online processing reflected a near-normal pattern, the sentence was understood correctly, although comprehension was delayed. In contrast, when offline performance was not successful, this could be traced back to online processing routines being deviant from healthy processing mechanisms. Thus, in addition to the aphasic parsing system working in a slowed-down fashion, it was also affected by intermittent disruptions of specific parsing routines. This idea has already been suggested by Caplan and colleagues (2007) who argued for an intermittent deficiency explanation and our data clearly support this view.

In contrast to the studies by Dickey and colleagues (Dickey et al., 2007; Dickey & Thompson, 2009), we did not observe a late-emerging competition between the Subject and the Object in the non-canonical sentences as the source for IWAs' incorrect answers. Instead our data indicate that whenever the sentences were processed incorrectly, the online processing routines were different from controls from the very beginning of the parsing process. However, it is exactly this early emerging preference for a canonical interpretation of non-canonical sentences and the unsuccessful attempts to inhibit this competitor interpretation—i.e., inability to revise—that seems to have much in common with the deviant online processing pattern observed by Dickey et al.

A related suggestion is that the many early fixations on the foil picture might be an indicator that IWAs with syntactic comprehension disorders make their initial parsing decisions in a deterministic fashion on the basis of a stochastic process: The parser decides to adopt either a canonical or a non-canonical analysis of the incoming sentence. This speculative suggestion is supported by the fact that whenever the aphasic parsing system encounters an intermittent deficiency, the IWA from early on has no choice but to resort to alternative sources to figure out a possible sentence interpretation. Later, IWAs are unable to revise their initial but wrong parse despite an intriguing finding in their eye-movement patterns that hinted at an unconscious attempt of such reanalysis. These attempts were reflected in a temporary decrease of fixations to the wrong picture and an increase in fixations to the target picture during the verb region for canonical sentences and during the Subject-NP for non-canonical sentences. Attempts to reanalysis, however, were weak and quickly abandoned as the IWAs' eyes returned to the wrong picture, and they continued to pursue the initial syntactic structure that eventually would result in an incorrect response. In any event, it is clear from the current findings that the issue of IWAs' deterministic parsing and their failure to compute reanalysis warrants further investigation.

There remain two other interesting questions that should be considered in future research. Although none of our participants showed any obvious signs of visual or hearing deficits, and motor responsiveness seemed unimpaired, a screening for vision, hearing, and motor abilities would have been helpful in order to avoid possible confounding factors. Furthermore, future research might benefit from more detailed controlling for severity of specific syntactic deficits in aphasia. In order to do so, it would be desirable to develop suitable, well-controlled tests of syntactic comprehension in German involving different sentence structures and tasks (see for example Burchert, Schröder, Stadie, De Bleser, & Lorenz, 2010).

To summarise, the present study provides new evidence against the assumption of the trace deletion theory that agrammatic IWAs' reliance on a guessing strategy in identifying the correct agent in a non-canonical sentence causes their chance performance. Taken together with the results from the previous studies (e.g., Caplan et al., 2007; Caplan & Waters, 2003; Dickey et al., 2007; Dickey & Thompson, 2009), we conclude that chance performance on non-canonical sentences in aphasia is not necessarily due to random guessing, and thus does not really reflect "chance".

What seems more plausible, then, is that in some instances the aphasic parser processes sentences normally (although often more slowly) and hence arrives at the correct sentence interpretation, whereas in other instances it fails and a comprehension problem arises. Caplan et al. (2007, p. 139) referring to a self-paced listening task, expressed this idea in the following way:

> . . . correct responses are often associated with normal—or near normal—online pacing, strongly suggesting that patients sometimes process sentences correctly and sometimes not, not that they assign no structure or meaning, or more than one structure and meaning, and select their response randomly from the set of the responses that the task allows.

We believe that in cases where normal-like online processing routines are not available to the parser this is due to intermittent deficiencies of specific parsing operations. These lead the parser to be highly vulnerable to influence from non-syntactic, alternative sources—namely, heuristics—to assign an interpretation (cf. Avrutin, 2006). This account of sentence comprehension deficits in aphasia is schematically represented in Figure 4. In addition to slower speed and intermittent deficiencies in performing syntactic operations, the agrammatic parser is further affected by disturbances in revising an initially assigned syntactic structure and fails to compute reanalysis even when one is detected.

As a final point, we would like to emphasise the implications of this study for further investigations of online sentence processing in aphasia. Due to the fact that IWAs' online processing routines are not always equal, it is important for further

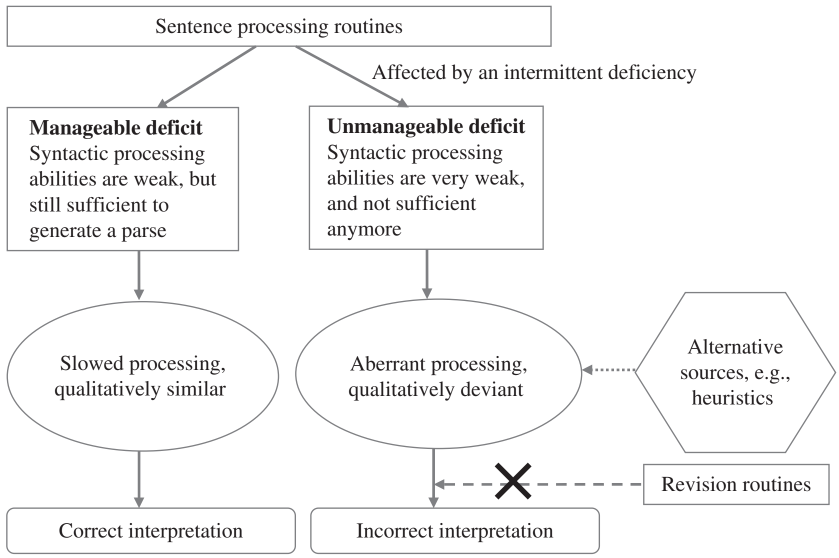

Figure 4. An intermittent deficiency account of sentence comprehension disorders in aphasia.

studies to analyse correct and incorrect answers separately in order to look for possible dissociations. We believe that this approach will contribute to a better understanding of the origin of syntactic comprehension disorders in aphasia.

