The Relativized Minimality Approach to Comprehension of German Relative Clauses in Aphasia

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ABSTRACT

It is a well-attested finding in head-initial languages that individuals with aphasia (IWA) have greater difficulties in comprehending object-extracted relative clauses (ORCs) as compared to subject-extracted relative clauses (SRCs). Adopting the linguistically based approach of Relativized Minimality (RM; Rizzi, 1990, 2004), the subject-object asymmetry is attributed to the occurrence of a Minimality effect in ORCs due to reduced processing capacities in IWA (Garraffa & Grillo, 2008; Grillo, 2008, 2009). For ORCs, it is claimed that the embedded subject intervenes in the syntactic dependency between the moved object and its trace, resulting in greater processing demands. In contrast, no such intervener is present in SRCs. Based on the theoretical framework of RM and findings from language acquisition (Belletti et al., 2012; Friedmann et al., 2009), it is assumed that Minimality effects are alleviated when the moved object and the intervening subject differ in terms of relevant syntactic features. For German, the language under investigation, the RM approach predicts that number (i.e., singular vs. plural) and the lexical restriction [+NP] feature (i.e., lexically restricted determiner phrases vs. lexically unrestricted pronouns) are considered relevant in the computation of Minimality. Greater degrees of featural distinctiveness are predicted to result in more facilitated processing of ORCs, because IWA can more easily distinguish between the moved object and the intervener.

This cumulative dissertation aims to provide empirical evidence on the validity of the RM approach in accounting for comprehension patterns during relative clause (RC) processing in German-speaking IWA. For that purpose, I conducted two studies including visual-world eye-tracking experiments embedded within an auditory referent-identification task to study the offline and online processing of German RCs. More specifically, target sentences were created to evaluate (a) whether IWA demonstrate a subject-object asymmetry, (b) whether dissimilarity in the number and/or the [+NP] features facilitates ORC processing, and (c) whether sentence processing in IWA benefits from greater degrees of featural distinctiveness. Furthermore, by comparing RCs disambiguated through case marking (at the relative pronoun or the following noun phrase) and number marking (inflection of the sentence-final verb), it was possible to consider the role of the relative position of the disambiguation point. The RM approach predicts that dissimilarity in case should not affect the occurrence of Minimality effects. However, the case cue to sentence interpretation appears earlier within RCs than the number cue, which may result in lower processing costs in case-disambiguated RCs compared to number-disambiguated RCs.

In study I, target sentences varied with respect to word order (SRC vs. ORC) and dissimilarity in the [+NP] feature (lexically restricted determiner phrase vs. pronouns as embedded element). Moreover, by comparing the impact of these manipulations in case- and number-disambiguated RCs, the effect of dissimilarity in the number feature was explored. IWA demonstrated a subject-object asymmetry, indicating the occurrence of a Minimality effect in ORCs. However, dissimilarity neither in the number feature nor in the [+NP] feature alone facilitated ORC processing. Instead, only ORCs involving distinct specifications of both the number and the [+NP] features were well comprehended by IWA. In study II, only temporarily ambiguous ORCs disambiguated through case or number marking were investigated, while controlling for varying points of disambiguation. There was a slight processing advantage of case marking as cue to sentence interpretation as compared to number marking.

Taken together, these findings suggest that the RM approach can only partially capture empirical data from German IWA. In processing complex syntactic structures, IWA are susceptible to the occurrence of the intervening subject in ORCs. The new findings reported in the thesis show that structural dissimilarity can modulate sentence comprehension in aphasia. Interestingly, IWA can override Minimality effects in ORCs and derive correct sentence meaning if the featural specifications of the constituents are maximally different, because they can more easily distinguish the moved object and the intervening subject given their reduced processing capacities. This dissertation presents new scientific knowledge that highlights how the syntactic theory of RM helps to uncover selective effects of morpho-syntactic features on sentence comprehension in aphasia, emphasizing the close link between assumptions from theoretical syntax and empirical research.

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LIST OF ABBREVIATIONS

Apart from units of measurement and time, the abbreviations for Latin words, and those approved for the use in APA publications (Americal Psychological Association, 2019), the following abbreviations are utilized in this dissertation:

-NP	Lack of the lexical restriction feature
+NP	Presence of the lexical restriction feature
+R	Scope-discourse feature
ACC	Accusative
AoI	Area of Interest
D	Determiner
DP	Determiner phrase
IWA	Individuals with aphasia
M	Mean
MASC	Masculine
N	Noun
NEUT	Neuter
NOM	Nominative
ORC	Object relative clause
PL	Plural
PLP	Proportion of looks to the patient
PLT	Proportion of looks to the target
RC	Relative clause
RM	Relativized Minimality
RoI	Region of Interest
SD	Standard deviation
SE	Standard error
SG	Singular
SRC	Subject relative clause
VP	Verbal phrase
wh	Operator feature
X	Target or moved element

Y	Trace
Z	Intervener
θ	Thematic role
ϕ	Phi features

LIST OF ORIGINAL JOURNAL ARTICLES

The cumulative dissertation is based on the following peer-reviewed publications:

Study I

Adelt, A., Stadie, N., Lassotta, R., Adani, F., & Burchert, F. (2017). Feature dissimilarities in the processing of German relative clauses in aphasia. *Journal of Neurolinguistics*, *44*, 17–37. https://doi.org/10.1016/j.jneuroling.2017.01.002

Study II

Adelt, A., Burchert, F., Adani, F., & Stadie, N. (2020). What matters in processing German object relative clauses in aphasia – timing or morpho-syntactic cues? *Aphasiology*, *34*, 970–998. https://doi.org/10.1080/02687038.2019.1645290

I. SYNOPSIS

1 GENERAL INTRODUCTION

Aphasia – an acquired language impairment in adults resulting from brain damage, such as stroke, traumatic brain injuries, or tumors – has been explored by researchers from various perspectives (Lesser & Milroy, 1993). However, theoretical developments and empirical findings from one discipline like aphasiology, linguistic theory, and psycholinguistics often go unnoticed by one another (Gahl & Menn, 2016), despite the potential for linguistic theory to be “the best tool for the investigation of aphasia” (Schaeffer, 2000, p. 50). Linguistic theory has greatly informed empirical research as it makes clear predictions which can be either supported or disconfirmed by the data (Garraffa & Fyndanis, 2020). That way, empirical findings from individuals with aphasia (IWA) contribute to the discussion as to what causes particular difficulties associated with language breakdown.

Early research on aphasia focused solely on morphological and syntactic deficits in language production, known as agrammatism (Clark, 2011). Caramazza and Zurif (1976) were the first to extend the term agrammatism to selective deficits in comprehending semantically reversible sentences with non-canonical word order, such as passives or object relative clauses (ORCs). Since then, researchers have sought to generate explanations for agrammatic sentence comprehension. Most theories have been grounded on notions from theoretical syntax, such as syntactic movement, traces, long-distance dependency, among others, implying a close link between linguistic theory and sentence processing (see Clark, 2011; Druks, 2016; Garraffa & Fyndanis, 2020, for reviews on linguistically informed accounts of language impairment in aphasia).

Some of the most influential theories in this context (for example, Trace Deletion Hypothesis, e.g., Grodzinsky, 1990, 1995, 2000) attribute agrammatic sentence comprehension to a lack of grammatical knowledge. However, in case of correct sentence interpretation, IWA exhibit qualitatively similar patterns of online processing compared to non-brain-damaged control participants (e.g., Caplan et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2015; Pregla et al., 2022). These findings challenge the notion that specific properties of grammar are damaged due to language impairment. Instead, syntactic processing in IWA is rather slowed down or weak, while syntactic representations are intact (Caplan et al., 2007; Haarmann

& Kolk, 1991; Zurif et al., 1993; among others). In light of these findings, the linguistically based concept of Relativized Minimality (RM; Rizzi, 1990) has been adopted to account for the selective difficulties IWA experience in comprehending movement-derived sentences (Garraffa & Grillo, 2008; Grillo, 2005, 2008, 2009). Due to limited processing capacities, IWA cannot activate the full array of morpho-syntactic features associated with moved constituents. As a result, the presence of an intervening element which has to be crossed in the establishment of a syntactic dependency between the moved element and its trace gives rise to so-called Minimality effects. The concept of Minimality has been extensively studied in both syntactic theory and empirical research. This raises the question of whether the RM approach can be regarded as a unitary concept to describe sentence processing across different populations (Rizzi, 2018). While this account has been intensively investigated in the study of sentence comprehension in impaired and unimpaired language acquisition (e.g., Adani, 2011; Adani et al., 2010; Belletti et al., 2012; Friedmann et al., 2015; Varlokosta, Nerantzini, & Papadopoulou, 2014), empirical evidence interpreting sentence comprehension performance in IWA in terms of RM is at present tenuous. Therefore, in her concluding remarks on the RM approach, Druks (2016) calls for more empirical studies in aphasia:

> It is not just that more data need to be collected, but a programme of how to test [RM] must be worked out. … Eye-tracking while listening to sentences and looking at relevant picture(s) is claimed to be a promising methodology to find out about listeners' hypotheses regarding the meaning of the sentences they hear as they unfold. … Eye-tracking may possibly prove to be a useful paradigm to consider employing in testing [RM]. (p. 124)

In this spirit, this thesis aims to provide empirical evidence on the validity of the RM approach (Garraffa & Grillo, 2008; Grillo, 2008, 2009; Rizzi, 1990) regarding the comprehension and processing of relative clauses (RCs) in German-speaking IWA. For that purpose, two studies were conducted (see Chapters 5 and 6) to experimentally investigate several types of relative clauses (RCs), collecting behavioral data (accuracy rates and response times in a referent-identification task) as well as online eye-movement data. This allowed for the testing of different predictions derived from the theoretical assumptions of the RM approach.

The dissertation is divided into two parts: Part I contains the synopsis of the cumulative dissertation. In the subsequent sections of Chapter 1, I will review the underlying theoretical and empirical background of the RM approach as well as methodological considerations for addressing the research questions outlined in Chapter 2. In Chapter 3, I will summarize the empirical studies and their major results, before combining these findings in a joint discussion and conclusion in Chapter 4. Part II comprises the two peer-reviewed articles that have been published in international journals.

1.1 Sentence comprehension in aphasia

IWA often experience difficulties in comprehending sentences in the absence of comprehension deficits at the word level. Crucially, impairments in sentence comprehension occur when sentence structures are derived by syntactic movement (Friedmann & Shapiro, 2003; Grodzinsky, 1989, 2000; among others). Theoretical linguistics refers to syntactic movement as the extraction of a constituent from its base-generated position, moving it to another position in the sentence. The moved constituent leaves a trace at its base position, which is assigned the thematic role of agent or patient by the verb. Therefore, moved constituents have to be linked to their trace through a thematic chain in order to correctly assign thematic roles and derive sentence meaning (Chomsky, 1973).

In their seminal work, Caramazza and Zurif (1976) demonstrated that IWAs' difficulties in comprehending movement-derived sentences are determined by two factors: semantic reversibility and word order. A declarative sentence is referred to as being semantically reversible when both participants of an event could logically be assigned the thematic roles of agent or patient (e.g., *The father washes the son*). That means that either participant performing the action would be plausible. In semantically irreversible sentences, one participant of the event is inanimate (e.g., *The father washes the car*) and thus, the roles of agent and patient are predetermined based on animacy (animate = agent, inanimate = patient). In contrast to irreversible sentences, IWA have greater difficulties in comprehending semantically reversible sentences.

A second factor influencing sentence comprehension in aphasia is word order. Comprehension of semantically reversible sentences with canonical word order (i.e., subject before object), such as actives, subject clefts, and subject relative clauses

(SRCs), is usually better than chance level in behavioral tasks like sentence-picture matching. In contrast, comprehension performance on their non-canonical counterparts (i.e., object before subject), such as passives, object clefts, and ORCs does not significantly differ from chance level (Caramazza & Zurif, 1976; Mitchum & Berndt, 2008; Schwartz et al., 1980; among others). This selective failure to interpret semantically reversible sentences with non-canonical word order is often referred to as agrammatic sentence comprehension and was originally associated with Broca's aphasia (e.g., Caramazza & Zurif, 1976; Schwartz et al., 1980). However, later studies found the same performance pattern in other aphasia syndromes as well (e.g., Caramazza & Miceli, 1991; Goodglass et al., 1979; Hanne et al., 2015; Martin & Blossom-Stach, 1986; Martini et al., 2020).

