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Journal:	*Aphasiology*
Manuscript ID:	APH-PA 15-015.R2
Manuscript Type:	Paper
Date Submitted by the Author:	n/a
Complete List of Authors:	Hanne, Sandra; University of Potsdam, Department of Linguistics Burchert, Frank; University of Potsdam, Department of Linguistics Vasishth, Shravan; University of Potsdam, Department of Linguistics
Keywords:	wh-questions, subject-object asymmetry, sentence-comprehension deficits, online sentence processing, anticipatory eye-movements

On the nature of the subject-object asymmetry in wh-question comprehension in aphasia: Evidence from eye-tracking

Sandra Hanne, Frank Burchert, & Shravan Vasishth

Department of Linguistics, University of Potsdam, Potsdam, Germany

Corresponding author:

Sandra Hanne

Department of Linguistics

University of Potsdam

Karl-Liebknecht-Str. 24-25

14476 Potsdam

Phone: +49 331 2772390

E-mail: hanne@uni-potsdam.de

Acknowledegements

We thank the individuals who participated in this study. We would also like to thank Tom Fritzsche and Felix Engelmann for their valuable advice in data analysis and programming, Anne Adelt and Elisa Rath for assisting with data collection and the audiences of the 14th International Science of Aphasia and the 13th annual conference of the Gesellschaft für Aphasieforschung und -behandlung (GAB). We thank the two anonymous reviewers for their constructive recommendations on an earlier version of this manuscript. This research was supported by the Deutsche Forschungsgemeinschaft, grant VA-482 4-1.

Abstract

Background: Individuals with aphasia (IWA) show deficits in comprehending object-extracted declaratives while comprehension of subject-extracted structures is relatively preserved. It is a matter of debate whether this subject-object asymmetry also arises for comprehension of wh-questions. Successful comprehension of wh-questions critically entails correct resolution of a filler-gap dependency. Most previous studies have used only offline accuracy measures to investigate wh-question comprehension in aphasia. Online studies exploring syntactic processing in real time are needed in order to draw inferences about gap-filling abilities in IWA and to identify the point of breakdown in sentence comprehension.

Aims: This study aimed at investigating processing of subject and object who-questions in German-speaking IWA and in a group of controls by combining an offline and online method. Applying a variant of the visual-world eye-tracking paradigm, we measured participants' eye-movements while they performed the same offline task, which is frequently used to assess comprehension of declaratives (sentence-picture matching). We further aimed to explore the impact of case-marking cues on processing of wh-questions.

Outcomes & Results: Concerning online processing of who-questions in controls, we found anticipation of the most likely post-verbal theta-role immediately after processing the case-marked wh-pronoun in both, subject and object questions. In addition, we observed an unexpected advantage of object over subject questions in terms of processing time. The offline results for IWA revealed that there were three heterogeneous patterns: (i) symmetrical comprehension with equal impairments for both question types, (ii) asymmetrical performance with better comprehension of subject than object who-questions, (iii) a reversed asymmetry with better comprehension of object as compared to subject questions. For online processing of both types of who-questions, IWA showed retained abilities in postulating the gap and in associating the filler with this gap, although they were slower as compared to controls. Moreover, similarly to controls, they anticipated the most likely post-verbal theta-role.

Conclusions: For controls, the findings provide evidence for rapid resolution of the filler-gap dependency and incremental processing of case-marking cues, reflected in early prediction of upcoming syntactic structure. We attribute faster processing of object questions to faster alignment of the anticipated element with a semantically more salient character. For IWA, the online data provide evidence for retained predictive abilities in processing of filler-gap dependencies in wh-questions, but prediction was delayed. This is most likely attributed to delayed integration of case-marking cues.

Keywords: wh-questions, subject-object asymmetry, sentence-comprehension deficits, online sentence processing, anticipatory eye-movements

Introduction

The majority of studies on sentence comprehension deficits in aphasia have focused on reversible declarative sentences and only little is known about comprehension of interrogative structures in aphasia. Syntactically, wh-questions are similar to declaratives in the sense that both involve movement operations and syntactic dependencies between a dislocated argument and the corresponding trace (also referred to as gap). We therefore would expect to find the same subject-object asymmetry for wh-question comprehension as has been observed for declaratives: Individuals with aphasia (IWA) perform better on comprehending subject-extracted as compared to object-extracted sentences, hence a classical effect of canonicity.

There is evidence that IWA show difficulties in comprehending wh-questions (Avrutin, 2000; Gallagher & Guilford, 1977; Grodzinsky, 2000). Studies focusing on which- vs. who-questions found that the classical asymmetry also holds for which-questions, but does not emerge for comprehension of who-questions (Avrutin, 2006; Hickok & Avrutin, 1995, 1996). This finding was related to differential discourse properties of which- vs. who-questions that lead to higher processing demands for which- questions (Kaan, Harris, Gibson, & Holcomb, 2000) rendering them more prone to impairment (Grodzinsky, 2000, 1995; Hickok & Avrutin, 1996).

In contrast to which-questions, who-questions are non-referential, that is, they do not presuppose a specified set of referents in discourse (Cinque, 1992; Pesetsky, 1987) and, thus, it is assumed that they are less problematic for IWA. Yet, many studies found evidence for impaired comprehension of who-questions (Cho-Reyes & Thompson, 2012; Kljajevic & Murasugi, 2010; Neuhaus & Penke, 2008; Salis & Edwards, 2008; Thompson, Choy, Holland, & Cole, 2010; Thompson, Tait, Ballard, & Fix, 1999).). As previous studies have focused on offline tasks, little is known about online processing of wh-questions in aphasia.

In this paper, we specifically focus on the comprehension asymmetry for wh-questions in German. We explore comprehension of subject-and object-extracted matrix who-questions in IWA and a control group of age-matched healthy adults. Our study investigates offline comprehension and online processing of who-questions in a combined fashion using the visual-world paradigm, which has been shown to be suitable for studying healthy as well as aphasic sentence processing (Burchert, Hanne, & Vasishth, 2013; Dickey & Thompson, 2009; Hanne, Burchert, De Bleser, & Vasishth, 2015; Meyer, Mack, & Thompson, 2012; Thompson & Choy, 2009). More specifically, we tracked participants' eye-movements while they performed a sentence-picture matching task.

Processing of subject-and object-extracted wh-questions in unimpaired listeners

In wh-questions, one of the verb argument-NPs is dislocated from its canonical base position to the Specifier position (Spec) of the Complementizer Phrase (CP) (see Burchert, 2008, for an overview of German syntax). In subject-extracted who-questions, a *wh*-operator substitutes the subject-NP in its base position in Spec IP and moves to Spec CP via wh-movement, leaving behind a trace. By contrast, in object questions, the *wh*-operator is displaced from its base position in VP. In who-questions, the dislocated argument (more specifically, the *wh*-operator) is realized overtly as a *wh*-pronoun: for example, *Wer* (who_{NOM}) in subject-extracted questions and *Wen* (who_{ACC}) in object questions (see examples (1) and (2)[i]).

(1) Subject-extracted who-question

Wer_i sieht t_i den Mann?

Who_{NOMi} $\text{see}_{\text{3rd pers. sg.}}$ t_i the_{ACC} man

Who is seeing the man?

(2) Object-extracted who-question

Wen_j sieht der Mann t_j?

Who_{ACCj} $\text{see}_{\text{3rd pers. sg.}}$ the_{NOM} man t_j

Who is the man seeing?

In both cases, the wh-pronoun (also called the filler or antecedent) is co-indexed with the trace (or gap) in order to indicate the dependency relation between them. The distance between the filler and the gap in terms of intervening words as well as phrase structure nodes is greater in object than in subject questions. Examples (3) and (4) provide the abstract underlying phrase structure representation for German matrix who-questions.

(3) **Syntactic structure of a subject-extracted matrix wh-question**

[$_{CP}$ wh-element$_{subject}$ [$_{Comp}$ verb [$_{IP}$ trace$_{subject}$ (subject gap site) [$_{VP}$ object [$_{V}^{0}$ verb base position]]]]]

(4) Syntactic structure of an object-extracted matrix wh-question

[$_{CP}$ wh-element$_{object}$ [$_{Comp}$ verb [$_{IP}$ subject [$_{VP}$ trace$_{object}$ (object gap site) [$_{V}^{0}$ verb base position]]]]]

In order to resolve *filler-gap dependencies* in sentences containing dislocated arguments, the parser relies on an *active filler strategy* (Frazier and Clifton, 1989). The Active Filler Hypothesis assumes that, on encountering a filler, the search for a gap is initiated immediately. In the absence of any unambiguous case information indicating an object question, the parser will rank the option of postulating a trace in the subject's base position (Spec IP) higher than expecting a lexical NP in that position; that is, the parser will actively predict potential gap sites based on grammatical (Frazier & Flores D'Arcais, 1989; Stowe, 1986) as well as semantic requirements (Aoshima, Phillips, & Weinberg, 2004). Therefore, wh-questions are preferably interpreted as subject questions, although they may need to be revised towards an object question if the initial wh-element was ambiguous with respect to its case-marking. In this case, processing demands increase as is evident from reading time, eye-tracking and ERP studies (Frazier & Flores D'Arcais, 1989; Kaan, et al., 2000; Schlesewsky, Fanselow, Kliegl, & Krems, 2000; Stowe, 1986; Stowe, Tanenhaus, & Carlson, 1991; Sussman & Sedivy, 2003).