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APPENDIX

TABLE A1
Linguistic stimuli used in the experiment

Item number	*Item*	*Translation*
Canonical Condition (SVO Sentences)		
1	Der Vater badet den Sohn.	The father is bathing the son.
2	Der Sohn fängt den Vater.	The son is catching the father.
3	Der Arzt impft den Mann.	The doctor is vaccinating the man.
4	Der Sohn kitzelt den Vater.	The son is tickling the father.
5	Der Vater kneift den Sohn.	The father is pinching the son.
6	Der Vater küsst den Sohn.	The father is kissing the son.
7	Der Mann liebt den Hund.	The man loves the dog.
8	Der König misst den Sohn.	The king is measuring the son.
9	Der Landwirt ruft den Klempner.	The farmer is shouting out to the plumber.
10	Der Zwerg schiebt den Mann.	The dwarf is pushing the man.
11	Der Sohn schlägt den Mann.	The son is hitting the man.
12	Der Mann schubst den Dieb.	The man is shoving the thief.
13	Der Gärtner sticht den Maurer.	The gardener is stabbing the bricklayer.
14	Der Vater streichelt den Sohn.	The father is petting the son.
15	Der Mönch tauft den Mann.	The monk is christening the man.
16	Der Panda trägt den Gorilla.	The panda is carrying the gorilla.
17	Der Gaul tritt den Esel.	The horse is kicking the donkey.
18	Der Zwerg wäscht den Mann.	The dwarf is washing the man.
19	Der Eber weckt den Hund.	The boar is wakening the dog.
20	Der Schwan zieht den Karpfen.	The swan is pulling the carp.
Non-canonical Condition (OVS Sentences)		
21	Den Vater badet der Sohn.	The son is bathing the father.
22	Den Sohn fängt der Vater	The father is catching the son.
23	Den Arzt impft der Mann.	The man is vaccinating the doctor.
24	Den Sohn kitzelt der Vater.	The father is tickling the son.
25	Den Vater kneift der Sohn.	The son is pinching the father.
26	Den Vater küsst der Sohn.	The son is kissing the father.
27	Den Mann liebt der Hund.	The dog loves the man.
28	Den König misst der Sohn.	The son is measuring the king.
29	Den Landwirt ruft der Klempner.	The plumber is shouting at the farmer.
30	Den Zwerg schiebt der Mann	The man is pushing the dwarf.
31	Den Sohn schlägt der Mann.	The man is hitting the son.
32	Den Mann schubst der Dieb.	The thief is shoving the man.
33	Den Gärtner sticht der Maurer.	The bricklayer is stabbing the gardener.
34	Den Vater streichelt der Sohn.	The son is stroking the father.
35	Den Mönch tauft der Mann.	The man is christening the monk.
36	Den Panda trägt der Gorilla.	The gorilla is carrying the panda.
37	Den Gaul tritt der Esel.	The donkey is kicking the horse.
38	Den Zwerg wäscht der Mann.	The man is washing the dwarf.
39	Den Eber weckt der Hund.	The dog is awakening the boar.
40	Den Schwan zieht der Karpfen.	The carp is pulling the swan.

TABLE A2
Coefficients, standard errors, *t*-values and *p*-values for eye-movement analyses

Group and response type	*ROI*	*Coefficient*	*Standard error*	*t-value*	*p-value*
Controls canonical	Subject	–0.00899	0.02011	–0.477	.66
	Verb	–0.02277	0.02258	–1.008	.33
	Object	0.14571	0.01866	7.81	<.01
	Post-offset	0.24148	0.02213	10.910	<.01
IWAs canonical correct responses	Subject	–0.02022	0.03664	–0.552	.59
	Verb	0.00199	0.03616	0.055	.96
	Object	0.04217	0.02189	1.926	.08
	Post-offset	0.21409	0.01776	12.050	<.01
IWAs canonical incorrect responses	Subject	–0.08931	0.03611	–2.474	.03
	Verb	–0.01394	0.08587	–0.162	.87
	Object	–0.07640	0.10340	–0.739	.47
	Post-offset	–0.14660	0.03448	–4.251	<.01
Controls non-canonical	Object	0.01599	0.01627	0.983	.34
	Verb	0.05020	0.01862	2.696	.02
	Subject	0.15027	0.01735	8.662	<.01
	Post-offset	0.23562	0.01835	12.84	<.01
IWAs non-canonical correct responses	Object	0.09209	0.05865	1.570	.14
	Verb	0.12198	0.04944	2.467	.03
	Subject	0.14268	0.04049	3.524	<.01
	Post-offset	0.15998	0.02958	5.408	<.01
IWAs non-canonical incorrect responses	Object	–0.005373	0.025933	–0.207	.84
	Verb	–0.10003	0.04236	–2.361	.04
	Subject	–0.05374	0.04446	–1.209	.25
	Post-offset	–0.14563	0.04903	–2.970	.01