Two categories of theoretical accounts have been proposed to explain IWAs' impaired comprehension of semantically reversible sentences with non-canonical word order, namely representational and processing accounts (see Clark, 2011; Druks, 2016; Garraffa & Fyndanis, 2020, for an overview). First, representational accounts attribute agrammatic sentence comprehension to deficits in syntactic representations, such as a loss of syntactic traces (Trace Deletion Hypothesis; Grodzinsky, 1986, 1989, 1990) or the deficient formation of syntactic dependencies between moved constituents and their traces (Double Dependency Hypothesis; Mauner et al., 1993). Second, processing accounts posit that sentence comprehension deficits in aphasia stem from a slowdown or a weakness in the syntactic processing system. While syntactic representations are assumed to be intact in these approaches, the processing accounts conceptualize processing limitations in different ways: Slower-than-normal activation of syntactic information (Haarmann & Kolk, 1991), slowed-down online assembly of phrase structures (Burkhardt et al., 2003), or intermittent deficiencies in performing syntactic operations simultaneously due to reduced processing capacities (e.g., Caplan, 2006; Caplan et al., 2006, 2007; Hanne et al., 2011; Pregla et al., 2022) give rise to failure in sentence comprehension. This thesis focuses on the RM approach, which combines the two aforementioned categories of accounts and attributes IWAs' difficulties in comprehending non-canonical sentences to a "processing derived structural deficit" (Grillo, 2008, p. 79). The aim of this thesis is to investigate whether this approach can account for the aforementioned comprehension asymmetry by examining the processing of RCs in German-speaking IWA. In the following section, I will introduce the syntactic properties of RCs with special reference to German, the language under investigation in this thesis.

1.2 Properties of RCs in German

A lot of research in the linguistic field over the past few decades has focused on the processing and comprehension of restrictive RCs. Restrictive RCs are introduced by a relative pronoun that modifies a noun. In examples (1a) and (1b), the embedded clause serves as a modifier of the determiner phrase (DP) *the boy*, which is referred to as the RC head.

(1)

a. (I see) [the boy] who ___ kissed [the girl] (SRC)

b. (I see) [the boy] who [the girl] kissed ___ (ORC)

Restrictive RCs (and RCs in general) are of particular interest in psycho- and neurolinguistic research because the extracted DP (*the boy* in 1a and 1b) is assigned its syntactic function and thematic role only after intervening material is processed (Traxler et al., 2002). In SRCs (example 1a), the RC head noun is extracted from the subject position of the verb in the RC (i.e., *kissed*), which assigns the thematic role of agent to the trace (marked by underscores). Through a thematic chain, the thematic role is transmitted from the trace to the moved RC head noun. In ORCs (example 1b), the RC head is extracted from the object position, where the trace mediates the thematic role of patient to the RC head (e.g., Haegeman, 1994; Heim & Kratzer, 1998).

So far, most research on RC processing focused on English, in which sentence interpretation is determined by word order (as seen in 1a and 1b). However, German SRCs and ORCs do not differ in word order and form syntactic minimal pairs. Despite this special feature, there has been limited research on the comprehension of RCs in German-speaking IWA.

Since German is a verb-final language, word order expectations play a minor role (Vasishth & Drenhaus, 2011). Hence, listeners or readers have to analyze morpho-syntactic markings to derive correct meaning of semantically reversible sentences.

In German, case marking on masculine singular nouns and number-marking of inflected verbs in agreement with the subject can provide cues to sentence meaning. Specifically, unambiguous case marking on the relative pronoun (2a) or the determiner of the embedded constituent (2b) can disambiguate between SRC and ORC interpretations. In example (2a), the relative pronoun is marked for nominative (masculine singular RC head noun, *der*) or accusative (*den*), disambiguating the RC towards an SRC or ORC interpretation, respectively (immediately case-disambiguating condition). In example (2b), case marking of the relative pronoun is ambiguous due to case syncretism, allowing for both nominative and accusative interpretations (neuter/feminine singular RC head noun, *das/die*). Disambiguation is achieved through an unambiguous case marker on the determiner of masculine singular nouns (*der/den*) as embedded constituent (early case-disambiguating condition). On the other hand, in number-marked RCs (example 2c), case marking of both the relative pronoun (neuter/feminine singular RC head noun*, das/die*) and the determiner of the embedded constituent (masculine plural, *die*) is ambiguous between nominative and accusative. Sentence meaning can be inferred from inflection of the sentence-final verb in the RC (late number-disambiguated condition), which is unambiguously marked for person and number (3rd person singular/plural, *kitzelt/kitzeln*). Thematic role assignment is mediated through subject-verb agreement. When the verb is singular, it agrees with the RC head, resulting in an SRC. In case of plural marking, the verb agrees with the embedded constituent, resulting in an ORC. As seen in examples (2a-c), case and number, as disambiguating cues to sentence interpretation, differ regarding their relative position within RCs (marked in bold face).

(2)

a. *Immediately case-disambiguated SRC / ORC*
Wo ist der Esel, **der / den** den / der Hahn kitzelt?
Where is the donkey that is tickling the rooster?/that the rooster is tickling?

b. *Early case-disambiguated SRC / ORC*
Wo ist das Schaf, das **der / den** Igel kitzelt?
Where is the sheep that is tickling the hedgehog?/that the hedgehog is tickling?

c. *Late number-disambiguated SRC / ORC*
Wo ist das Reh, das die Frösche **kitzelt / kitzeln**?
Where is the deer that is tickling the frogs?/that the frogs are tickling?

In what follows, I will first outline the RM approach to locality (Rizzi, 1990, 2013) and describe how this syntactic theory is extended to neurolinguistic research in order to account for agrammatic sentence comprehension (Garraffa & Grillo, 2008; Grillo, 2009).

1.3 RM and its extension to the study of sentence comprehension in aphasia

Based on a finite set of elements (e.g., lexical words, morphemes), natural languages can generate a (probably) infinite number of possible sentences (Chomsky, 1957). Hence, there must be certain rules and principles in the human language processor which allow for comprehension of these mostly unpredictable sentences. One of these pervasive properties of natural languages is locality. With respect to syntax theory, syntactic relations (e.g., movement) have to be local. That means that they have to be satisfied in the smallest structural domain (i.e., Minimal Configuration) in which they can be satisfied. RM captures this idea by restricting the sentence part in which a local relation can be computed (Rizzi, 2004). Hence, RM is an economy principle, which is formally defined as follows (adapted from Rizzi, 2004, 2013):

(3) Given the configuration … X … Z … Y …
Y is in a Minimal Configuration with X iff there is no Z such that
a. Z intervenes between X and Y, and
b. Z is of the same structural type as X.

Within the RM approach, intervention is defined based on c-command (Reinhart, 1976). That means that Z is considered an intervener if it c-commands the trace Y, but not the moved element X. Moreover, Rizzi (2004) defines different feature classes, based on the Cartographic Approach (Cinque, 2006). According to this approach, each position in the syntactic tree is defined by a particular set of morpho-syntactic features. Therefore, features can be grouped into distinct classes given the typology in (4). Importantly, intervention only occurs within the same featural class and not across classes.

(4)

a. Argumental: person, number, case, gender
b. Quantificational: wh, Neg., measure, focus, . . .
c. Modifier: evaluative, epistemic, Neg., frequentative, celerative, measure, manner, . . .
d. Topic

(Rizzi, 2004, p. 243)

Taken together, locality in terms of RM means that a local relation between two elements cannot hold if there is a third element which intervenes and is a potential bearer of the same relation. Thereby, RM reduces ambiguity as the closest element always 'wins' in cases where two elements compete for a syntactic relation with another element (Rizzi, 2004).
Based on the definition in (3), RM can account for numerous syntactic phenomena such as *wh*-islands. According to RM, example (5a) is considered ill-formed because the *wh*-element *who* (Z) intervenes between the moved *wh*-element *when* (X) and its trace (Y) (intervention marked by symbol ✖). Since both *when* and *who* belong to the Quantificational feature class, the intervener *who* is regarded as a possible bearer of the local relation. However, in (5b), the embedded subject *John*, occupying the same position as *who* in (5a), does not intervene in the syntactic relation between *when* and the trace. This is due to the fact that *John* is not of the same structural type as *when*, thus, there is no intervention.

(5)

a. * When do you wonder who left ___?

X Z Y

b. When do you think John left ___?

X Y

(Rizzi, 2013, p. 172)

Adopting the RM approach, it is proposed that the asymmetry in comprehending semantically reversible canonical and non-canonical sentences in aphasia can be attributed to the correct application of the locality principle to an impoverished syntactic representation (Garraffa & Grillo, 2008; Grillo, 2005, 2008, 2009). In the so-called Generalized Minimality approach, Grillo (2009) combines processing-based and representational explanations of the canonicity effect in aphasia. The approach claims that reduced processing capacities result in underspecification of morpho-syntactic features whose activation is slowed down or decays faster than normal. Especially, scope-discourse related features (related to the periphery of the clause and the verbal phrase, i.e., quantificational and discourse-related features such as *wh*, topic and focus) are assumed to be underspecified (i.e., reduced in number and quality) in IWAs' syntactic representation in case of a processing deficit. This is due to the fact that scope-related features are assumed to be accessed later in deriving the representation. Example (6a) shows a fully specified representation of an ORC. In examples (6b) and (6c), underspecified representations of ORCs and SRCs are provided, with feature impoverishment and the change in feature classes compared to the fully specified representation being highlighted in bold face.

(6)

a. *Fully specified representation of ORC*

[The boy] who [the girl] kissed ___

(D, N, θ_2, $\phi_{SG,\,ACC}$, wh)$_{ClassQ}$ (D, N, θ_1, $\phi_{SG,\,NOM}$)$_{ClassA}$ (D, N, θ_2, $\phi_{SG,\,ACC}$, wh)$_{ClassQ}$

X Z Y

b. *Impoverished representation of ORC*

[The boy] who [the girl] kissed ___

(D, N, $\boldsymbol{\theta_?}$, $\boldsymbol{\phi_{SG}}$)$_{\mathbf{ClassA}}$ (D, N, $\boldsymbol{\theta_?}$, $\boldsymbol{\phi_{SG}}$)$_{ClassA}$ (D, N, $\boldsymbol{\theta_?}$, $\boldsymbol{\phi_{SG}}$)$_{\mathbf{ClassA}}$

X Z Y

c. *Impoverished representation of SRC*

[The boy] who ___ kissed [the girl]

(D, N, $\boldsymbol{\theta_?}$, $\boldsymbol{\phi_{SG}}$)$_{\mathbf{ClassA}}$ (D, N, $\boldsymbol{\theta_?}$, $\boldsymbol{\phi_{SG}}$)$_{\mathbf{ClassA}}$

X Y

adopted from Grillo (2008)

In example (6a), the presence of the features [$\phi_{SG, ACC}$, wh] makes the moved object (*the boy*) distinct from the embedded subject (*the girl*), which carries the features [$\phi_{SG, NOM}$]. Especially, the operator feature [wh] leads to distinct feature classes: The former belongs to the Quantificational class, whereas the latter belongs to the Argumental class. Consequently, the two constituents can be distinguished when establishing the movement dependency between the object and its trace.