A preference for subject-extraction along with additional processing costs for object questions has also been found for German unambiguous object who-questions like (1) and (2), which provide a very early and reliable morphological cue indicating non-canonical word order (Fanselow, Kliegl, & Schlesewsky, 1999)[ii]. Higher processing demands for unambiguous object as compared to subject who-questions have also been found in ERP studies (Felser, Clahsen, & Münte, 2003; Fiebach, Schlesewsky, & Friederici, 2002; Friederici, Schlesewsky, & Fiebach, 2003).

In summary, for the comprehension of who-questions the parser needs to resolve the filler-gap dependency between the dislocated argument, which is overtly realized as a wh-pronoun, and the trace left behind in base position. In object-extracted questions, the distance between the filler and the gap is greater as compared to questions with subject extraction. Studies on who-question comprehension involving language-unimpaired participants revealed a preference to associate the filler with the earliest possible position, even if this is not possible because the position is already filled by a lexical item instead of a trace. This active search for a filler leads to a processing advantage for subject questions and increased processing demands for object questions as the parse needs to be revised towards the dispreferred structure. For German, additional processing load for object-initial structures is even observed for questions with unambiguous case-marking cues indicating an object extraction.

Comprehension of subject-and object-extracted who-questions in aphasia

Studies investigating processing of who-questions in aphasia have raised the question of whether there is a similar subject-object asymmetry as has been observed for comprehension of declaratives. Concerning declaratives, IWA perform better in comprehending sentences in which the subject precedes the object (such as actives, subject-relatives and subject-clefts) as compared to structures in which the object has been extracted and, thus, precedes the subject (e.g., topicalized sentences, object-relatives, object-clefts) (for example, Cho-Reyes & Thompson, 2012; Caplan, Waters, & Hildebrandt, 1997; Burchert, De Bleser, & Sonntag, 2003).

However, the picture is less clear for comprehension of subject as compared to object who-questions. While some studies failed to show diverging effects (Cho-Reyes & Thompson, 2012; Fyndanis, Varlokosta, & Tsapkini, 2010; Hickok & Avrutin, 1996; Stavrakaki & Kouvava, 2003), others have reported dissociations between both types of who-questions (Neuhaus & Penke, 2008; Kljajevic & Murasugi, 2010; Salis & Edwards, 2008; Thompson et al., 1999).

Yet, the results were mixed for individual subjects: While some IWA showed symmetrical, albeit mostly impaired performance, other IWA performed better with subject as compared to object questions, that is, who-question comprehension was asymmetrical. From a processing point of view, it is argued that this subject-object asymmetry is similar to the one observed for comprehension of declaratives: Object extraction is considered to be more complex, since the distance between the filler and the gap is greater than in subject questions. Thus, the filler needs to be maintained in memory for longer than is necessary for comprehension of subject questions. These increased processing demands render object questions especially difficult for IWA because of their compromised processing resources. This view is corroborated by recent findings from factor analyses of sentence comprehension performance in IWA (Caplan, Michaud, & Hufford, 2013; Gutman, DeDe, Michaud, Liu, & Caplan, 2010).

However, the picture is complicated by findings of a reversed asymmetry with better comprehension of object as compared to subject who-questions (Thompson et al., 1999; Kljajevic & Murasugi, 2010; van der Meulen, Bastiaanse, & Rooryck, 2005; van der Meulen, Bastiaanse, & Rooryck, 2002). This reversed asymmetry cannot be explained in terms of sentence complexity or greater distance between the filler and the gap. However, it may be accounted for by an influence of morphology on IWA's performance because, for languages characterized by a rich morphological system, morphological cues like case marking may facilitate sentence comprehension. For Serbo-Croatian speaking IWA, there is evidence that morphological cues can help to override deficits in assigning thematic roles in declaratives (Smith & Mimica, 1984). Thus, case-marking information on the wh-pronoun and the post-verbal NP in who-questions in combination with the higher informational value of accusative case may have led to better comprehension of object questions (Kljajevic & Murasugi, 2010). In Serbo-Croatian, accusative case is assumed to be a more reliable cue than nominative case because it is always associated with the thematic role of theme, while nominative NPs are ambiguous with respect to their thematic role (nominative case can mark the role of agent, experiencer or instrument).

For comprehension of declaratives in German-speaking IWA, there is evidence that they can use unambiguous morphological markers for predicting upcoming syntactic structure, although the integration of these cues is delayed (Hanne et al., 2015). So far, two studies have investigated who-question comprehension in German IWA (Neuhaus & Penke, 2008; Wimmer, 2009). However, despite the presence of at least one overt case-marker, the reversed comprehension asymmetry (i.e., better performance with object than subject questions) was not observed. Instead, Neuhaus and Penke (2008) suggest that object who-questions will generally be more difficult than subject who-questions and an individual patient's performance will be subject to an implicational scale: if comprehension on a more difficult type of question is good, it will also be retained for the less complex type. This proposal predicts that a reversed asymmetry with better comprehension of object than subject who-questions should not occur.

Taken together, studies on who-question comprehension in aphasia have reported patterns of symmetrical impairment (i.e., equally impaired comprehension of subject and object who-questions) as well as asymmetrical performance. Moreover, there is evidence for two different types of asymmetries: while some IWA perform better in comprehending subject than object who-questions, the reversed asymmetry with better comprehension of object who-questions has also been observed. This pattern is surprising given that with declaratives the asymmetry entails an advantage for sentences in which the subject precedes the object.

The role of the task and method in studying who-question comprehension in aphasia

A possible reason for the differential results concerning a subject-object asymmetry in who-question comprehension is the heterogeneity of tasks used to assess sentence comprehension. Studies have used figurine-pointing (after the scenario had been acted-out by the experimenter) (Hickok & Avrutin, 1996; Kljajevic & Murasugi, 2010; Salis & Edwards, 2008; Thompson et al., 1999), grammaticality-judgement (Stavrakaki & Kouvava, 2003), actor/theme identification through picture-pointing (Fyndanis et al., 2010; Neuhaus & Penke, 2008; Thompson et al., 1999; van der Meulen et al., 2005; Wimmer, 2009) and sentence-picture matching (Cho-Reyes & Thompson, 2012). Although performance seems to be comparable for figurine-pointing and actor/theme identification on pictures (Thompson et al., 1999), it is an open question whether who-question comprehension varies with task demands. Such an interaction of task-related demands and performance on tests of syntactic comprehension is indicated by the finding of dissociations across tasks in a large group of IWA (Caplan et al., 2013). As regards findings of a subject-object asymmetry in aphasic comprehension of declaratives, most studies have used sentence-picture matching (with a foil picture showing a theta-role reversal). In order to figure out whether a similar asymmetry exists for who-question comprehension, the same task should be used to avoid a possible effect of differential task-demands interfering with performance of IWA. Yet, only one study so far has used this task to assess who-questions in aphasia (Cho-Reyes & Thompson, 2012).

With respect to the method used to investigate who-question comprehension in aphasia, most studies so far only measured accuracy scores and little is known about IWA's online processing of who-questions. However, online studies tapping sentence comprehension in real-time are essential in order to determine what exactly causes the comprehension problems. Using eye-tracking in the visual-world paradigm, Dickey, Choy, and Thompson (2007) found that IWA are capable of postulating the gap in object who-questions online in the same manner as control participants do. Both groups showed evidence of rapidly associating the filler with the gap, as looks to the object significantly increased at the gap site. However, this was only observed for trials in which comprehension was successful, while for incorrect responses, there was a high amount of looks to the subject of the question. Dickey et al. (2007) assume that these looks were evoked by late-emerging effects of the subject competitor, which IWA are especially vulnerable to. Crucially, these results point to the importance of studying sentence comprehension in aphasia online, as has been done in several other eye-tracking studies (Bos, Hanne, Wartenburger, & Bastiaanse, 2014; Choy & Thompson, 2010; Dickey & Thompson, 2009; Meyer et al., 2012; Thompson & Choy, 2009). The finding of differential eye-movement patterns for correct versus incorrect offline responses emphasizes that it is essential to partition the online data by response accuracy and to analyze correct and incorrect sentence processing separately (as has been suggested by, e.g., Burchert et al., 2013; Caplan, Waters, DeDe, Michaud, & Reddy, 2007; Hanne et al., 2015; Hanne, Sekerina, Vasishth, Burchert, & De Bleser, 2011).

Aims of the study and predictions

Our study has three goals: Firstly, we aim to investigate offline comprehension of subject and object who-questions in German-speaking IWA in order to identify their individual asymmetrical or symmetrical performance patterns. Specifically, we aim to explore whether for cases of asymmetrical comprehension, the direction of the asymmetry indeed resembles the one found for comprehension of declaratives in aphasia, that is, better comprehension of subject as compared to object questions. Crucially, for adequate comparability, we use the same task used to assess syntactic comprehension of declaratives: sentence-picture matching involving a foil picture with reversal of theta-roles.

The second aim of our study is to explore processing of who-questions in unimpaired participants and in aphasia *online*. Therefore, we monitor participants' eye-movements during the sentence-picture matching task. For IWA, this combination of both, the offline accuracy and the eye-movements, enables us to study their online processing patterns in cases of successful as well as unsuccessful (i.e., erroneous) comprehension of who-questions. Specifically, we aim to investigate whether IWA show retained abilities in postulating the gap in who-questions and to determine the point of breakdown in IWA.