Due to reduced processing resources, IWA cannot access the [wh] feature of the moved object, resulting in an impoverished syntactic representation of ORCs (6b). As a result, both the moved object and the embedded subject belong to the Argumental class. Consequently, RM blocks the formation of a movement dependency between the object (*the boy*) and its trace because the embedded subject is considered a potential bearer of the dependency, making the assignment of thematic roles impossible. Hence, the presence of the intervening subject in the syntactic dependency gives rise a so-called Minimality effect (adopting the term from Grillo, 2005, 2009). This often leads to comprehension performance at chance, which "is ultimately due to the confusion generated by the minimality effect" (Grillo, 2008, p. 88). Additionally, as illustrated in example (6b), other relevant morpho-syntactic features, such as case and number, are likely to be compromised in syntactic representations of IWA. Regarding SRCs, Grillo (2008) argues that even an underspecified representation does not lead to comprehension difficulties in IWA, because no other element intervenes in the syntactic dependency between the moved element and its trace (as shown in example 6c). Therefore, the application of the locality principle yields the correct link between the moved subject and the trace. In other words, due to impoverishment in morpho-syntactic features, the presence of the intervening subject in ORCs results in a Minimality effect, because IWA adhere to the locality principle. The confusion generated by the Minimality effect makes the interpretation of non-canonical sentences more likely to be compromised as compared to SRCs, where no such intervener is present (Grillo, 2008).[1]

[1] In a similar vein, the Intervener Hypothesis (Engel et al., 2018; Sheppard et al., 2015; Sullivan et al., 2017) attributes IWAs' difficulties in comprehending movement-derived sentences to the presence of an intervener in the dependency between an extracted element and its trace. Moreover, the RM approach shares certain characteristics with the psycholinguistic account of similarity-based interference (Gordon et al., 2001, 2004). The current dissertation is not designed to distinguish between these explanations, but considerations regarding such an investigation in future research are discussed in Chapter 4.2.

In addition, Grillo (2009) emphasizes "that a difference on a single feature of the same class (e.g. a mismatch in gender or number features) is not enough to avoid a minimality effect unless that feature introduces a change of class" (p. 1433). However, findings from language acquisition show that children's comprehension of ORCs improves when the moved object and the intervening subject differ with regard to morpho-syntactic features. Interestingly, Hebrew-speaking children demonstrate better comprehension performance in case of dissimilarity in the gender feature (i.e., one masculine, one feminine) as compared to similarity (i.e., both masculine or feminine) (Belletti et al., 2012). However, no such effect was found in Italian. This language-specific effect of feature dissimilarity is attributable to the different status of morpho-syntactic features across languages. In Hebrew, gender is a morpho-syntactic feature that attracts syntactic movement of the subject to the subject position of the clause in order to agree with the inflected verb. Therefore, gender is referred to as a syntactically active feature, which is realized in the agreement morphology of finite verbs. Only syntactically active features enter the computation of Minimality. Hence, dissimilarity in the gender feature improves comprehension of ORCs in Hebrew children, because they can distinguish the constituents more easily. On the other hand, in Italian, finite verbs are inflected for number (and person). Thus, only number is regarded as a syntactically active feature in Italian, as evidenced by children's improved performance in comprehending ORCs with dissimilar number features relative to similar number feature specifications (Adani et al., 2010). Similar results have been reported for English-speaking children (Adani et al., 2014) and an Italian-speaking IWA (Martini et al., 2020).

Moreover, there is evidence from psycholinguistic research that the Minimality effect in ORCs can be alleviated by manipulating the moved object and the intervener in terms of lexical restriction (expressed as the [+NP] feature). Lexically restricted DPs are nominal expressions introduced by a determiner (e.g., *the boy* in RCs) or a *wh*-word (e.g., *which boy* in *wh*-questions) carrying the [+NP] feature. In contrast, lexically unrestricted DPs such as pronouns (e.g., *he*) or bare *wh*-words (e.g., *who*) lack the [+NP] feature. A number of studies found that the subject-object asymmetry is reduced or even eliminated when the intervener in an ORC is a pronoun rather than a lexical DP. This phenomenon, known as pronoun facilitation, has been demonstrated in both non-brain-damaged adults (e.g., Gordon et al., 2001, 2004; Reali & Christiansen, 2007; Roland et al., 2012; Villata et al., 2016; Warren & Gibson, 2002) and typically developing children (e.g., Arnon, 2010; Brandt et al., 2009; Friedmann et al., 2009; Haendler et al., 2015). As opposed to morpho-syntactic features such as gender or number, the [+NP] feature should not impact the occurrence of Minimality effects since it is embedded within the DP. Nevertheless, Belletti and Rizzi (2013) explicitly highlight the [+NP] feature as being involved in the computation of Minimality. Rizzi (2018) claims that lexical restriction participates in determining the landing site of syntactic movement.

It appears that not only morpho-syntactic features but also other features such as lexical restriction affect Minimality effects, as long as they are involved in syntactic movement. Following this line of reasoning, Rizzi (2018) revised the original definition of RM as follows:

(7) Featural Relativized Minimality

In … X … Z … Y … a local relation between X and Y is disrupted when

a. Z c-commands Y and Z does not c-command X.

b. Z matches X in terms of Relevant Syntactic Features.

Capitalizing on this definition and psycholinguistic research findings, the degree of overlap in relevant syntactic features between the moved object and the intervening subject is hypothesized to determine the strength of the Minimality effect and can be operationalized in terms of set-theoretic relations (Belletti et al., 2012; Friedmann et al., 2009; Rizzi, 2018). Table 1.1 illustrates the possible relations that can hold between the featural specifications of the moved element X and the intervener Z considering the relevant features A, B, and C attached to these elements.

Table 1.1

Set-theoretic relations between the moved element (X), its trace (Y), and the intervener (Z) and unimpaired adult speakers' and children's ability to compute relation according to RM (based on Belletti et al., 2012; Friedmann et al., 2009)

Set-theoretic relation	X	Z	Y	Unimpaired adult grammar	Child grammar
Identity (8a)	A …	A …	A …	×	×
Inclusion (8b)	A, B …	A …	A, B …	✓	×
Intersection (8c)	A, B …	A, C …	A, B …	✓	✓
Disjunction (8d)	A …	B …	A …	✓	✓

Note. × = ruled out by RM, ✓ = tolerated by RM.

When the featural specifications of both elements X and Z are identical (8a), no local relation can be established between the moved element X and its trace Y, because the intervener Z blocks chain formation due to locality. In contrast, no relevant features are shared in the Disjunction relation (8d). Therefore, the syntactic dependency between the moved element X and its trace Y can be easily established. Moreover, structures are well-formed according to RM, when the featural specification of the intervener is properly included in the featural specification of the moved element (i.e., Inclusion relation, 8b) or when the moved element and the intervener differ in at least one relevant feature (i.e., Intersection relation, 8c).
With respect to data from language acquisition, Friedmann et al. (2009) and Belletti et al. (2012) assume that the developing processing system requires are higher degree of featural distinctiveness as compared to adults (see Table 1.1): Whereas children have difficulties in dealing with Inclusion, adults can properly interpret these structures. However, as evidenced in online measures of sentence processing, non-brain-damaged adults experience greater processing costs when computing Inclusion as compared to Disjunction (see Belletti & Rizzi, 2013, for an overview). That means that the principle of RM is at play in both adults and children, but locality is computed in a more restrictive manner in children, as it only tolerates cases of greater featural distinctiveness (see also Costa et al., 2012). One aspect that is still left unclear is how the degree of featural distinctiveness is related to sentence comprehension patterns in IWA.

To sum up, the Generalized Minimality approach attributes IWAs' difficulties in comprehending ORCs to the presence of an intervening element in the movement dependency between the moved object and its trace, giving rise to Minimality effects. Previous studies from language acquisition have shown that ORC processing can be less demanding when the moved object and the intervener differ in the specification of relevant morpho-syntactic features. More specifically, higher degrees of feature dissimilarity alleviate the Minimality effect to a greater extent. In the following, I will summarize the predictions made by the RM approach with respect to RC processing and review empirical evidence regarding the subject-object asymmetry and the effect of feature dissimilarity in aphasia.

1.4 RM and RC processing in aphasia

Based on the theoretical framework of RM, the Generalized Minimality approach (Grillo, 2008) predicts the occurrence of a subject-object asymmetry in RC processing in aphasia. Furthermore, it suggests that processing of ORCs can be facilitated by manipulating the moved object and the intervening subject in terms of dissimilarity of relevant morpho-syntactic features (Rizzi, 2018). In German, verbs are inflected for number (and person) and number triggers syntactic movement to the subject position. This means that number is regarded as a syntactically active feature and that the Minimality effect caused by the embedded subject in ORCs can be alleviated when the moved object and the embedded subject differ in the number feature. However, dissimilarity in case should not affect the Minimality effect, as case is not considered a relevant feature. Additionally, pronouns used as embedded subjects are predicted to facilitate ORC processing due to dissimilarity in terms of the [+NP] feature.

In what follows, I will present existing evidence related to the predictions of the RM approach, with a special focus on the investigation of RC processing in German-speaking IWA.

1.4.1 Empirical evidence on the subject-object asymmetry

Across head-initial languages, IWA demonstrate better comprehension of SRCs as compared to ORCs in sentence-picture matching (e.g., Friedmann, 2008; Friedmann et al., 2010; Garraffa & Grillo, 2008; Grodzinsky, 1989; Lukatela et al., 1995; Terzi & Nanousi, 2018; Varlokosta, Nerantzini, Papadopoulou, et al., 2014; see Lau & Tanaka, 2021, for a review across various languages and populations).[2] Additionally, studies using online measures of sentence processing found evidence of a subject-object asymmetry, with faster self-paced listening times observed for SRCs compared to ORCs (Caplan et al., 2007).

Prior to this dissertation project, there was limited experimental work on the subject-object asymmetry in German-speaking IWA. Burchert et al. (2003) investigated comprehension of different semantically reversible canonical and non-canonical sentence structures in a sentence-picture verification task and found no significant differences in IWAs' comprehension of SRCs and ORCs at the group level. More recent research by Pregla et al. (2021) revealed higher accuracy rates and faster response times for SRCs as compared to ORCs in object manipulation (i.e., acting out the sentence meaning with figurines) and sentence-picture matching. Likewise, eye-gaze data collected during the administration of the sentence-picture-matching task indicated that IWA have greater processing difficulties in ORCs than in SRCs. The higher error rate in ORCs in the offline task can be traced back to the application of an agent-first strategy. Once, IWA employ the heuristic strategy, they can hardly revise their initial misinterpretation (Pregla et al., 2022).

In sum, in line with the predictions of the RM approach, there is considerable cross-linguistic evidence of a subject-object asymmetry in offline tasks in aphasia, while online data on RC processing are still scarce.

[2] In head-final languages such as Mandarin and Cantonese Chinese, there is evidence of a processing advantage of ORCs over SRCs in IWA (e.g., Hsiao & Gibson, 2003; Su et al., 2007).

1.4.2 Empirical evidence on the facilitating effect of feature dissimilarity

Following the RM approach, dissimilarity in relevant syntactic features between the moved object and the intervening subject is expected to facilitate processing of ORCs. In the next section, I will provide an overview of previous studies that have explored the facilitating effect of the morpho-syntactic features case and number in sentence processing in German. Subsequently, I will summarize studies that have investigated the role of lexical restriction ([+NP] feature) in sentence processing.