Finally, we designed the study in a fashion that allows us to explore the impact of morphological cues, in particular unambiguous case markers, on the processing of who-questions. If participants are able to parse the wh-structure and to correctly postulate the corresponding gap in subject and object who-questions, we expect to see rapid resolution of the filler-gap dependency as soon as the post-verbal NP provides the lexical information necessary to identify the picture answering the question correctly. Moreover, if the wh-element, and especially its case cue is recognized correctly, we expect to find anticipation of the most likely theta-role for the post-verbal NP before hearing it, that is, participants should predict an upcoming theme theta-role in subject who-questions while in object questions an NP carrying the role of agent should be anticipated.

Concerning participants' eye-movements, we hypothesize that correct resolution of the filler-gap dependency should be reflected in a significant increase in gazes to the target picture as soon as the post-verbal lexically specified NP has been provided. Furthermore, if participants correctly postulate the corresponding gap in subject and object who-questions, we expect to find evidence for anticipation of a post-verbal agent in object questions and of a post-verbal theme in subject questions. This anticipation should be reflected in a higher proportion of looks to agent characters in object as compared to subject questions and in a higher proportion of looks to theme characters in subject as compared to object questions. For control participants, we hypothesize that these anticipatory eye-movements can be detected immediately after processing of the wh-element, that is, upon hearing the verb.

For eye-movements of IWA, in trials with correct offline comprehension, we generally predict patterns similar to controls, that is, correct filler-gap resolution should be reflected in a significant increase in gazes to the target picture. However, if syntactic processing is delayed in aphasia, we predict this increase to arise later than in controls. Furthermore, if IWA are able to postulate the gap correctly in subject and object questions, we expect to find anticipation of the most-likely post-verbal theta role, similarly to the pattern predicted for controls. Yet, we hypothesize that anticipatory eye-movements to the agent or theme characters emerge later in IWA than in controls due to delayed sentence processing. Finally, if erroneous comprehension of subject and object questions is associated with (temporary) deficiencies in filler-gap dependency resolution, we predict to find divergent gaze patterns for IWA's correct vs. incorrect offline responses.

Methods

Participants

The experiment had two groups: 26 control participants without any history of neurological, psychiatric, hearing or learning impairments (12 male, 14 female; age range: 30 - 70 years, *M* = 60 yrs, *SD* = 12) and six IWA (4 male, 2 female, age range: 41-60 years, *M* = 52, *SD* = 8.2). The IWA had suffered from a unilateral lesion in their language-dominant hemisphere. Post-onset time ranged between 2 and 19 years. Table 1 provides demographic and neurological data for IWA.

---------- Table 1 about here ----------

The aphasia syndrome and severity was assessed using the classification system of the Aachen Aphasia Test (Huber, Poeck, Weniger, & Willmes, 1983). IWA were required to have preserved auditory analysis as well as retained auditory single-word comprehension (assessed through selected tasks of LeMo, De Bleser, Cholewa, Stadie, & Tabatabaie, 2004). In addition, we evaluated syntactic comprehension using a sentence comprehension assessment (Saetze Verstehen; Burchert, Lorenz, Schröder, De Bleser, & Stadie, 2011). All IWA showed preserved abilities in comprehending semantically irreversible sentences. However, performance on reversible OVS sentences was at chance while comprehension of SVO sentences was above chance, that is, IWA exhibited a subject-object comprehension asymmetry for declarative sentences. Table 2 provides results of the language assessments. All participants were native speakers of German and, with the exception of one IWA, they were (pre-morbidly) right-handed. They all had normal or corrected-to-normal vision. Participants wearing glasses were told to do so during the experiment. According to medical report, none of the IWA had any history of hearing difficulties. Participants were recruited via announcement and paid for participation.

---------- Table 2 about here ----------

Sentence Material

Overall, there were 66 questions of which six were used as practice items. The experimental set included targets in two conditions (subject and object who-questions, n=20 each, see Table A1 in the Appendix) and fillers (irreversible what-questions, n=20). The practice items comprised two fillers and two items of each target condition, respectively.

The target questions were derived from a set of semantically reversible declarative sentences involving 20 different transitive verbs. This set has been controlled for semantic plausibility in a rating study, which had established that, in each sentence, both nouns have equal probability of being the agent of the event. Details of this rating can be found in Hanne et al. (2015). All nouns included in the targets were animate, simple and masculine. Hence, the wh-element (either *wer* - who_{NOM} or *wen* - who_{ACC}) as well as the determiner of the post-verbal NP (either *der* - the_{NOM} or *den* - the_{ACC}) were unambiguously marked for nominative or accusative case. Examples are provided in (5a) – (5c).

(5a) Subject-extracted who-question (SubjQu)

Wer kneift den Vater?

who_{NOM} pinches the_{ACC} father

`Who is pinching the father?'

(5b) Object-extracted who-question (ObjQu)

Wen kneift der Vater?

Who_{ACC} pinches the_{NOM} father

`Who is the father pinching?'

(5c) Filler

Was filmt der Clown?

`What is the clown filming?'

Sentences were digitally recorded in a designated recording room equipped with a sound booth and mixing console. They were spoken by a trained female native speaker of German and post-processed using Praat software (Boersma & Weenink, 2009). In order to control for prosodic characteristics of the targets, recordings for both conditions were matched with respect to four parameters: (1) the F0 contour, (2) the F0 rise time, (3) the duration of constituents, and, (4) the speech rate. The F0 contour was determined by calculating for each item the overall amount of F0 rise, that is the difference between minimum and maximum F0 (in Hz) within the wh-element. There were no statistically significant differences across the two conditions (SubjQu: M = 211.13 Hz, SD = 23.6; ObjQu: M = 211.41 Hz, SD = 24.4; t = 0.1, p > .05, paired t-test, two-sided). We controlled for the F0 rise time by calculating the amount of time between the point of minimum and maximum F0 within the wh-question-element. Statistical comparisons revealed that recordings for both conditions were matched in this respect (SubjQu: M = 366 ms, SD = 0.05; ObjQu: M = 387 ms, SD = 0.04; t = 1.8, p > .05, paired t-test, two-sided). Finally, we determined for each target question the duration of the three sentence constituents: the wh-element, the verb, the post-verbal NP. Mean constituent durations per condition are provided in Table 3. There were no statistically significant differences across the two conditions (wh-element: t = 1.9, p > .05; verb: t = 1.9, p > .05, post-verbal NP: t = -1.8, p > .05). However, when we looked at the duration of the wh-element in more detail, it turned out that, for some recordings, its duration was less than 400 ms. Therefore, we decided to paste an interval of 500 ms silence between the wh-element and the verb of each recording.

---------- Table 3 about here ----------

For the final target recordings, the mean overall speech rate in terms of syllables per seconds was 2.11 (*SD* = 0.33) for subject-questions and 2.10 (*SD* = 0.33) for the object-questions. Finally, all recordings were normalized using Audacity software (version 2.02, web.audacityteam.org).

Visual Material

For each event mentioned in the target questions, we assembled two black-and-white line drawings. The target picture depicted an event, which would answer the question correctly, whereas the foil picture showed a theta-role reversal and, thus, depicted an incorrect answer to the question. For example, for the target question provided in (5a) the correct picture showed a son pinching a father, while, in the foil picture, the son was being pinched by the father. The foil pictures for the irreversible fillers contained a non-matching agent for the event mentioned in the question. For example, for the filler given in (5c) the target picture showed a clown filming a forest, whereas in the foil picture a monk was doing the filming.

All pictures were of comparable size and scene content and controlled for comprehension agreement. The action direction (i.e. the spatial position of the theme or object in relation to the agent) was balanced across all pictures. Sample pictures are provided in Figures 1 and 2.

---------- Figure 1 about here ----------

---------- Figure 2 about here ----------

Procedure

Participants performed an auditory sentence-picture matching task while their eye-movements, accuracy and reaction times were being measured. The task was to identify the picture that correctly answers the question.

Eye-movements were recorded binocularly at a sampling rate of 60 Hz using a remote Tobii T120 eye-tracking system (accuracy: 0.5 degrees, head-move-tolerance: 30 x 22 x 30 cm; Tobii Technology AB, Sweden). The pictures for a given item were assembled into a CINEPAC encoded movie file in AVI format using Adobe Flash CS4 (Adobe Systems Incorporation, 2008) and presented on the eye-tracker screen (size: 17 inch, resolution: 1280 x 1024 pixels). The picture size was 550 x 380 pixels and both pictures were shown next to each other, separated by a black bar comprising 100 pixels. Target picture position (left vs. right) was balanced across all trials. The background colour was set to black. The eye-tracking data was collected using Tobii Studio software (Professional Edition, version: 1.5.17, Tobii Technology AB, Sweden) installed on a computer with Windows Operating System XP Pro, SP3, on an IntelCore2 processor with 2 GB RAM.

For each trial, participants saw the two pictures (target and foil) for a fixed preview time of 15 s. During preview time, the persons or objects depicted in the pictures as well as the action were being mentioned auditorily in a short description. For the example given in (5a), the description is provided in (6).