1.4.2.1 Morpho-syntactic features case and number

In languages other than German, processing of ORCs in typically developing children (Italian: Adani et al., 2010, English: Adani et al., 2014) as well as IWA (Italian: Martini et al., 2020) has been shown to be facilitated through manipulation of the number feature. Conversely, dissimilarity in case, a feature that is not considered to be syntactically active, has no facilitating effect on ORC comprehension in IWA (Hebrew: Friedmann et al., 2017; Greek: Terzi & Nanousi, 2018). With respect to German, both number and case marking allow disambiguation towards sentence meaning (see Chapter 1.2). Still, the RM approach predicts that dissimilarity in number results in a processing advantage in ORCs as opposed to case, because only number is considered as a relevant feature in the computation of Minimality. Therefore, case- and number-disambiguated RCs provide an opportunity to gain further insight into the status of different morpho-syntactic features in RM.
In processing case-marked RCs, German-speaking IWA have difficulties in utilizing case marking to determine sentence meaning (Burchert et al., 2001). Moreover, processing of the case cue is slowed down in IWA (Pregla et al., 2022). However, sentence material in previous studies did not include verb arguments with different specifications in terms of number, which is predicted to facilitate ORC processing.
Regarding the manipulation of dissimilarity of the number feature, Burchert et al. (2003) examined IWAs' comprehension performance on globally ambiguous RCs (i.e., both verb arguments are singular and agree with the RC verb) and unambiguously number-marked RCs (i.e., one argument is singular, the other is plural). Dissimilarity in terms of number led to slightly improved comprehension in

IWA as compared to similar number features (73.4% and 68.7% correct responses, respectively). However, it remains unclear whether this finding can be attributed to the effect of feature dissimilarity or to the fact that sentences including feature dissimilarity were unambiguous, whereas sentences with feature similarity were ambiguous. More recently, Lissón et al. (2023) assessed IWAs' comprehension of ORCs disambiguated through case marking at the relative pronoun. Additionally, the authors manipulated whether the constituents matched or mismatched in terms of number. In the mismatch condition, number provided an additional cue to sentence meaning. However, there was no facilitating effect of dissimilarity in number, which is inconsistent with the predictions of the RM approach. Instead, Lissón et al. (2023) suggest that IWA rely more on case information. Still, it remains unclear whether number dissimilarity alone (without disambiguation through case) can facilitate processing of ORCs in IWA.

Even though the RM account predicts that only dissimilarity with respect to number is considered in the computation of Minimality, case also provides relevant information to sentence interpretation. In German, the case marking cue (case of relative pronoun or determiner of embedded constituent) appears earlier in RCs than the number cue (inflection of RC verb, see examples 2a-c). Consequently, the earlier points of disambiguation in case-marked sentences could override a potential facilitating effect of number dissimilarity. Previous studies investigating both case and number marking in IWA provided contradicting evidence as to which cue is harder to process. While Burchert et al. (2003) reported that IWA have greater difficulties in processing number marking as compared to case marking, Hanne et al. (2015) found the reverse pattern. However, neither Burchert et al. (2003) nor Hanne et al. (2015) compared case and number marking directly, while controlling for varying points of disambiguation. Hence, it remains unclear as to whether case and number differ in terms of their status in Minimality or whether processing is influenced by varying points of disambiguation.

1.4.2.2 Lexical restriction

Based on data from language acquisition, dissimilarity in lexical restriction is proposed to reduce IWAs' processing difficulties in non-canonical sentences (Friedmann et al., 2009). For example, studies investigating comprehension of *who*-

and *which*-questions found a selective deficit in comprehending object-extracted *which*-questions (e.g., *Which boy is the girl kissing ___?*) as opposed to object-extracted *who*-questions (e.g., *Who is the girl kissing ___?*) (Hickok & Avrutin, 1996; Sheppard et al., 2015; Varlokosta, Nerantzini, Papadopoulou, et al., 2014).[3] Within the RM approach, this asymmetry can be accounted for by feature dissimilarity in terms of [+NP]. While both the moved object (*which boy*) and the intervening subject (*the girl*) are lexically restricted in object *which*-questions, the moved object (*who*) in object *who*-questions is not.

Regarding RC processing in aphasia, only one study so far investigated the effect of feature dissimilarity in terms of [+NP]: Varlokosta, Nerantzini, Papadopoulou, et al. (2014) assessed comprehension of free and restrictive ORCs in Greek with similar and dissimilar [+NP] specifications of the moved object and the embedded subject. The authors found no facilitative effect of feature dissimilarity in ORC comprehension. They argue that difficulties in comprehending ORCs occur irrespective of the specification of the [+NP] feature, because accurate comprehension also requires activation of morpho-syntactic features, such as case, number, and gender. However, it has to be noted that SRCs and ORCs are no strict minimal pairs in Greek, but word order provides a cue to sentence meaning. That means that these morpho-syntactic features appear at varying positions within the sentence as a function of canonicity. Hence, it remains an open issue if IWA benefit from dissimilarity of the [+NP] feature in German, the language under investigation, where SRCs and ORCs are syntactic minimal pairs.

In sum, dissimilarity in the [+NP] feature has been found to alleviate Minimality effects in the comprehension of non-canonical *wh*-questions in aphasia. In contrast, no such facilitating effect occurred in IWAs' comprehension of ORCs.

1.5 Methodological background

In the current dissertation project, a combination of different experimental methods is used to measure offline and online processing of RCs in German-speaking IWA and non-brain-damaged adults as controls. Offline tasks provide data on the end product of sentence processing, as participants are required to provide an explicit

[3] Diverging comprehension patterns have been reported in Salis & Edwards (2005) and Thompson et al. (1999).

response to a stimulus. In contrast, online tasks measure sentence processing in real-time as the sentence unfolds.
The studies included in this thesis combine an auditory referent-identification task (offline method) and the collection of eye-movement data during sentence processing (online method). In what follows, I will describe the experimental tasks in order to investigate the predictions of the RM approach.

1.5.1 Offline method: Referent identification

Sentence comprehension in aphasia is widely tested using sentence-picture matching (Caramazza & Zurif, 1976; Friedmann & Gvion, 2012; Garraffa & Grillo, 2008; Pregla et al., 2021; Terzi & Nanousi, 2018; among others). This task requires participants to point to one picture matching the auditory or written presentation of a sentence. Typically, the target picture displays the action mentioned in the sentence with the correct mapping of thematic roles of agent and patient on the two actors, whereas the distractor picture usually portrays the reversal of thematic roles of the sentence DPs (Burchert et al., 2013). Alternatively, researchers used sentence-picture verification (e.g., Burchert et al., 2003), which requires participants to determine whether the presented sentence matches a picture. Either task for testing sentence comprehension provides categorical data in terms of correct or incorrect responses. Hence, participants' performance can be compared to chance level (i.e., hit rate of .5 in case of one correct and one incorrect response option). Traditionally, agrammatic sentence comprehension has been described as a dissociation between performance above chance level for semantically reversible canonical sentences and performance at chance for non-canonical sentences (Caramazza & Zurif, 1976; Mitchum & Berndt, 2008; Schwartz et al., 1980; among others). Apart from response accuracy, response or reaction times (i.e., the time it takes to select a picture) can be used as dependent measures, reflecting processing costs associated with syntactic structures. Typically, more complex stimuli such as ORCs result in longer response times as compared to SRCs (e.g., Delgado et al., 2021; Friederici et al., 2001).
However, the use of visual scenes as the one described above does not meet the felicity conditions for the appropriate usage of RCs. Since restrictive RCs are used to restrict a referent set (Eisenberg, 2002), RCs are only felicitous if the visual scene displays at least two referents from which the intended referent is selected.

According to the Referential Principle, adults expect the following linguistic context to differentiate between two potential referents and use the referential context to resolve temporary syntactic ambiguity (e.g., Crain & Steedman, 1985; Tanenhaus et al., 1995). These conditions are met in a so-called referent-identification task, which is employed in the studies included in this thesis: In such a task, the visual scene consists of some referent of type A (= agent) performing an action on another referent of type B in the middle who in turn performs the same action on another referent of type A (= patient). This way, the visual context acts as a referential context in accordance with the Referential Principle. This form of context has been successfully used in studying comprehension of *wh*-questions as well as RCs in aphasia (e.g., Hickok & Avrutin, 1996; Nerantzini, Varlokosta, et al., 2014; Sheppard et al., 2015; Varlokosta, Nerantzini, Papadopoulou, et al., 2014).

1.5.2 Online method: Eye tracking while listening

Behavioral offline data in terms of accuracy are not sufficient to study sentence comprehension deficits in aphasia because they only reflect the end product of sentence processing (e.g., Burchert et al., 2013; Caplan et al., 2007). That means that offline tasks cannot provide information about the underlying mechanisms in real-time sentence processing.

Eye tracking is one online method that addresses this limitation and allows monitoring processing as language unfolds over time (e.g., Boland, 2004). This methodology is based on the finding that participants' eye gaze is closely time-locked to the processing of heard language (initially, Cooper, 1974; followed by Tanenhaus et al., 1995). In particular, listeners shift their gaze towards a corresponding object within 200 ms after the object was named (Cooper, 1974). Allopenna et al. (1998) later introduced the term visual-world paradigm (see Boland, 2004; Huettig et al., 2011, for a review). In visual-world experiments, eye trackers measure participants' eye movements while they listen to sentences and inspect a visual scene (e.g., a set of objects or drawings of actions). In the analysis of eye-gaze data, proportion of fixations on single elements (e.g., target or patient) can be compared to the sum of fixations to all elements in the visual display. Accordingly, eye-movement data can be recorded simultaneously with an offline task such as sentence-picture matching or referent identification (see Burchert et al., 2013, for a review).

Over the past 15 years, the visual-world paradigm has been successfully used to study online sentence processing in aphasia (e.g., Dickey et al., 2007; Hanne et al., 2011; Meyer et al., 2012; Sheppard et al., 2015; Thompson & Choy, 2009). In fact, previous studies demonstrated that IWAs' performance in offline tasks does not sufficiently reflect what eye-movement data reveal about their preserved sentence processing abilities. Specifically, IWAs' eye-gaze patterns differ in correct and incorrect offline responses. In correct trials, IWAs' eye movements are qualitatively similar to those of non-brain-damaged controls, but deviate when offline responses are incorrect (e.g., Caplan et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2015; Pregla et al., 2022). Hence, it becomes clear that the measurement of eye movements, in addition to an offline task, is crucial to gain deeper insights into the syntactic processing deficit in aphasia. Existing evidence testing the predictions of the RM approach in IWA is mostly restricted to behavioral data (e.g., Friedmann, 2008; Garraffa & Grillo, 2008; Martini et al., 2020; Nerantzini, Varlokosta, et al., 2014; Varlokosta, Nerantzini, Papadopoulou, et al., 2014). Therefore, the studies included in the thesis collect both offline and online data in order to extent previous findings and explore whether Minimality effects become evident also in online processing of RCs (see Druks, 2016).

2 RESEARCH QUESTIONS AND STUDY DESIGN

As pointed out in the previous sections, the theoretical framework of RM has greatly informed empirical research on the processing of semantically reversible RCs. It is assumed that intervention as proposed by RM can constitute a unitary approach to explain difficulties in RC processing observed across different populations and languages (Rizzi, 2018). So far, the majority of studies investigating the predictions of the RM approach collected behavioral data in typically developing children. With respect to the investigation of the RM approach in aphasia, previous studies primarily focused on the comprehension asymmetry between SRCs and ORCs, without addressing the facilitating effect of feature dissimilarity. Moreover, online measures of sentence processing have barely been used to test the RM approach, even though eye tracking is considered a useful tool to further investigate its predictions (Druks, 2016).

The aim of the dissertation project was to investigate IWAs' offline comprehension and online processing of German SRCs and ORCs to evaluate whether the RM approach appropriately accounts for empirical data in aphasia. For that purpose, two studies were conducted including a visual-world experiment embedded within an auditory referent-identification task. Target sentences were case- and number-disambiguated SRCs and ORCs with different degrees of featural overlap between the constituents and varying points of disambiguation. Table 2.1 summarizes the experimental design used in the two studies and gives an example of each condition with its English translation. For each experimental condition, the internal feature structure of the moved constituent (X), its trace (Y), and the intervening constituent (Z) is provided together with the resultant set-theoretic relation (based on Belletti et al., 2012).