(6) Auf diesen Bildern sehen Sie jeweils einen Vater und einen Sohn.
Die Handlung ist kneifen.
`In these pictures, you see a father and a son, respectively.'
`The action is pinching.'

Towards the end of the preview time, a prompt sentence was played. This prompt was the same for each trial and requested participants to `find the picture answering the following question'. Following the preview, the picture presentation was interrupted and an asterisk appeared for 600 ms in the middle of the screen to centre participants' eye gaze. Afterwards, both pictures re-appeared on the screen and the question was played.

Participants responded by button press using two fingers of the left hand (i.e., the non-paralyzed hand for the IWA)[iii]. Maximum response time was set to 15000 ms. Each participant received one of four different pseudo-randomized presentation lists of the whole set of items. In each of these lists, the first item and every third one following was a filler with pairs of targets in between, rendering four different orders of conditions (Filler-SubjQu-ObjQu, Filler-ObjQu-SubjQu, Filler-SubjQu-SubjQu, Filler-ObjQu-ObjQu). No more than two adjacent items were of the same condition. Moreover, a SubjQu- and ObjQu-version of the same verb were separated by at least three different intervening items.

The practice items were administered in a paper-and-pencil version prior to the eye-tracking experiment and they were repeated on the eye-tracker during the practice phase. Participants were comfortably seated approximately 60 cm in front of the screen. Calibration was performed using a 9-point procedure displaying red dots on a black screen. The calibration procedure was repeated after the practice phase was finished and halfway during the experiment.

Prior to testing, every participant was provided with a written description of the experiment and the eye-tracking method. After all possible questions had been answered, participants signed informed consent according to the Declaration of Helsinki. Testing took place in a designated eye-tracking laboratory at the University of Potsdam and took approximately 60 minutes for IWA and 45 minutes for controls.

Data analysis

Null responses in the sentence-picture matching task (i.e., no reaction within 15 s after sentence onset) were treated as errors. For controls, only correct responses entered the analyses of RTs and eye-movements. For IWA, we did separate analyses of their RT and eye-movement data for correct and incorrect responses.

For the analysis of eye-movement data, we present two different analyses. In the first analysis, each of the two pictures (the target and foil) constituted the *visual areas of interest* (AoIs) for which participants' gaze proportions were measured. The goal of this analysis was to determine from which point in time onwards participants were able to identify the target picture. In the second analysis, we collapsed participants' gazes to the two agent characters in both pictures (i.e., the agent of the target and the agent of the foil picture) and to the two characters denoting the theme theta-role (i.e., the theme in the target and the theme in the foil). The goal of this was to investigate whether the wh-element and its case cue are being processed correctly and whether participants anticipate the theta-role of the post-verbal NP.

Gaze position was defined based on the combined eye-tracking data from both eyes and in order to be treated as a gaze the combined gaze position of both eyes had to be stable in a radius of 35 pixels for at least 100 ms. Based on the x-y-gaze coordinates delivered by the output files of the Tobii raw data for each time stamp (which is every 16 ms at a sampling rate of 60 Hz), we analyzed, for each trial within each participant, where the eyes fixated at, by determining what these coordinates correspond to in terms of the visual areas of interest (i.e., the target and foil picture, defined according to their corner specifications in pixels, and the agent and theme, also defined on pixel position). Following this, data were collapsed within each participant and item for each of the *auditory regions of interest* (RoIs). Auditory RoIs consisted of the wh-pronoun (including a 500 ms pasted silence), the verb and the post-verbal NP and were defined individually for each item by determining the duration of the wh-element, the verb and NP2 of that item (using Praat software; Boersma, & Weenink, 2009). The preview RoI was always the first 15 seconds of a trial and the period of silence after question offset until the participant's button press was the final RoI, termed silence.

For statistical analysis, the dependent variable was either the average proportion of fixation to the target (and foil) picture or the proportion of gazes to the agent or theme characters for each RoI for each item and each participant. We used linear mixed models with participants and items as random effects, fitted with a binomial link function for data on accuracy, and a Gaussian link function for RT and eye-movement data. Depending on the outcome measure, we treated condition, group and RoI as fixed effects. Concerning contrast coding, the group of controls was treated as baseline category. For the RoI predictor, we applied a successive differences contrast coding, so that from the second RoI onwards (verb), gaze proportions of each RoI were compared to those of the previous RoI. We estimated model parameters using the maximum likelihood estimation and determined statistical significance of predictors by model comparisons using the generalised likelihood ratio test for which we report the chi-square statistic. For the coded contrasts of significant predictors, unless stated otherwise, we provide coefficient estimates (*b*), 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 0.05. For the generalized linear mixed models, *p*-values are provided in addition to *z*-scores.

Results

Accuracy and Reaction Times

Controls' accuracy was at ceiling in both conditions (Subj-qu: $M = 0.97$, $SE = 0.01$, Obj-qu: $M = 0.98$, SE = 0.01). The group of IWA performed worse than controls (Subj-qu: $M = 0.64$, $SE = 0.04$, Obj-qu: $M = 0.66$, $SE = 0.04$). There were no null responses. For statistical analysis of the accuracy group data, a generalized linear mixed model was fit including condition, group and the interaction as predictors. Results are provided in Table 4. As revealed by model comparisons, there was a significant main effect of group. The effect of condition was not significant and there was no interaction. This indicates that overall IWA performed worse than controls, independent of condition.

---------- Table 4 about here ----------

In addition to this group analysis, IWA's accuracy data was subjected to a single-case analysis using the binomial and the chi-square statistic. This was done in order to (1) determine the level of performance with respect to chance and (2) identify intra-individual effects of question type on comprehension performance, that is, to identify possible asymmetrical or symmetrical performance patterns. The results are provided in Table 5. These analyses revealed three distinct patterns: Two IWA (Pq3, Pq5) performed at chance in both conditions without a significant difference, indicating that comprehension was symmetrical and, thus, equally impaired for subject and object who-questions. For Pq2 comprehension performance was asymmetrical with significantly higher accuracy on subject as compared to object questions; the pattern reported in previous studies, which is also reflected in terms of above chance vs. chance performance in the two conditions. Finally, three IWA (Pq1, Pq4, Pq6), showed a pattern of a reversed comprehension asymmetry: accuracy was higher on object as compared to subject questions. This intra-individual dissociation was significant for Pq1, whose performance was above chance in both conditions (yet, accuracy was marginally significant higher with object as compared to subject questions) and Pq4, who performed at chance with subject questions and above chance on object questions and for whom the individual effect of question type was significant. Pq6 also showed a dissociating pattern with chance performance on subject questions and above chance performance on object questions (but the difference between conditions was not significant).

---------- Table 5 about here ----------

Concerning the RT data, for both groups, latencies were higher for subject as compared to object who-questions (Controls: Subj-qu: M = 2878, SE = 59.79, Obj-qu: M = 2718, SE = 53.9; IWA: Subj-qu: M = 4829, SE = 144.01, Obj-qu: M = 4508, SE = 176.88). Model comparisons of mixed models including condition, group and their interaction as predictors revealed main effects of condition and group, but no interaction (see Table 6). A separate model fitted to only IWA's data including accuracy as a predictor revealed no effect of response accuracy on IWA's RTs ($X^2(5) = 0.27$, $p > .05$), indicating that IWA were slower independent of response accuracy.

---------- Table 6 about here ----------

Eye-movements

Gazes to target picture

For this analysis, we operationalized the dependent measure as the gaze proportions to the target picture (i.e., the picture correctly matching the sentence) for each of the five RoIs (preview, wh-pronoun, verb, post-verbal NP (NP2) and silence). For IWA, the gaze data was split into correct and incorrect offline responses and both datasets were compared against controls' gaze data of correct responses (which constitutes most of controls' data). Gaze proportions to the target picture for both groups' trials with correct offline responses are provided in Figure 3. Figure 4 shows gaze proportions for IWA's incorrect responses in the sentence-picture-matching task.

---------- Figure 3 about here ----------

---------- Figure 4 about here ----------

As for the accuracy and RT data, we fit linear mixed models with participants and items as random effects. The fixed effects included group, condition and RoI, as well as the respective interactions. Results are provided in Table 7. For gaze proportions of correct responses, model comparisons revealed main effects of group and RoI. The RoI predictor significantly interacted with group, and there was a marginal RoI x condition interaction. For the first three RoI contrasts (preview, wh-element and verb) there were no significant changes in gaze proportions for both conditions and groups. However, the effect of RoI was significant at NP2 and significantly interacted positively with condition at this RoI contrast, indicating that immediately after processing the verb, gaze proportions to the target increased and this increase was higher for object questions as compared to subject questions. However, for the NP2 RoI contrast, there was also a significant interaction with group (note that the sign for this coefficient was negative), which indicates that the effect was evident for controls only while for IWA gaze proportions to the target did not yet significantly increase (see Figure 3). At silence, there was a main effect of RoI, without any interactions, indicating a significant increase in both conditions for both groups.

Comparing IWA's gaze data of their *incorrect* responses against controls' data (correct responses) yielded main effects of group and RoI and a significant interaction of the two predictors. There was no significant effect of condition. The interaction was significant at NP2, indicating that, for IWA, gazes to the target did not increase while they did so in controls. This is similar to the results for the NP2 region in IWA's correct responses. However, the interaction was also significant during silence, reflecting the decrease in IWA's gazes to target, which was not observed for their correct responses.