Table 2.1

Summary of the experimental design

RC type	Disambiguation	Embedded constituent	Internal feature structure			Set-theoretic relation	Example with English translation	Study
			X	Z	Y			
SRC	Case – immediate	Full DP (9a)	+R +NP +SG	-	+R +NP +SG	No intervention	Wo ist der Hund, der den Igel kitzelt? *(Where is the dog that is tickling the hedgehog?)*	I
		Pronoun (9b)	+R +NP +SG	-	+R +NP +SG	No intervention	Wo ist der Fisch, der ihn kitzelt? *(Where is the fish that is tickling him?)*	I
	Number – late	Full DP (9c)	+R +NP +SG	-	+R +NP +SG	No intervention	Wo ist das Schwein, das die Wölfe kitzelt? *(Where is the pig that is tickling the wolves?)*	I
		Pronoun (9d)	+R +NP +SG	-	+R +NP +SG	No intervention	Wo ist die Kuh, die sie kitzelt? *(Where is the cow that is tickling them?)*	I
ORC	Case – immediate	Full DP (9e)	+R +NP +SG	+NP +SG	+R +NP +SG	Inclusion	Wo ist der Hund, den der Igel kitzelt? *(Where is the dog that the hedgehog is tickling?)*	I & II
		Pronoun (9f)	+R +NP +SG	+SG	+R +NP +SG	Inclusion	Wo ist der Fisch, den er kitzelt? *(Where is the fish that he is tickling?)*	I

Table 2.1 (continued)

RC type	Disambiguation	Embedded constituent	Internal feature structure			Set-theoretic relation	Example with English translation	Study
			X	Z	Y			
	Case – early	Full DP (9g)	+R +NP +SG	+NP +SG	+R +NP +SG	Inclusion	Wo ist das Reh, das der Frosch kitzelt? *(Where is the deer that the frog is tickling?)*	II
	Number – late	Full DP (9h)	+R +NP +SG	+NP +PL	+R +NP +SG	Intersection	Wo ist das Schwein, das die Wölfe kitzeln? *(Where is the pig that the wolves are tickling?)*	I & II
		Pronoun (9i)	+R +NP +SG	+PL	+R +NP +SG	Disjunction	Wo ist die Kuh, die sie kitzeln? *(Where is the cow that they are tickling?)*	I

Note. X = target or moved element, Z = intervener, Y = trace, RC = relative clause, SRC = subject relative clause, ORC = object relative clause, DP = determiner phrase, +R = scope-discourse feature attracting the head of the relative clause, +NP = lexical restriction feature, +SG = singular, +PL = plural.

Based on the framework of RM and previous findings, the following research questions are addressed in the dissertation:

Research question 1: Is there a subject-object asymmetry in IWAs' processing of German RCs? (study I)

The RM approach attributes the occurrence of a subject-object asymmetry to the presence of the embedded subject in ORCs, giving rise to a Minimality effect. No such intervener is present in SRCs. Hence, higher accuracy rates for SRCs (9a-d) as compared to ORCs (9e-i) would corroborate this assumption. Moreover, faster online processing of SRCs than ORCs is predicted in terms of a faster change in the proportion of looks to the target as soon as IWA derive correct sentence meaning.

Research question 2: Do number and case affect RC processing differently? (studies I and II)

Following the RM approach, processing costs in ORCs can be reduced through dissimilarity between the moved object and the embedded subject with regard to relevant (i.e., syntactically active) features. In German, number is considered to be a syntactically active feature because it triggers movement to the subject position and is realized in the agreement morphology of the tensed verb. In contrast, case does not trigger syntactic movement, but is assigned by verbs or nouns (Haider, 2010). Hence, the objective is to investigate the impact of number and case as grammatical features in the processing of German RCs and evaluate whether they matter in the computation of Minimality. Moreover, case and number differ regarding their relative position of disambiguation. Therefore, two separate research questions regarding the varying effects of case and number on RC processing are investigated.

Research question 2a: Does number dissimilarity facilitate ORC processing in IWA? (studies I and II)

RM predicts that dissimilarity between the moved object and the embedded subject in terms of number alleviates the Minimality effect in ORCs. That means that number-marked ORCs (9h-i, i.e., different values for number) are expected to result in higher accuracy rates and faster changes in target looks as compared to case-marked ORCs (9e-g, same value for gender). Prior to this dissertation project, the impact of number dissimilarity on ORC processing has not been specifically investigated in German-speaking IWA.

Research question 2b: Does the point of disambiguation impact IWAs' processing of RCs? (studies I and II)

In German, disambiguation between SRC and ORC interpretations can be achieved through unambiguous number and case marking. So far, studies testing case and number markings as cues to sentence meaning provided contradicting results as to which cue is harder to process (Burchert et al., 2003; Hanne et al., 2015). If sentence processing is impacted by the relative position of the disambiguation point, case-marked RCs (9a-b, e-g) are predicted to be comprehended better and processed faster as compared to number-marked RCs (9c-d, i). Additionally, significant differences in comprehension accuracy and processing speed (in terms of reaction times and eye-gaze data) are expected within case-marked ORCs, yielding lower processing costs in immediately relative to early disambiguated ORCs (9e and 9g, respectively). Sentence processing of the same disambiguating morpho-syntactic cue at different points within the sentence has not yet been undertaken in IWA. Such a comparison provides an interesting test case for the investigation of the role of timing of disambiguation in RC processing.

Research question 3: Do pronouns as intervening subject facilitate IWAs' ORC processing? (study I)

The RM approach predicts that dissimilarity in the [+NP] feature (lexical restriction) leads to reduced processing costs in ORCs. Pronoun facilitation in the offline data is predicted to be evidenced by higher accuracy rates for ORCs with a pronoun (different values for the [+NP] feature, 9f, 9i) compared to a full DP (same value for the [+NP] feature, 9e, 9g-h) as embedded subject. Regarding online data, a stronger change in the proportion of target looks is expected in ORCs with embedded pronouns than with full DPs as soon as IWA determine sentence meaning.

Research question 4: Does ORC processing in IWA benefit from higher degrees of featural distinctiveness? (studies I and II)

The degree of featural dissimilarity between the moved object and the embedded subject is assumed to modulate the strength of Minimality effects: The greater the degree of dissimilarity, the weaker the Minimality effect, as IWA can more easily distinguish between the two constituents given their reduced processing capacities. However, there is still uncertainty as to which degree of featural distinctiveness can be correctly processed by German-speaking IWA: Is the comprehension impairment restricted to case-marked ORCs where the syntactic dependency crosses an intervening subject whose featural specification is included in the featural specification of the moved object (9e-g; Martini et al., 2020)? Or does the syntactic processing system in IWA even require constituents with disjoint featural specifications (9i) in order to correctly comprehend ORCs? In this respect, German provides a suitable testing case because it has a relatively rich grammatical morphology and allows for modification of several featural specifications (see Table 2.1).

To answer these research questions, we conducted two experimental studies addressing RC processing in IWA and age-matched non-brain-damaged adults as controls:
Study I (Adelt et al., 2017; Chapter 5) investigated whether RM can account for the subject-object asymmetry and facilitative effect of pronouns in the offline and online processing of RCs. Target items were manipulated in terms of word order (SRC vs. ORC) and the presence or absence of the [+NP] feature in the embedded constituent (full DP vs. pronoun). Moreover, we examined the effect of varying degrees of feature dissimilarity between the moved and the embedded constituents in both case- and number-disambiguated RCs.
Study II (Adelt et al., 2020; Chapter 6) examined whether processing of case- and number-disambiguated ORCs is determined by feature dissimilarity or the timing of disambiguation. Unlike in study I, we tested only temporarily ambiguous ORCs with varying points of disambiguation by collecting offline (accuracy and reaction times) and online data (eye-tracking).
The results of the studies are summarized and discussed in the following chapters.

3 SUMMARY OF THE STUDIES AND THE MAJOR RESULTS

In the two studies included in this thesis, IWA and non-brain-damaged control participants were presented with short movie clips depicting cartoon animals interacting with each other. In each visual scene, one animal of type A (e.g., a dog, the agent animal) was performing a fictitious action (e.g., tickling) on the animal of type B in the middle (e.g., a hedgehog), who was performing the same action on another animal of type A (e.g., another dog, the patient animal). The clips were accompanied by orally presented RCs as target sentences. Target sentences were *where*-questions introducing right-branching RCs (see Table 2.1, e.g., *Wo ist der Hund, den der Igel kitzelt?*). Participants were asked to select the correct referent of the RC head noun by determining whether it was modified by an SRC (agent animal as target) or an ORC (patient animal as target). Accuracy (and reactions times in study II) in the referent-identification task as well as eye-movement data were collected as measures of offline sentence comprehension and online sentence processing.

In **study I**, IWA demonstrated a subject-object asymmetry in terms of more accurate comprehension of SRCs as compared to ORCs. However, this effect was limited to offline data in case-marked RCs and was not evident in number-marked RCs. Moreover, there was a facilitative effect of dissimilarity in the [+NP] feature in the offline comprehension of number-marked ORCs, but not of case-marked ORCs: IWA performed better in comprehending ORCs with a pronoun (i.e., dissimilarity in the [+NP] feature) as compared to a full DP as embedded constituent (i.e., similarity in the [+NP] feature).

Online eye-gaze data showed a subject-object asymmetry in both case- and number-marked RCs. The change in the proportion of looks to the patient animal[4] occurred later in ORCs as compared to SRCs. While IWA looked away from the patient animal in case-marked SRCs already during the relative clause, they looked at it more often only after sentence offset in the ORC condition. Likewise, in number-marked RCs, the change in the proportion of looks to the patient animal occurred after sentence

[4] The patient animal was the correct referent of RC head in ORCs, but the incorrect referent of RC head in SRCs. Hence, an increase in the proportion of looks to the patient indicates correct processing of ORCs. In contrast, successful processing of SRCs can be inferred from a decline in the proportion of looks to the patient.

offset (i.e., after the disambiguating verb inflection) with a faster change in SRCs than in ORCs. However, there was no unequivocal evidence of pronoun facilitation in IWAs' online data.

In **study II**, accuracy rates in the comprehension of case- and number-marked ORCs did not differ significantly. Comparison to chance revealed that only comprehension of early case-disambiguated ORCs was above chance. In contrast, comprehension performance in immediately case-disambiguated and late number-disambiguated ORCs was at chance level. Reaction time data showed that IWA processed case-marked ORCs faster than number-marked ORCs. Regarding online processing, the proportion of looks to the patient animal (i.e., the target) increased only after sentence offset in case of correct offline responses. Hence, IWA seem to delay their decision until the complete presentation of the sentence, regardless of the point of disambiguation within the sentence. If the offline response was incorrect, the proportion of looks to the target picture decreased after sentence offset.

4 CONCLUSIONS AND FURTHER RESEARCH DIRECTIONS

This thesis includes two studies investigating RC processing in German-speaking IWA and non-brain-damaged adults as controls by combining the visual-world paradigm with an auditory referent-identification task. The purpose of the present dissertation was to evaluate whether behavioral data (accuracy rates, reaction times) as well as eye-movement data are in accordance with the predictions of the RM approach. The RM approach offers a comprehensive explanation of comprehension patterns observed in different populations. However, while RCs have been widely studied in psycholinguistic research, processing of these complex syntactic structures has been rarely investigated in neurolinguistics. Hence, the experimental findings shed new light on IWAs' underlying difficulties in comprehending different types of RCs. In the following, I will interpret the results with respect to the research questions of the dissertation project and discuss their implications for further studies.

4.1 Major conclusions

The RM approach predicts that IWAs' difficulties in comprehending semantically reversible non-canonical ORCs can be attributed to Minimality effects induced by the presence of the embedded subject (Grillo, 2008, 2009). Moreover, according to RM, Minimality effects can be alleviated by manipulating the internal feature structure of the moved object and the intervening subject (Belletti et al., 2012; Friedmann et al., 2009). Table 4.1 summarizes the research questions addressing separate predictions made by the RM approach that guided the present dissertation and the main findings from the two studies. Although there is evidence of a subject-object asymmetry, indicating the occurrence of intervention, feature dissimilarity per se did not modulate the Minimality effect. Contrary to the predictions of RM, neither dissimilarity in the number nor in the [+NP] feature alone facilitated ORC processing. Instead, only ORCs involving distinct specifications of both features were well comprehended by IWA.