---------- Table 7 about here ----------

Gazes to Agent and Theme characters

The dependent measures for this analysis were participants' eye-movements to agent and theme characters of both pictures. Figure 5 provides the respective gaze proportions for both groups' trials with correct offline responses by group and condition. IWA's gazes to agents and themes in their incorrect responses are provided in Figure 6. For each RoI, we fit separate linear mixed models for controls and IWA's gazes to agent and theme characters, respectively, including participants and items as random effects and condition as a fixed effect. Results are given in Table 8.

---------- Figure 5 about here ----------

---------- Figure 6 about here ----------

For controls' gazes to the *agent* characters, there were no differences between conditions during preview and the wh-element. Upon hearing the verb, controls had significantly more gazes to the agent characters in object questions as compared to subject questions. The same was found for. This pattern indicates that immediately after hearing the case cue of the wh-pronoun in object questions, controls started to anticipate a post-verbal NP carrying the agent theta-role. The early difference already at the verb indicates that an object-extracted wh-structure was built up including a gap postulated in object base-position as soon as the wh-element and its accusative case cue were processed. During silence, there was also a significant difference between conditions. However, the direction of the effect had changed and gazes to agent characters were lower in object as compared to subject condition, indicating that participants directed their gaze towards the character answering the question (which is an agent in subject questions).

For IWA's correct responses, gazes to the agent characters differentiated not yet at the verb, but only during NP2. However, the direction of the effect was similar to controls: there were more gazes to the agents for object as compared to subject questions. This indicates that IWA started anticipating the theta-role of the post-verbal NP later than controls and needed the combined information of the wh-element and the verb in order to pursue a wh-structure parse and to postulate the corresponding gap. However, they did process the wh-element and its case cue similar to controls, albeit not as incrementally as controls did. In contrast, for IWA's incorrect responses, there were no differences between conditions, neither at the verb nor during NP2 and also not for any other RoI, indicating that in cases of erroneous processing, they did not anticipate upcoming sentence elements in the same manner as controls did, and the wh-structure was not parsed correctly.

For controls' gazes to the *theme* characters, we found no significant differences during the first two RoIs. However, controls' gazes to the themes were higher for subject questions as compared to object questions at the verb and NP2. This indicates that, in subject questions, controls anticipated a post-verbal NP carrying a theme theta-role immediately after processing the wh-element and its nominative case cue. In order to do so they must have postulated a wh-structure including a gap in subject base-position. The effect of condition was also significant during silence, but again in the opposite direction, that is, there were more gazes to the themes for object as compared to subject questions. Similar to the effect for gazes to the agents, this indicates that controls directed their gaze towards a character answering the question, which is a theme in object questions.

For IWA, for correct responses, gazes to the theme characters were affected by condition only during NP2 and the direction of the effect was comparable to controls with a higher amount of gazes to themes in subject as compared to object questions. There were no significant differences for the verb or for any other RoI. This result indicates that IWA correctly anticipated the theta-role of the post-verbal NP, although they did so later than controls. IWA needed to process the wh-element carrying the nominative case cue and the verb in order to postulate a wh-structure including a gap in in subject base-position. For IWA's incorrect responses, there was no effect of condition on gazes to the theme characters during the verb, NP2 or for any of the other RoIs. This is similar to the finding for their gazes to agents (in incorrect responses) and indicates lack of anticipation and incorrect parsing of the wh-structure.

---------- Table 8 about here ----------

Discussion

This study investigated comprehension of subject and object who-questions in IWA and age-matched controls. We aimed to test whether IWA show the same subject-object comprehension asymmetry as has been reported for declaratives, that is, better comprehension of subject- as compared to object-extracted structures or whether individual asymmetrical or symmetrical performance patterns can be identified. Monitoring participants' eye-movements during sentence-picture matching allowed us to additionally explore *online* processing of who-questions in order to reveal whether IWA show retained abilities in parsing wh-structures and in correctly postulating the respective gap. The combination of both measures, offline accuracy and eye-movements, enabled us to study IWA's online processing in cases of successful as well as unsuccessful (i.e., erroneous) comprehension. Finally, the who-questions used in this study also allowed for testing the impact of unambiguous case-marking cues on processing of filler-gap dependencies in controls and IWA. The offline results point to the existence of heterogeneous, individually distinctive performance patterns in who-question comprehension in aphasia. The eye-tracking data reveal new insights regarding predictive processes and gap-filling during comprehension of who-questions in unimpaired listeners and indicate that IWA are able to parse wh-structures and to postulate gaps accordingly, although they do not engage in prediction as fast as controls do. We will first discuss the results for processing of who-questions in control participants, before reviewing the findings for IWA.

Processing of who-questions in unimpaired listeners

Concerning accuracy, as expected, controls performed at ceiling with both, subject and object who-questions, in the sentence-picture matching task. However, RTs were higher for subject than for object who-questions. This result is in contrast to previous studies (Schlesewsky et al., 2000; Fanselow et al.,

1999) that reported higher latencies for object-extracted questions in German. The advantage of object questions in terms of faster processing times was also reflected in controls' eye-movements: Although there was a significant increase in gazes to the target picture (i.e., the picture answering the question correctly) during the post-verbal NP in both conditions, gaze proportions were higher for object than for subject who-questions at this RoI.

Firstly, the increase in gazes to the target picture in both conditions, arising immediately after the verb, indicates incremental processing of the wh-element and its unambiguous case cue (Wer_{NOM} in subject questions, Wen_{ACC} in object questions). For subject questions, the nominative case marker led controls to successfully build up a wh-structure containing a gap in subject-position. They further must have correctly associated the filler (i.e., the wh-pronoun) with this gap and anticipated a post-verbal NP carrying the theme theta-role. This is evidenced by their gaze proportions to the theme characters (i.e., the theme in the target picture and the theme in the foil picture), which are significantly higher for subject than for object questions. Crucially, these anticipatory eye-movements are evident already during processing of the verb, indicating that the wh-pronoun and its case marking were sufficient to trigger prediction of the most likely post-verbal theta-role (which is a theme in subject questions).

In contrast, for controls' processing of object questions, we found significantly higher gaze proportions to the agent characters at the verb, reflecting their anticipation of a post-verbal NP carrying the theta-role of agent. This suggests that the accusative case marker of the wh-element provided enough information for controls to build up a wh-structure including a gap in object-position. Thus, the case cue of the wh-element immediately influenced participants' parsing decision and their prediction of upcoming sentence elements. Instead of postulating a gap in subject base-position, which would be predicted by the active filler hypothesis, participants postulated a gap in object base-position and actively associated the wh-element with the object trace. This suggests that the accusative case cue of the wh-pronoun immediately triggered the active search for a filler for an object gap. We therefore assume that the preference for subject-extraction found in studies involving locally case-ambiguous questions (Schlesewsky et al., 2000) is overridden immediately in the presence of an unambiguous case cue indicating object-extraction.

But why did we observe faster end-of-sentence latencies and a higher amount of gazes to the target picture at the post-verbal NP for object questions? Assuming that the accusative cue in object questions triggers immediate postulation of a gap in object-position cannot by itself explain this advantage of object-extracted questions, as we would not expect to see such differences between conditions even if morphological information—the accusative case cue—immediately overrides the active filler parsing principle. Instead, we would expect similar results for both types of who-questions as in both types the wh-pronoun contains a morphological cue. We suppose that the task and material used in the current experiment might explain why we found an advantage of object over subject questions in terms of processing time. Firstly, previous studies on who-question comprehension in German unimpaired listeners used different types of questions (case-ambiguous matrix questions and indirect embedded questions). Secondly, previous studies did not involve a sentence-picture matching task with a target picture and a distractor picture displaying a theta-role reversal. As mentioned above, in our study, during processing of the object questions, participants showed the expected anticipation of a post-verbal agent character, whereas for processing of subject questions, they anticipated a post-verbal theme character. We suggest that the unexpected advantage of object questions could be explained when the concept of semantic saliency of theta-roles is taken into account. It is commonly assumed that the agent is the highest ranked theta-role in a thematic hierarchy in terms of semantic saliency (Jackendoff, 1972). In addition, studies on scene perception have found that agent characters are more salient and thus attract more visual attention than non-acting characters (Henderson & Ferreira, 2004). It could be the case that due to the higher semantic saliency of agent characters, aligning the syntactically anticipated post-verbal sentence constituent with the semantically more salient characters is easier when both are in correspondence than when they are not. Thus, in object questions, the anticipated element corresponds to the more salient character in the pictures and the prediction might be confirmed faster than in subject questions, in which the anticipated element is a theme and hence semantically less salient. This account would explain why, in our study, controls processed object-extracted who-questions faster than the subject questions, despite the higher cognitive load associated with the greater distance between the filler and the gap. However, further research is needed in order to investigate this issue in more detail.

Processing of who-questions in IWA

We now turn to the discussion of IWA's offline performance before reviewing the findings for their online processing of who-questions.

We used the same task to assess who-question comprehension as has been used to test comprehension of declaratives in the IWA of this study, that is, sentence-picture matching involving a target picture and a foil depicting a reversal of theta-roles. In the pre-test assessing comprehension of declaratives, all six IWA showed a subject-object comprehension asymmetry (see Table 2). The group analysis of accuracy for offline comprehension of who-questions (see section 5.1) suggests that, in contrast to comprehension of declaratives, offline comprehension of who-questions was symmetrical and equally impaired for both types of questions.