Table 4.1

Summary of the research questions and the main findings

Research question	Answer	Main finding
1. Is there a subject-object asymmetry in IWAs' processing of German RCs?	YES	Offline: Better comprehension of case-marked SRCs than of ORCs; Online: Faster online processing of SRCs than of ORCs (case- and number-marked)
2. Do number and case affect RC processing differently?		
2a. Does number dissimilarity facilitate ORC processing in IWA?	NO	Offline: Equally poor comprehension of ORCs with and without number dissimilarity
2b. Does the point of disambiguation impact IWAs' processing of RCs?	Probably YES	Offline: Faster response times in case-marked ORCs than in number-marked ORCs, above-chance performance in early case-disambiguated ORCs; Online: Faster processing of case-marked than number-marked SRCs, no difference in ORC conditions
3. Do pronouns as intervening subject facilitate IWAs' ORC processing?	YES	Offline: Better comprehension of number-marked ORCs with embedded pronoun than with full DP
4. Does ORC processing in IWA benefit from higher degrees of featural distinctiveness?	YES	Good comprehension in ORCs with Disjunction relation, poor comprehension in ORCs with Inclusion and Intersection relations

Note. RC = relative clause, SRC = subject relative clause, ORC = object relative clause, DP = determiner phrase, IWA = individuals with aphasia.

In the next paragraphs, I will discuss the findings with respect to the research questions and propose their implications for the theory of sentence comprehension deficits in IWA.

First, a subject-object asymmetry was observed in both case- and number-marked RCs, at least in the online data (**research question 1**). This finding of greater processing costs associated with ORCs compared to SRCs in IWA corroborates the assumption of the RM approach that the embedded subject in ORCs intervenes in the processing of the syntactic dependency between the moved object and its trace.

According to Grillo (2008), underspecified syntactic representations of ORCs, which result from reduced processing capacities, cause confusion in IWA due to the Minimality effect. Referring to Hickok et al. (1993), Grillo suggests that syntactic representations are constantly affected by underspecification. Online data reported in this thesis show how IWA process complex sentences given syntactic representations involving Minimality. In accordance with findings from previous studies (Dickey & Thompson, 2009; Hanne et al., 2015), we observed diverging eye-gaze patterns as a function of accuracy in the referent-identification task. Based on the findings from online sentence processing, I propose that IWA are in principle able to deal with intervention, even in less distinct featural configurations such as Inclusion and Intersection relations (see Table 2.1). However, less distinct featural specifications exceed IWAs' processing capacities more often, which results in lower comprehension accuracy. In that case, IWA have to resort to heuristics to determine sentence meaning. That means that IWA assign a subject-first interpretation, yielding incorrect responses. Hence, online data suggest that underspecification occurs only intermittently in cases of insufficient processing capacities devoted to sentence interpretation (see also Burchert et al., 2013; Caplan et al., 2007; Hanne et al., 2011; Pregla et al., 2022).

Findings regarding the other research questions were mostly restricted to the offline results. It can be speculated that effects of feature dissimilarity appear late and are, thus, not observable in the online data (see Contemori & Marinis, 2014, for discussion). Consequently, further research is needed to clarify if and how eye-tracking data can help investigating the RM approach.

Offline data from both studies revealed consistent evidence that dissimilarity in the number feature does not alleviate the Minimality effect in ORCs (**research question 2a**). IWA performed equally poorly in comprehending number-marked SRCs and

ORCs with two full DPs, yielding no significant subject-object asymmetry. Low comprehension in these conditions may be traced back to the late point of disambiguation, which occurs only sentence-finally at the inflected verb. At this point, both verb arguments have already been integrated into the syntactic structure, making number-marked RCs particularly difficult to process due to the length of ambiguity (e.g., Friederici et al., 1998). Hence, it appears that IWA cannot benefit from number dissimilarity in syntactically complex structures. In contrast, investigating non-canonical active sentences with object-verb-subject word order in IWA, Hanne et al. (2015) reported better performance in comprehending sentences involving number dissimilarity (i.e., number-marked sentences, 64% correct) as compared to sentences with both verb arguments in the singular (i.e., case-marked sentences, 46% correct). Therefore, I propose that in complex syntactic structures, dissimilarity in the number feature alone (i.e., Intersection relation, see Table 2.1) is not sufficient for IWA to overcome the Minimality effect due to other syntactic factors such as the length of ambiguity.

Apart from the prediction regarding the facilitative effect of number dissimilarity, comparison between case- and number-marked RCs sheds light on the processing of morpho-syntactic cues in aphasia (**research question 2b**). In line with findings from other studies looking at ORC processing in German-speaking IWA (Lissón et al., 2023), IWA benefit more from case marking as a cue to sentence meaning, while processing of number agreement appears to be impaired. The finding of better preserved processing of case- as compared to number-marked sentences in German complements previous studies (Burchert et al., 2003; Hanne et al., 2015) and points out the crucial role of case information as a cue to reanalysis of temporarily ambiguous sentences (Fodor & Inoue, 2000). However, it is important to note that the finding of a processing advantage for case cannot unequivocally be traced back to its earlier point of disambiguation compared to number, as evidenced by slightly better comprehension performance in early case-disambiguated ORCs (disambiguation at the determiner of the embedded subject) as compared to immediately case- disambiguated ORCs (disambiguation at the relative pronoun). Moreover, reaction times for both types of case-marked ORC did not differ significantly. In sum, it appears that even though RM predicts reduced processing costs in number-marked ORCs (due to feature dissimilarity), IWA rely more on case as a cue to sentence interpretation. However, the RM approach does not argue against the effect of other factors such as the relative position of disambiguation. Therefore, future research is needed to further disentangle the role of morpho-syntactic features in the computation of Minimality and real-time sentence processing.

There was a facilitating effect of pronouns as embedded subject in ORC processing (**research question 3**), which supports the predictions of the RM approach and aligns with previous findings in non-brain-damaged adults and typically developing children (Friedmann et al., 2009; Gordon et al., 2001, 2004; Reali & Christiansen, 2007; Roland et al., 2012; Villata et al., 2016; Warren & Gibson, 2002). However, this effect was observed only in number-marked ORCs and not in case-marked ORCs. Therefore, the Minimality effect in ORCs is alleviated by dissimilarity in the [+NP] feature, but only in combination with number dissimilarity. This finding suggests that comprehension performance in IWA benefits from a higher degree of featural dissimilarity. Importantly, solely dissimilarity in the [+NP] and the number features improved comprehension performance. The absence of pronoun facilitation in case-marked ORCs indicates that IWA cannot deal with sentences where the featural sets of the moved object and the intervening subject are in an Inclusion relation. Moreover, this finding further corroborates the assumption of the RM approach that case is not considered a relevant morpho-syntactic feature in the computation of Minimality, unlike number.

Combining the results from both studies, IWAs' comprehension of ORCs improved most when the moved object and the intervening subject were maximally different in terms of relevant features, namely number and lexical restriction (i.e., in number-marked ORCs with pronouns as embedded subject). Therefore, it can be concluded that a stronger degree of featural dissimilarity results in reduced processing difficulties because IWA can more easily distinguish between the moved object and the intervener as potential candidates for a relation with the trace (**research question 4**). When the two constituents differ only with respect to one relevant feature (i.e., lexical restriction or number), comprehension of ORCs remains poor. Hence, in contrast to findings from typically developing children (Belletti et al., 2012; Friedmann et al., 2009) and a single-case study in an Italian-speaking IWA (Martini et al., 2020), data from German-speaking IWA point towards the assumption that even the configuration of Intersection is problematic in aphasia. Instead, IWA can only process structures involving a Disjunction configuration properly due to their reduced computational capacities. Based on this observation, it can be assumed that IWA need a high degree of featural dissimilarity in syntactically complex structures such as RCs in order to derive correct sentence meaning.

Taken together, data from the current dissertation project show that the predictions, as originally proposed by the RM account, are only partially supported by empirical research on RC processing in German-speaking IWA. In processing complex syntactic structures, IWA are susceptible to the occurrence of the intervening subject in ORCs. The new findings reported in the thesis show that structural dissimilarity can modulate sentence comprehension in aphasia. More specifically, IWA can override Minimality effects in ORCs when feature dissimilarity between constituents is strongest in terms of a Disjunction relation. Finally, these findings highlight how syntactic theory helps to uncover impaired as well as preserved abilities in IWAs' sentence comprehension. Thus, I found evidence that underscores the close link between the theoretical framework of RM and empirical data on sentence processing in aphasia.

4.2 Directions for further research

This dissertation presents new scientific knowledge that highlights the role of morpho-syntactic features in the theory of sentence comprehension deficits in aphasia. Moreover, it provides implications concerning research on the relation between the RM approach and other language-related factors, as well as cognitive processes such as working memory. Moreover, the results have potential implications for clinical practice.

Findings from the current dissertation project reveal that IWA are sensitive to Minimality effects and the featural specification of the moved object and the intervening subject in ORCs. Specifically, successful comprehension of semantically reversible ORCs requires the highest degree of featural distinctiveness, namely in terms of a Disjunction relation. However, it remains unclear whether IWA could deal with less distinct relations, such as Intersection or Inclusion, in the comprehension of syntactically less complex structures. The results reported in Hanne et al. (2015) suggest that comprehension of non-canonical active sentences is facilitated when sentences involve an Intersection relation (number-marked sentences with different values for number) as opposed to an Inclusion relation (case-marked sentences with same value for number). Moreover, dissimilarity in the [+NP] feature has been shown to facilitate comprehension of non-canonical *wh*-questions (Hickok & Avrutin, 1996; Sheppard et al., 2015; Varlokosta, Nerantzini, Papadopoulou, et al., 2014), which are syntactically less complex than ORCs. Consequently, further research is needed to clarify whether syntactic complexity plays a role in the processing of different levels of featural set relations. In order to test this hypothesis, future studies should investigate comprehension of sentences with varying degrees of featural distinctiveness by systematically manipulating syntactic complexity (e.g., actives, *wh*-questions, RCs).

This thesis focused on RM as explanatory approach to agrammatic sentence comprehension in aphasia. Yet, the theoretical framework of RM shares certain properties with the similarity-based interference account proposed by Gordon et al. (Gordon et al., 2001, 2004). Both theories assume that the presence of an element which is crossed in the establishment of a syntactic dependency plays a key role in the occurrence of intervention or interference, respectively. Moreover, the notion of similarity is crucial in determining whether the element hinders the establishment of the dependency or not. However, in the RM approach, intervention is traced back to the grammatical principle of locality. Therefore, Minimality effects occur only under specific circumstances, emphasizing the syntactic grounding of RM: First, it posits that only elements that are c-commanded by a moved constituent and c-command the trace position are potential interveners. Second, only syntactically active features matter in the computation of Minimality. Consequently, the RM approach differentiates between set-theoretic relations such as Disjunction, Intersection, and Inclusion, which can affect sentence comprehension differently. By contrast, similarity-based interference is grounded on the domain-general effect of increased working memory load in case of similarity. Thus, any element can potentially give rise to interference, regardless of its structural position, and similarity in any syntactic or semantic feature is assumed to impact the occurrence of interference (Villata & Franck, 2016). The main finding of this thesis, namely preserved comprehension of number-marked ORCs with an embedded pronoun (i.e., dissimilarity in terms of number and [+NP] features), provides support for the RM approach and underlines the selective notion of feature dissimilarity in the computation of Minimality (see also Belletti et al., 2012, for discussion). However, it is still left unclear whether "RM may be looked at as the domain-specific grammaticalization" (Rizzi, 2018, p. 362) of similarity-based interference. Therefore, it is left for future research to assess sentence comprehension involving also those features that are not considered syntactically active, such as animacy and gender in German. By this means, selectivity and domain-general effects of dissimilarity in sentence processing and their relation to the RM approach and the similarity-based interference account can be explored further.

According to Generalized Minimality (Grillo, 2005, 2008, 2009), the occurrence of Minimality effects in IWA can be traced back to reduced processing capacities. Considering the converging evidence of a close relation between working memory and sentence processing in aphasia (e.g., Caplan & Waters, 1999; Ivanova et al., 2015; Sung et al., 2009), future research should take into account different measures of cognitive functioning and their contribution to the occurrence of Minimality effects. In Portuguese-speaking non-brain-damaged adults, the subject-object asymmetry was modulated by reading span as a measure of working memory capacity. In contrast, measures of resistance to interference, lexical knowledge, and lexical access ability were not related to the occurrence of Minimality (Delgado et al., 2021). Findings from such an investigation in aphasia would contribute to a better understanding of the underlying impairments in agrammatic sentence comprehension.