However, such a group analysis of offline accuracy data based on mean performance across IWA can mask important dissociations within individual subjects (Caramazza & McCloskey, 1988). Therefore, we conducted a single-case analysis in order to identify individual asymmetrical or non-asymmetrical comprehension patterns in IWA. This analysis revealed that the overall group pattern of symmetrical who-question comprehension with equal impairment for both subject and object questions held true only for two out of the six IWA (Pq3 and Pq5). For the other IWA, we found intra-individual dissociations across question types, reflecting asymmetrical comprehension of who-questions. Yet, only one participant (Pq2) exhibited the asymmetrical pattern reported in previous studies (Neuhaus & Penke, 2008): above chance performance on subject questions and chance performance on object questions. The direction of this dissociation is in line with the classical subject-object comprehension asymmetry observed for comprehension of declaratives in aphasia (which was also present in this IWA, see Table 2). However, for the remaining three IWA (Pq1, Pq4, Pq6), despite asymmetrical performance for declaratives, the comprehension asymmetry was in the other direction for who-questions, that is, comprehension was significantly better for object than for subject questions. Such a pattern has not been reported in previous studies on who-question comprehension in German-speaking IWA and cannot be explained in terms of higher processing demands induced by the greater distance between filler and gap.. This assumption would predict the opposite pattern and thus only explains the finding of a classical subject-object asymmetry for participant Pq2. The implicational scaling account by Neuhaus and Penke (2008) also does not explain our finding of a reversed asymmetry in German IWA. This account predicts that preserved comprehension of a more difficult type of question (i.e., object questions) will be accompanied by retained comprehension of the less complex type (i.e., subject questions). Our observation of better comprehension of object who-questions is not in line with this prediction.

A reversed asymmetry with better comprehension of object questions has also been observed for Serbo-Croatian and French speaking IWA (Kljajevic & Murasugi, 2010; van der Meulen et al., 2005). Similar to German, Serbo-Croatian has a rich system of overt morphological cues. As suggested by Kljajevic and Murasugi (2010), the case-marking information of the wh-pronoun and the post-verbal NP in who-questions may facilitate comprehension in some IWA. This account assumes that case cues in object questions are more reliable, for example in terms of their informational value for theta-role assignment. Thus, an advantage for object questions emerges and performance with object-extracted who-questions is better than for subject questions.

As mentioned above in the discussion of controls' data, we also found an advantage of object questions in terms of faster end-of-sentence RTs for controls in our study. In fact, concerning RTs in IWA, we observed the same effect: their end-of-sentence responses were faster for object as compared to subject who-questions, although they were overall slower than controls. For controls, faster processing of object questions was also reflected in their eye-movements, as there were significantly more gazes to the target picture during the post-verbal NP in the object as compared to the subject condition. This was not the case during processing of the post-verbal NP in IWA. However, for their trials with correct offline responses, IWA's gazes to the target significantly increased during the following RoI in both conditions. This suggests a successful parsing of the wh-structure, although the wh-element and its unambiguous case cue were processed not as fast as in controls.

Furthermore, the analyses of IWA's gaze proportions to the agent and theme characters revealed a similar pattern of anticipation with respect to the most likely theta-role of the post-verbal NP. For successful processing of subject who-questions, IWA predicted a post-verbal theme rather than an agent, while for object questions prediction of an agent rather than a theme was evident. In the discussion of controls' data we suggested that, due to the higher semantic saliency of agent characters, aligning an anticipated agent character with the visually presented characters might be easier as compared to aligning an anticipated theme with the semantically less salient depicted character. This proposal might explain faster processing of object compared to subject who-questions not only in controls, but also in IWA. Moreover, it might explain why some IWA show a reversed subject-object comprehension asymmetry. Future research is needed in order to test this hypothesis in more detail.

Returning to IWA's gazes to agent and theme characters, in contrast to controls, processing of only the wh-pronoun and its case cue was not sufficient to trigger anticipation in IWA, but they showed a delay in directing their gaze towards the respective characters. For correct responses to subject-extracted questions, IWA's gaze proportions to the theme characters increased immediately after the verb. For controls, this increase was observed already at the verb region. Nevertheless, the finding for IWA's processing of subject questions provides evidence that they had successfully built up a wh-structure with a gap in subject base-position and associated the wh-filler with this gap, although this process was delayed compared to controls. Similarly, after hearing the verb in object questions, IWA's gazes to the agent characters were significantly higher than for the same RoI in subject who-questions. This suggests that they were building up the wh-structure and correctly postulated the gap in object base-position. In order to do so, they must have used the accusative case cue of the wh-pronoun accordingly. However, similar to the finding for processing of subject who-questions, the process of postulating the correct gap and associating the filler with this gap in order to engage in correct prediction of upcoming sentence elements did not proceed as fast as in controls. Contrary to controls, for IWA's correct trials in both conditions, the wh-pronoun and its case cue alone were not sufficient to trigger anticipation of the most likely theta-role for the post-verbal NP, but IWA needed longer in order to correctly associate the filler with its gap and to engage in prediction.

The finding of retained gap-filling abilities for successful processing of who-questions in IWA is basically in line with the results for English-speaking IWA (Dickey et al., 2007). However, while Dickey and colleagues found that IWA were as fast as controls in processing the filler-gap dependency in who-questions, we observed a clear delay in the time course of wh-structure parsing and gap-filling in IWA. We suggest that this delay can be associated with a slowdown in integrating the case cue of the wh-element in time. Delayed integration of overt morphological cues has also been found for comprehension of declaratives in German-speaking IWA (Hanne et al., 2015) and it is likely that comparable integration problems lead to delays in processing wh-structures. If IWA were processing the case-marking information of the wh-pronoun as incrementally as controls do, we would expect to see earlier prediction of the most likely post-verbal referent, that is, anticipatory eye-movements should occur already at the verb. However, IWA needed more time to engage in prediction and directed their gaze towards the respective characters only after the verb had been heard.

The differences between our findings and those of Dickey et al. (2007) could also be due to differences in the procedure and the visual material. In contrast to the present study, which involved a sentence-picture matching task with two pictures depicting the same action but with reversed theta-roles, Dickey and colleagues used visual panels of four objects or persons, with three of them being mentioned in the question. Moreover, the task was not to identify the picture that correctly matched the question. Instead, participants were required to answer the question. It could be the case that in a design more similar to Dickey and colleagues, the IWA of our study would show faster gap-filling effects and anticipation. Future research is needed in order to investigate in more detail if processing of the filler-gap dependency or anticipation of upcoming sentence elements or both proceeds in a slower fashion in IWA compared to controls.

In contrast, for IWA's incorrect responses in both conditions, we found no evidence for anticipation of upcoming sentence elements. This suggests that, in cases of erroneous who-question comprehension, they had not parsed the wh-structure correctly and failed to postulate the gap accordingly. In addition, there was no increase in gazes to the target picture following processing of the post-verbal NP. Instead, gazes to the target decreased and IWA directed their gaze towards the foil picture. This suggests that, in incorrect responses, IWA additionally failed to use the case cue of the post-verbal NP, which could be assumed to be helpful as a kind of adaptive last-resort process in order to reconstruct the wh-structure accordingly. The late-emerging preference for the foil picture we observed for IWA's incorrect processing of who-questions could be considered similar to the results for erroneous trials in the study by Dickey et al. (2007). In that study, IWA experienced competition from a subject distractor in late regions of object questions (after the gap site) in trials with incorrect end-of-sentence responses. If such competition of a subject distractor were also the source of comprehension failure in the IWA in our study, we would expect to see a gaze preference for agent characters at the final RoI in object questions. Although our data do not provide evidence for such an agent preference (see Figure 6), the high amount of gazes to the foil picture at the final RoI (see Figure 3) is indicative of competition from the semantically reversed interpretation of the question. Similar results have been found for comprehension of declaratives in German-speaking IWA (Hanne et al., 2015).

Conclusion

Our findings for controls provide evidence for incremental processing of the wh-element and its unambiguous case cue in subject as well as object who-questions. Moreover, the wh-pronoun and its case marking were sufficient to trigger anticipation of the most likely post-verbal theta-role in both types of questions. Yet, surprisingly we found an advantage of object over subject questions in terms of processing time. We attribute this finding to faster alignment of the anticipated element with a semantically more salient character in the pictures.

For offline comprehension of subject and object who-questions in aphasia, our data provide evidence for the existence of heterogeneous deficits across IWA. Each of the IWA in this study showed a classical subject-object comprehension asymmetry for declaratives (as evidenced by better comprehension of SVO compared to OVS sentences). However, for who-questions, the comprehension asymmetry was not as straightforward as for declaratives. Instead, we found three different patterns: (i) symmetrical comprehension with equal impairments for both question types, (ii) asymmetrical performance with better comprehension of subject compared to object who-questions (i.e., a classical subject-object asymmetry), (iii) a reversed asymmetry with better comprehension of object compared to subject questions.

Concerning online processing, IWA showed retained abilities in parsing both types of wh-structures and in postulating the gap as well as associating the filler with this gap. Moreover, they are able to anticipate upcoming syntactic structure based on the current parse, indicating retained predictive abilities in IWA. However, processing of the filler-gap dependency is delayed as compared to controls. This delay is most likely attributed to delayed integration of the wh-element's case cue.