Finally, the results from this thesis have also clinical implications. Data on the comprehension of German RCs suggest that IWAs' difficulties in comprehending movement-derived sentences are determined not solely by the factors semantic reversibility and canonicity, but also by the degree of featural distinctiveness. Along these lines, the RM approach offers the possibility to evaluate subtle effects of different morpho-syntactic features on sentence comprehension. Consequently, tools for assessing preserved and impaired sentence processing abilities in aphasia should consider varying degrees of dissimilarity by controlling the material with respect to relevant morpho-syntactic features. Moreover, the RM approach and assumptions about set-theoretic relations between constituents provide a means to rank treatment materials according to their level of syntactic complexity by systematically decreasing the degree of feature dissimilarity (see Table 2.1 for a proposal on German ORCs). In this way, the linguistic theory of RM goes beyond making predictions regarding sentence comprehension patterns in IWA and inspires clinical practice in assessing and treating sentence comprehension deficits in aphasia.

II. ORIGINAL JOURNAL ARTICLES

5 FEATURE DISSIMILARITIES IN THE PROCESSING OF GERMAN RELATIVE CLAUSES IN APHASIA[5]

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ABSTRACT

The cross-linguistic finding of greater demands in processing object relatives as compared to subject relatives in individuals with aphasia and non-brain-damaged speakers has been explained within the Relativized Minimality approach. Based on this account, the asymmetry is attributed to an element intervening between the moved element and its extraction site in object relatives, but not in subject relatives. Moreover, it has been proposed that processing of object relatives is facilitated if the intervening and the moved elements differ in their internal feature structure. The present study investigates these predictions in German-speaking individuals with aphasia and a group of control participants by combining the visual world eye-tracking methodology with an auditory referent-identification task. Our results provide support for the Relativized Minimality approach. Particularly, the degree of featural distinctness was shown to modulate the occurrence of the effects in aphasia. We claim that, due to reduced processing capacities, individuals with aphasia need a higher degree of featural dissimilarity to distinguish the moved from the intervening element in object relatives to overcome their syntactic deficit.

[5] This chapter is adapted from: Adelt, A., Stadie, N., Lassotta, R., Adani, F., & Burchert, F. (2017). Feature dissimilarities in the processing of German relative clauses in aphasia. *Journal of Neurolinguistics*, *44*, 17–37. https://doi.org/10.1016/j.jneuroling.2017.01.002

5.1 Introduction

It is a well-attested finding that subject-extracted relative clauses (SRCs) in head-initial languages are easier to process than object-extracted relative clauses (ORCs) for individuals with aphasia and non-brain-damaged healthy adults (e.g., Bader & Meng, 1999; Burchert et al., 2003; Caplan et al., 2007; Caramazza & Zurif, 1976; Garraffa & Grillo, 2008; Traxler et al., 2002).[6] Relative clauses are characterized by the displacement of the head noun from its argument position in the embedded clause, resulting in a long-distance dependency between the moved argument (*the boy*) and its extraction site, which is marked by underscores in the following examples (e.g., Chomsky, 1995; Haegeman, 1994). In SRCs, the head noun is linked to the subject position (1), while it is linked to the object position in ORCs (2).

(1) (I see) the boy who __ is kissing the girl (SRC)

(2) (I see) the boy who the girl is kissing __ (ORC)

Over the past decades, several approaches have been proposed to account for the so-called subject-object asymmetry. For example, Grillo (2005, 2008, 2009) adopted the linguistically based approach of Relativized Minimality (RM; Rizzi, 1990, 2013) and attributed the asymmetry to the occurrence of a Minimality effect (adopting the term from Grillo, 2005, 2009; Varlokosta, Nerantzini, Papadopoulou, et al., 2014). In Grillo's adaptation of RM, it is claimed that greater demands in processing ORCs are caused by the presence of the embedded subject (*the girl* in example (2)), which has to be crossed when establishing the syntactic relation between the moved object and its extraction site. Friedmann, Belletti, and Rizzi (2009) extended the RM approach to explain patterns of sentence comprehension in language acquisition. They suggested that the Minimality effect is reduced when the intervening subject in ORCs is a pronoun, which was shown to enhance comprehension of ORCs in typically developing children and healthy adult speakers (Brandt et al., 2009; Gordon et al., 2001, 2004; Haendler et al., 2015; Reali & Christiansen, 2007; Warren & Gibson,

[6] In head-final languages (e.g., Basque, Japanese, and Chinese), there is evidence of a processing advantage of ORCs over SRCs (e.g., Carreiras et al., 2010; Hsiao & Gibson, 2003; Ishizuka et al., 2006).

2002). This facilitative effect of pronouns was attributed to feature dissimilarity between the moved and the intervening element in terms of [+NP]. Thus, the question arises as to whether individuals with aphasia (IWA) also exhibit such a pronoun facilitation effect in spoken sentence processing. There is some evidence suggesting that ORC comprehension in IWA does not benefit from dissimilar [+NP] features (Varlokosta, Nerantzini, Papadopoulou, et al., 2014). However, so far, only one type of disambiguating morphosyntactic feature, namely case marking, has been used to investigate the effect of pronoun facilitation. The present study investigates RC processing in German, a language where both case and number marking are involved in disambiguating between SRCs and ORCs. Hence, the study extends previous work targeting the impact of pronouns on RC processing in aphasia.

In the following, we first detail the results from studies investigating the subject-object asymmetry in healthy adults and IWA and the theoretical approach of RM. Then, we introduce our notion of feature dissimilarity and describe what previous studies on the pronoun facilitation effect revealed about the impact of feature dissimilarity.

5.1.1 Subject-object asymmetry in the processing of relative clauses

In IWA, the subject-object asymmetry in terms of higher accuracy on SRCs as compared to ORCs has been observed cross-linguistically using different offline methods such as spoken sentence-picture matching (Friedmann, 2008; Friedmann et al., 2010; Garraffa & Grillo, 2008; Grodzinsky, 1989; Lukatela et al., 1995; Martin, 1987; Varlokosta, Nerantzini, Papadopoulou, et al., 2014) and spoken sentence-picture verification (Burchert et al., 2003). Within online measures, a processing disadvantage for ORCs as compared to SRCs has been observed in terms of slower self-paced listening times (Caplan et al., 2007). Initially, this selective comprehension difficulty for sentences with a non-canonical word order (object-before-subject) such as ORCs was primarily associated with non-fluent Broca's aphasia (Caramazza & Zurif, 1976; Schwartz et al., 1980). Later studies, though, revealed that impaired sentence comprehension is also present in other fluent aphasia types (e.g., Caramazza & Miceli, 1991; Goodglass et al., 1979; Martin & Blossom-Stach, 1986).

In non-brain-damaged adult speakers, the presence of a subject-object asymmetry is usually restricted to online tasks such as speeded grammaticality judgment (Bader & Meng, 1999), self-paced listening and reading (Caplan et al., 2007; Gordon et al., 2001, 2004; Mak et al., 2002, 2006), eye-tracking while listening and reading (Dickey & Thompson, 2009; Traxler et al., 2002), and event-related brain potentials studies (Friederici et al., 1998; Mecklinger et al., 1995). In contrast to IWA, healthy speakers show no processing disadvantage for ORCs in terms of lower accuracy in offline tasks such as spoken sentence-picture matching (Friedmann et al., 2010) or verification (Burchert et al., 2003).

Since the subject-object asymmetry is present both in IWA and healthy speakers, it appears that a unitary explanatory approach could have the potential to elucidate the underlying processes responsible for the asymmetry. So far, only separate explanatory approaches have been proposed to account for the asymmetry in unimpaired and impaired sentence processing (for healthy adults: Active Filler strategy, e.g., Frazier, 1987; Locality Theory and working memory, e.g., Gibson, 1998; expectation-based approach, Levy, 2008; for IWA: Derived Word Order Hypothesis, e.g., Bastiaanse & van Zonneveld, 2006; reduced processing capacities devoted to sentence processing, e.g., Caplan et al., 2007; Trace Deletion Hypothesis, e.g., Grodzinsky, 1995, 2000). Given the fact that Grillo (2005, 2008, 2009) proposed an extension of the linguistically based approach of RM (Rizzi, 1990, 2013) to explain this pattern, it seems that this approach has the potential for becoming such a unitary theoretical framework for the understanding of RC comprehension in different populations.

5.1.2 Relativized Minimality (RM)

In formal terms, RM is defined as follows (Rizzi, 1990, 2004): Given the configuration X … Z … Y, a local relation between X and Y can only hold, if there is no Z that:

(i) intervenes between X and Y, and

(ii) is of the same structural type as X.

Regarding sentence processing, RM is assumed to represent an economy principle in the sense that it restricts syntactic relations to the closest possible element that could potentially bear this relation. If Z is structurally similar to a moved constituent

X, the intervener Z can be regarded as a potential candidate for a relation to the extraction site Y. Regarding RC processing, the RM approach can be adopted to explain the processing advantage for SRCs over ORCs. The subject-object asymmetry is attributable to the fact that in ORCs (4), the syntactic relation between the moved object *the boy* and its extraction site has to be established over the embedded subject *the girl*, rendering the embedded subject an intervener, resulting in a Minimality effect. By contrast, in SRCs (3), no element intervenes between the moved subject *the boy* and its extraction site, yielding processing of this structure less demanding. However, as the syntactic processing system of healthy speakers is intact, the Minimality effect in ORCs can be overridden in accuracy data, but is still evident in online data, such as reading times (Grillo, 2008).

(3)	(I see)	[the boy]	who	___	is kissing	[the girl]	(SRC)
		X		Y		Z	
(4)	(I see)	[the boy]	who	[the girl]	is kissing	___	(ORC)
		X		Z		Y	

In extending the RM hypothesis to neurolinguistics, Grillo (2005, 2008) ascribed IWAs' selective deficits in comprehending non-canonical sentences, such as ORCs, to the occurrence of a Minimality effect. Moreover, Grillo assumes that the more pronounced subject-object asymmetry in IWA as compared to healthy speakers is caused by the stronger susceptibility to Minimality effects in IWA. Grillo's approach to the sentence comprehension deficit in IWA is very similar to the recently proposed Intervener Hypothesis (Sheppard et al., 2015; Sullivan et al., 2017). Evidence corroborating this assumption comes from data on the comprehension of Hebrew SRCs and ORCs, which can both involve an intervening or no intervening element (Friedmann & Gvion, 2012). IWAs' comprehension accuracy on sentences with an intervening element was lower than on those sentences without an intervener, regardless of word order. Taken together, the RM approach provides a linguistically motivated explanation of the well-established fact that ORCs demonstrate a processing disadvantage in comparison to SRCs.

5.1.3 Structural dissimilarity in terms of morpho-syntactic features reduces the Minimality effect

Based on results from experiments on RC comprehension, Costa, Grillo, and Lobo (2012) suggested that the occurrence of a Minimality effect in typically-developing children and healthy adult speakers of Portuguese is modulated by the internal feature structure of the moved and the intervening elements: Greater dissimilarity reduces the Minimality effects. Consequently, the question arises as to what determines the degree of dissimilarity. Along the lines of the feature-driven approach (Adani et al., 2010), we propose that the degree of dissimilarity between the moved and the intervening element is defined by the number of features that are carrying different specifications. That means that feature dissimilarity increases when the elements' features are distinct. Depending on the language under investigation, different features play a role in determining the degree of dissimilarity and, hence, influence the effect of an intervening element in ORCs. For example, dissimilar number features (i.e., one singular, one plural) have been shown to reduce Minimality effects in comprehending English or Italian ORCs in typically-developing children and also children with Specific Language Impairment (e.g., Adani et al., 2010, 2014). Moreover, in Hebrew, featural distinctiveness of gender (i.e., one masculine, one feminine) resulted in improved comprehension of ORCs in children (Belletti et al., 2012).