Errors in who-question comprehension can be associated with (intermittent) failures in parsing wh-dependencies and in using case cues properly.

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Footnotes

[i] Please note that verb movement is not illustrated in the examples.

[ii] It must be noted that the sentences examined in the study on processing of unambiguous questions were indirect embedded questions, contrary to the study looking at ambiguous questions, which involved matrix clauses.

[iii] The IWA, who had suffered a lesion in his right hemisphere and was pre-morbidly left-handed, used two fingers of the right hand.

Table 1

Demographic and neurological data for IWA.

IWA	Age	Gender	Handedness (side, score)*	Etiology	Localization	Time post-onset
Pq1	41	F	Right, +89	cerebral infarction	Left	14;3
Pq2	50	M	Right, +100	cerebral infarction	Left	12;11
Pq3	59	M	Right, +88	cerebral infarction	Left	10;11
Pq4	60	M	Left, -100	cerebral hemorrhage	Right	19;7
Pq5	58	F	Right, +100	cerebral infarction	Left	2;10
Pq6	44	M	Right, +100	cerebral infarction	Left	4;7

* Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971).

Table 2

Results of language assessments conducted with IWA.

	Aphasia classification		Single-word processing (% correct)		Sentence comprehension (% correct)		
IWA	**Aphasia syndrome**	**Severity score**	**Auditory discrimi-nation**	**Auditory word-picture matching**	**Irreversible sentences**	**Reversible SVO***	**Reversible OVS***
Pq1	Anomic	6.6	99	100	100	100	75
Pq2	Anomic	5.6	95	95	100	90	35
Pq3	Anomic	5.6	96	95	92	90	70
Pq4	Broca	5.0	95	95	100	95	65
Pq5	Broca	4.4	99	95	91	80	35
Pq6	Broca	5.2	97	100	96	95	40

*In the Sentence Comprehension Test, chance range is between 35-75%.

Table 3

Mean constituent durations (in milliseconds) for recorded sentences.

Condition	Wh-element	Verb	post-verbal NP
	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**
Sbj-qu	1005 (40)	405 (89)	735 (90)
Obj-qu	1015 (42)	417 (88)	714 (87)

Table 4

Model parameters for analyses of accuracy

Predictor	X^2	df	p	b	SE	z	p
Group	42.8	5	< .05	-3.078	0.288	-10.68	< .05
Condition	0.21	4	> .05	n/a	n/a	n/a	n/a
Group x Condition	0.03	6	> .05	n/a	n/a	n/a	n/a

n/a: not applicable (coefficients are only provided for significant predictors)

Table 5

Participants with aphasia: Single-case analyses of comprehension performance.

	Accuracy (% correct)		**Performance level**		**Individual effect of question type**			
IWA	**Sbj-qu**	**Obj-qu**	**Sbj-qu**	**Obj-qu**	X^2	***p*-value**	**Odds ratio**	**Pattern**
Pq1	75	95	above	above	3.13	.07	6.07	Sbj <$^{(*)}$ Obj
Pq2	80	35	above	chance	8.29	.004	6.55	Sbj >* Obj
Pq3	65	50	chance	chance	0.92	.34	0.55	Sbj = Obj
Pq4	45	90	chance	above	9.23	.002	10.3	Sbj <* Obj
Pq5	55	45	chance	chance	0.4	.53	0.68	Sbj = Obj
Pq6	65	80	chance	above	1.13	.29	2.11	Sbj < Obj

Table 6

Model parameters for analyses of reaction times

Predictor	X^2	df	p	b	SE	t
Condition	16.49	5	< .05	-155.19	37.62	-4.13
Group	45.52	6	< .05	1946.55	194.87	9.99
Group x Condition	0.08	7	> .05	n/a	n/a	n/a

n/a: not applicable (coefficients are only provided for significant predictors)

Table 7

Model parameters for analyses of gazes to target picture

Predictor	X^2	df	p	Contrast (if applicable)	b	SE	t
Correct responses							
Group	7.46	5	< .05				
RoI	1000.04	10	< .05	NP2	0.135	0.021	6.41
				Sil	0.295	0.022	13.42
RoI x Group	40.48	14	< .05	NP2	-0.162	0.042	-3.89
RoI x Condition	8.77	18	= .06	NP2	0.064	0.029	2.24
Incorrect responses							
Group	30.53	5	< .05				
RoI	804.17	10	< .05				
Condition	1.49	6	> .05				
RoI x Group	202.81	14	< .05	NP2	-0.176	0.054	-3.23
				Sil	-0.455	0.055	-8.32

Table 8

Model parameters for analyses of gazes to agents and themes

RoI	Gazes to Agent characters			Gazes to Theme characters		
	b	SE	t	b	SE	t
Controls						
Preview	-0.001	0.01	-0.11	0.001	0.01	0.1
Wh-element	0.016	0.02	0.82	-0.016	0.02	-0.83
Verb	0.261	0.03	10.19	-0.261	0.03	-10.2
NP2	0.208	0.02	11.27	-0.207	0.02	-11.23
Sil	-0.074	0.03	-2.87	0.073	0.03	2.83
IWA: Correct responses						
Verb	-0.013	0.07	-0.2	0.013	0.07	0.19
NP2	0.127	0.05	2.33	-0.126	0.05	-2.32
IWA: Incorrect responses						
Verb	-0.065	0.09	-0.71	0.063	0.09	0.69
NP2	-0.099	0.06	-1.57	0.101	0.06	1.59

List of figures.

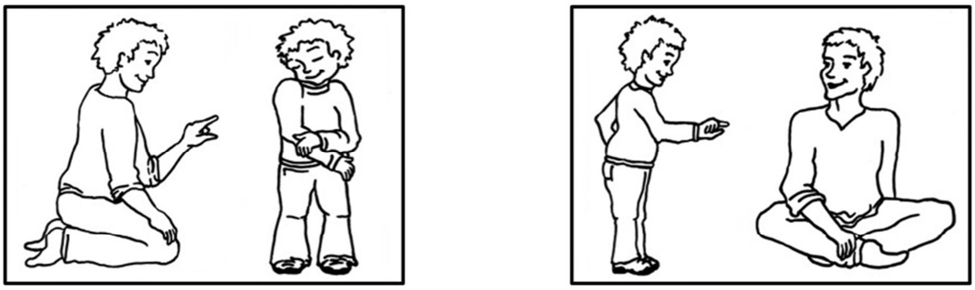

Figure 1: Sample pictures for the targets provided in (5-a) and (5-b)
311x105mm (72 x 72 DPI)

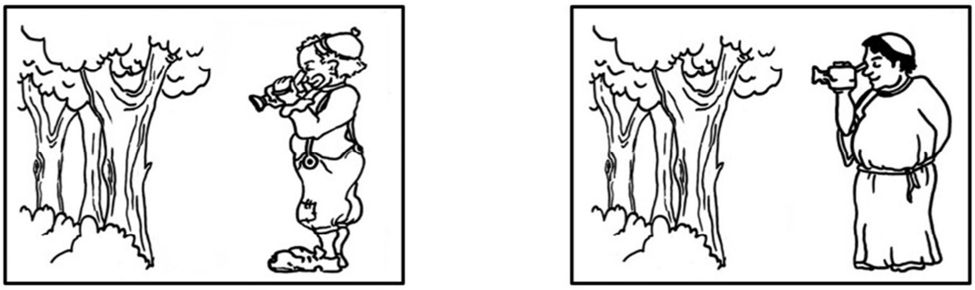

Figure 2: Sample pictures for the filler provided in (5-c).
311x105mm (72 x 72 DPI)

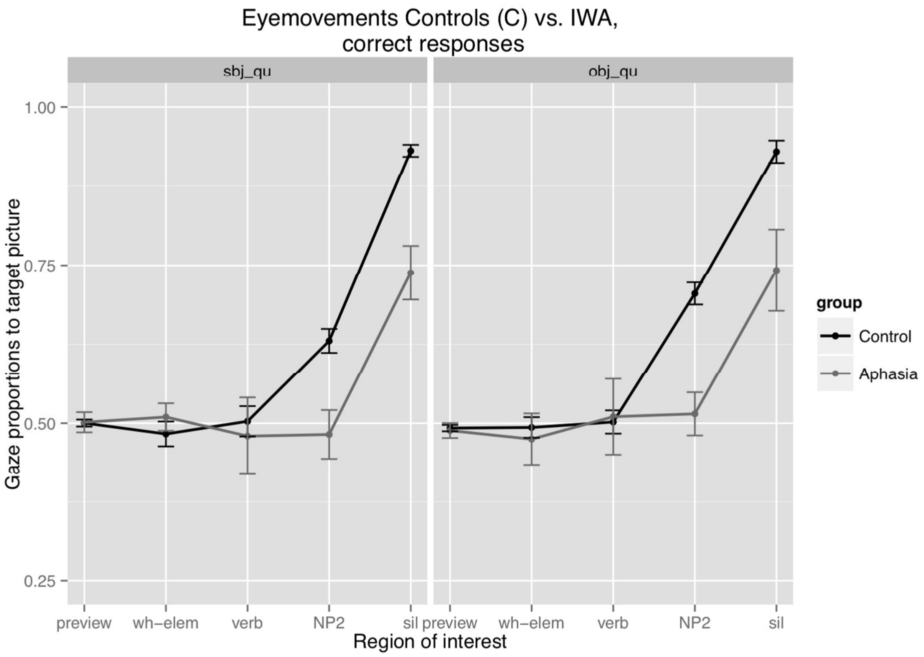

Figure 3: Gaze proportions to the target picture in correct trials, by condition and group. Error bars denote standard errors.
582x416mm (72 x 72 DPI)

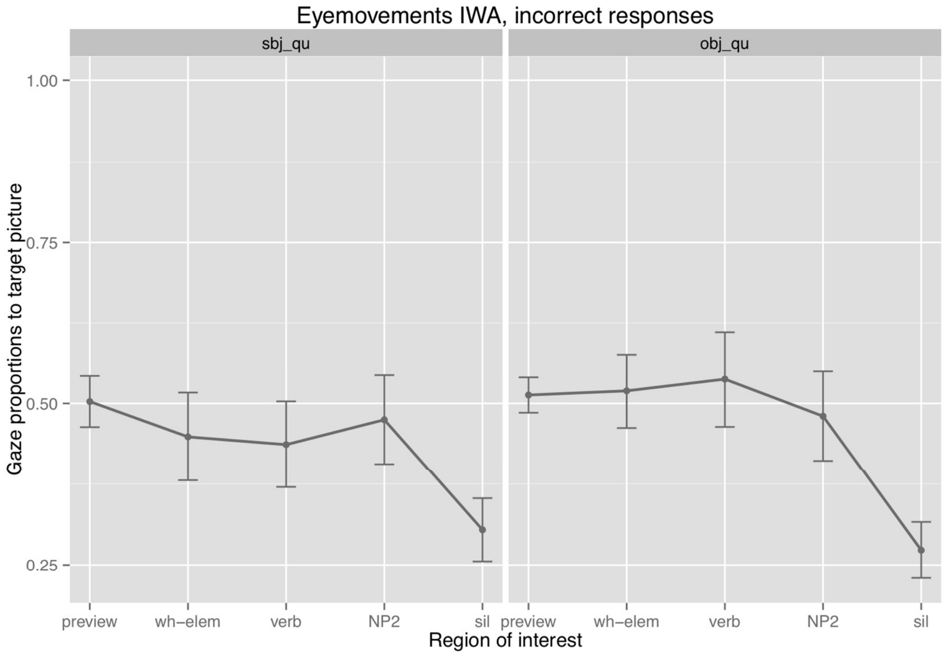

Figure 4: Gaze proportions to the target picture for IWA's incorrect trials, by condition. Error bars denote standard errors.
582x416mm (72 x 72 DPI)

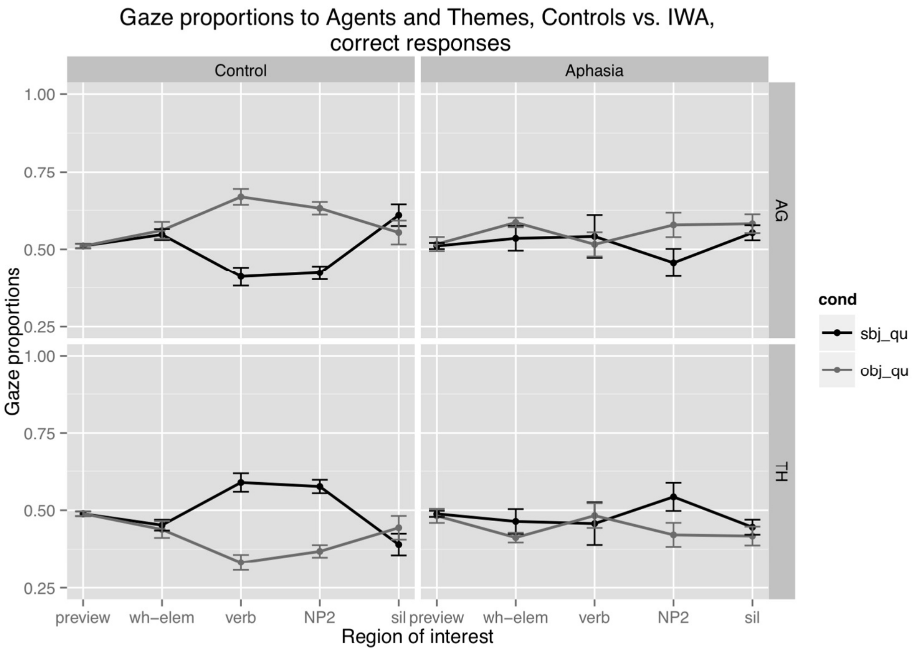

Figure 5: Gaze proportions to Agent and Theme characters in correct trials, by condition and group. Error bars denote standard errors.
624x436mm (72 x 72 DPI)

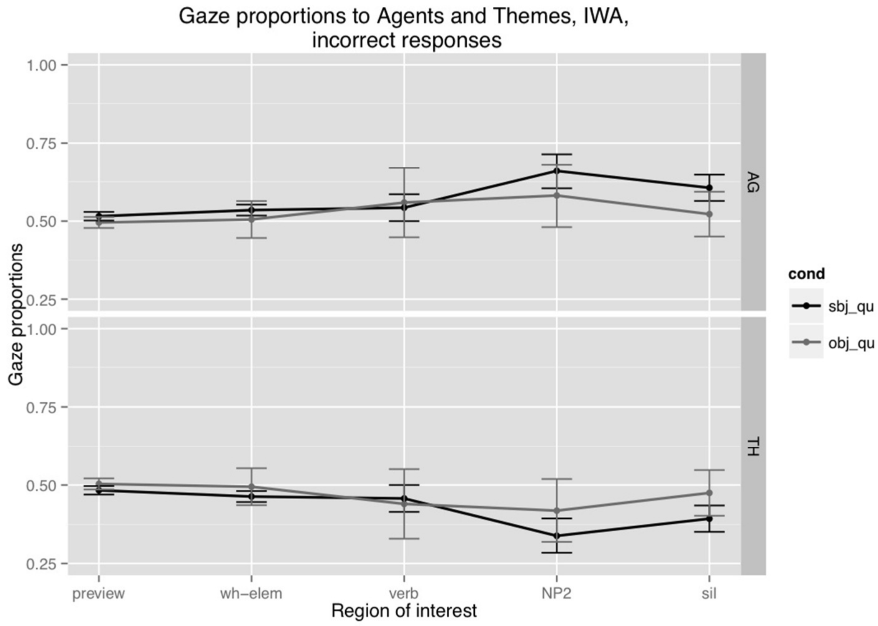

Figure 6: Gaze proportions to Agent and Theme characters for IWA's incorrect trials, by condition. Error bars denote standard errors.
416x279mm (72 x 72 DPI)

Appendix

Table A1.

Target sentences used in the experiment.

Item	Translation
SUBJECT-EXTRACTED QUESTIONS	
Wer badet den Schaffner?	Who is bathing the guard?
Wer fängt den Arzt?	Who is catching the doctor?
Wer filmt den Wirt?	Who is filming the innkeeper?
Wer jagt den Panda?	Who is chasing the panda?
Wer kitzelt den Vater?	Who is tickling the father?
Wer kneift den Sohn?	Who is pinching the son?
Wer küsst den Sohn?	Who is kissing the son?
Wer malt den Mönch?	Who is painting the monk?
Wer misst den Clown?	Who is measuring the clown?
Wer ruft den Koch?	Who is calling the chef?
Wer schlägt den König?	Who is hitting the king?
Wer schubst den Dieb?	Who is shoving the thief?
Wer sieht den Ritter?	Who is seeing the knight?
Wer sticht den Koch?	Who is stabbing the chef?
Wer streichelt den Hund?	Who is petting the dog?
Wer tritt den Esel?	Who is kicking the donkey?
Wer warnt den Teufel?	Who is warning the devil?
Wer wäscht den Zwerg?	Who is washing the dwarf?
Wer weckt den Mönch?	Who is wakening the monk?
Wer zieht den Schmied?	Who is pulling the smith?

OBJECT-EXTRACTED QUESTIONS	
Wen badet der Schaffner?	Who is the guard bathing?
Wen fängt der Arzt?	Who is the doctor catching?
Wen filmt der Wirt?	Who is the innkeeper filming?
Wen jagt der Panda?	Who is the panda chasing?
Wen kitzelt der Vater?	Who is the father tickling?
Wen kneift der Sohn?	Who is the father pinching?
Wen küsst der Sohn?	Who is the son kissing?
Wen malt der Mönch?	Who is the monk painting?
Wen misst der Clown?	Who is the clown measuring?
Wen ruft der Koch?	Who is the chef calling?
Wen schlägt der König?	Who is the king hitting?
Wen schubst der Dieb?	Who is the thief shoving?
Wen sieht der Ritter?	Who is the knight seeing?
Wen sticht der Koch?	Who is the chef stabbing?
Wen streichelt der Hund?	Who is the dog petting?
Wen tritt der Esel?	Who is the donkey kicking?
Wen warnt der Teufel?	Who is the devil warning?
Wen wäscht der Zwerg?	Who is the dwarf washing?
Wen weckt der Mönch?	Who is the monk wakening?
Wen zieht der Schmied?	Who is the smith pulling?