The present study focuses on German, which allows the manipulation of case and number features. Case-marked RCs involve two masculine singular nouns. They are disambiguated towards an SRC or ORC at the relative pronoun due to its unambiguous case marking of nominative or accusative. Consequently, case-marked RCs are structurally dissimilar in their specification of the case feature (nominative/accusative), whereas the gender and number features are similar (both masculine and singular, see example 5). By contrast, number-marked RCs involve a singular feminine or neuter noun and a plural noun (in example 6, a masculine noun). Due to case syncretism, number-marked RCs are ambiguous between SRC and ORC. In these instances, inflection of the sentence final verb will provide cues to sentence interpretation, since German verbs are inflected for person and number and agree with the subject. Hence, in number-marked RCs, the internal structure of the determiner phrases (DPs) involved can vary with respect to case (nominative/accusative), number (singular/plural) and gender (feminine or neuter/masculine) features. In sum, feature dissimilarity is greater in German number-marked than in case-marked RCs.

(5)	Wo ist der Hamster	den	der Frosch	wäscht?	(ORC)
		[ACC, SG, MASC]	[NOM, SG, MASC]		
	Where is the hamster that the frog is washing?				

(6)	Wo ist das Kamel	das	die Igel	waschen?	(ORC)
		[ACC, SG, NEUT]	[NOM, PL, MASC]		
	Where is the camel that the hedgehogs are washing?				

So far, studies have investigated the hypothesis of structural dissimilarity of morpho-syntactic features by considering only one feature (e.g., number or gender), but have never explored the interplay between several features. Moreover, the interplay of different morpho-syntactic features has not been tested in aphasia. Hence, our study examines the effect of the degree of structural dissimilarity in terms of morpho-syntactic features in Minimality effects.

Another feature that was shown to impact the Minimality effect in ORC processing is lexical restriction [+NP]. Lexically restricted DPs are nominal expressions introduced by a determiner (e.g., *the boy* in RCs) or a *wh*-word (e.g., *which boy* in *wh*-questions), whereas lexically unrestricted DPs are pronouns (e.g., *he*) or bare *wh*-words (e.g., *who*). Friedmann et al. (2009) investigated children's comprehension accuracy comparing ORCs with two fully specified DPs as head noun and embedded subject (i.e., structural similarity in terms of [+NP], such as example 4) and ORCs with a full DP as head noun and an impersonal *pro* subject, which is a null pronoun (i.e., structural dissimilarity in terms of [+NP]). The authors found that comprehension performance rose, if the constituents differed in their specification of the [+NP] feature (such as in example 7; henceforth referred to as pronoun facilitation). This means that dissimilarity of [+NP] between moved and intervening elements reduces the Minimality effect.

(7)	(I see)	[the boy]	who	[she]	is kissing	___	(ORC with embedded
		X		Z		Y	pronoun)

Existing self-paced reading experiments conducted with healthy adult participants (Gordon et al., 2001, 2004; Reali & Christiansen, 2007; Warren & Gibson, 2002) seem to corroborate these findings. Online processing of ORCs was facilitated, if the subject and object constituents were dissimilar with respect to [+NP]. Similarly, pronoun facilitation in ORC processing has been observed in typically developing children (Arnon, 2010; Brandt et al., 2009; Haendler et al., 2015).

While pronoun facilitation in ORC processing has been repeatedly observed in healthy adults and typically developing children, there is less clear evidence from IWA. Supposing that, due to processing capacity reductions, IWA are more prone to Minimality effects as a result of structural similarity (Garraffa & Grillo, 2008; Grillo, 2005), comprehension of ORCs involving structurally dissimilar moved and intervening constituents should improve in relation to structurally similar constituents. So far, in IWA, only the effect of structural dissimilarity in terms of [+NP] has been investigated. In comprehension studies on *who*- and *which*-questions (e.g., Hickok & Avrutin, 1995; Nerantzini, Varlokosta, et al., 2014; Sheppard et al., 2015; Thompson et al., 1999; Varlokosta, Nerantzini, Papadopoulou, et al., 2014), feature dissimilarity in [+NP] resulted in improved processing of structures involving an intervening element.

However, there is only one study so far examining pronoun facilitation as predicted by Friedmann et al.'s (2009) extension of RM. In Greek-speaking IWA, Varlokosta, Nerantzini, Papadopoulou, et al. (2014) investigated headed ORCs in which the subject was a quantificational restrictor (e.g., *someone*; carrying no [+NP] feature) or a quantificational phrase (e.g., *some clown*; carrying the [+NP] feature) and ORCs with a free relative restrictor with or without a DP. These manipulations resulted in similar and dissimilar [+NP] specifications of the moved object and the intervening subject. Contrary to the predictions of RM and the findings from studies on other sentence structures in IWA, there was no facilitative effect of dissimilar [+NP] specifications on accuracy. That means that pronouns did not facilitate ORC comprehension. The authors attributed the lack of pronoun facilitation to the fact that, besides the [+NP] feature, IWA additionally need to activate features, such as gender, case, and number, in order to distinguish the intervening from the moved constituent. However, due to reduced processing capacities (Haarmann & Kolk, 1991; Zurif et al., 1993), which prevent IWA from activating and/or maintaining the full internal feature structure of the elements involved (Grillo, 2008), the syntactic representation is impoverished, resulting in structural similarity between the moved and the intervening element and, thus, giving rise to Minimality effects. Hence, it appears that feature dissimilarity in terms of the [+NP] feature alone is not sufficient to override the Minimality effect (see also Costa et al., 2012). However, so far this proposal has not been systematically investigated by comparing sentence types involving constituents with varying degrees of featural dissimilarity. The present study further explores whether different degrees of structural dissimilarity bear upon pronoun facilitation, as predicted by Varlokosta, Nerantzini, Papadopoulou, et al. (2014) for neurolinguistics and Costa et al. (2012) for language acquisition.

5.1.4 Aims of the study and hypotheses

In this study, we present data from an eye-tracking experiment investigating whether the RM approach can capture the processing patterns of RCs in both German-speaking IWA and healthy adults. Investigating RCs with varying word order (canonical SRCs vs. non-canonical ORCs), we manipulated the structural similarity of the constituents in terms of [+NP]: While RC head was always specified as [+NP], the embedded constituent was either a full DP (i.e., carrying the feature [+NP]) or a personal pronoun (i.e., lacking the [+NP] feature). By comparing the impact of these manipulations in case- and number-marked RCs, we wanted to elucidate whether the notion of feature dissimilarity influences the subject-object asymmetry and pronoun facilitation in IWA (Costa et al., 2012).

So far, studies investigating the RM approach solely used offline methods (Friedmann et al., 2009; Friedmann & Gvion, 2012; Garraffa & Grillo, 2008; Varlokosta, Nerantzini, Papadopoulou, et al., 2014) and only few studies investigated the approach taking into account data obtained from online methods (Haendler et al., 2015; Sheppard et al., 2015). However, based on the finding that pronouns can also facilitate online processing of ORCs in healthy adults and typically developing children, the present study utilized the visual-world paradigm (Tanenhaus et al., 1995), as it has been shown to be a suitable online method to study sentence

processing in IWA (e.g., Dickey et al., 2007; Hanne et al., 2015; Meyer et al., 2012). Our experimental design combined the eye-tracking method with an auditory referent-identification task, which has been successfully used to study sentence comprehension abilities in IWA (Nerantzini, Varlokosta, et al., 2014; Sheppard et al., 2015; Varlokosta, Nerantzini, Papadopoulou, et al., 2014).
On the basis of the RM approach, we formulate the following hypotheses:

a) *Subject-object asymmetry:* According to the RM approach and in line with findings from previous research, we predict that a Minimality effect in terms of a subject-object asymmetry occurs both in healthy adults and IWA, whereas more accurate offline comprehension of SRCs as compared to ORCs is expected only for IWA. In the online eye-gaze data, we predict faster online processing of SRCs relative to ORCs in both participant groups, as evidenced by a faster change in the proportion of looks to the target picture as soon as participants derive the correct sentence meaning. In accordance with the hypothesis that a higher degree of structural similarity increases the Minimality effect, the presence of an intervening element should impede processing of ORCs more in case-marked than in number-marked RCs, resulting in a stronger subject-object asymmetry in the former type of sentences. This is due to the fact that the internal feature structures of the constituents in case-marked RCs are less distinct than those in number-marked RCs and are harder to be distinguished by IWA due to reduced processing capacities.
b) *Pronoun facilitation:* Following the adaptation of Friedmann et al. (2009) and in line with earlier findings, we expect to observe pronoun facilitation in ORCs. In the offline data, we predict higher accuracy rates for ORCs with a pronoun compared to a full DP as embedded subject. Online data are expected to reveal a stronger change in the proportion of looks to the target in ORCs with pronouns than with full DPs, once participants determine that the sentence has an ORC interpretation. Concerning the influence of structural similarity on pronoun facilitation, we expect that this effect is more pronounced in number- than in case-marked ORCs in IWA. Because of their reduced processing capacities, we predict that IWA can benefit from the dissimilarity of the [+NP] feature to a greater extent when the involved

constituents are more distinct. As the structural dissimilarity between the constituents in number-marked RCs is greater than in case-marked RCs, we assume that IWA can more easily distinguish the moved from the intervening element, when another dissimilar feature, namely [+NP], is added in number-marked than in case-marked RCs.

5.2 Methods

5.2.1 Participants

Ten IWA (3 female, 7 male) and 20 non-brain-damaged adults as controls (11 female, 9 male) participated in this study. All IWA sustained a single unilateral damage to their dominant hemisphere between 2 and 20 years ($M = 9.3$, $SD = 7.7$) prior to participation in this study. IWA ranged in age from 42 to 75 years ($M = 58.1$, $SD = 10.6$) and controls were aged between 38 and 75 years ($M = 58.7$, $SD = 10.1$). The two participant groups were matched with respect to age and education (age: $t(17.4) = 0.1$, $p = .89$, independent t-test, two-tailed; years of education: $M_{\text{IWA}} = 14.6$, $M_{\text{CONTROLS}} = 15.2$, $t(21.6) = 0.8$, $p = .44$, independent t-test, two-tailed). Table 5.1 provides demographic and neurological information about IWA. Except one participant (P03), all IWA were pre-morbidly right-handed, as evidenced by the Edinburgh Handedness Inventory (Oldfield, 1971). Moreover, classification of both the type and severity of aphasia was assessed with the Aachen Aphasia Test (Huber et al., 1983).

Table 5.1

Participants with aphasia: Demographic and neurological data

Subject	Sex	Age (years)	Years post-onset	Years of education	Etiology	Localization	Handedness[1]	Aphasia type[2]	Severity (standard nine)[2]
P01	F	49	20	11.5	Ischemic CVA	L	R	Broca	6.0
P02	M	60	2	15.0	Ischemic CVA	L	R	Broca	4.8
P03	M	62	20	17.0	Hemorrhagic CVA	R	L	Broca	4.8
P04	F	46	2	17.0	Ischemic CVA	L	R	Broca	4.6
P05	M	70	2	13.5	Ischemic CVA	L	R	Broca	4.2
P06	F	42	15	13.0	Ischemic CVA	L	R	Anomic	6.8
P07	M	64	4	15.0	Ischemic CVA	L	R	Anomic	6.4
P08	M	51	14	13.5	Ischemic CVA	L	R	Anomic	5.8
P09	M	61	12	15.5	Ischemic CVA	L	R	Anomic	5.6
P10	M	75	2	15.0	Ischemic CVA	L	R	Non-classifiable	6.6

[1]Edinburgh Handedness Inventory (Oldfield, 1971), [2]Aachen Aphasia Test (Huber et al., 1983).

Note. F = female, M = male, CVA = cerebral vascular accident, L = left, R = right.

Inclusion for the present study required deficits in comprehending non-canonical sentences, assessed with a German sentence comprehension test (Burchert et al., 2011). IWAs' comprehension of semantically reversible active sentences (case- and number-marked) and right-branching case-marked RCs was tested. All IWA scored two standard deviations below the mean from the respective age group of control participants in at least one type of non-canonical sentences (i.e., object-before-subject active sentences or ORCs), which was considered to reflect impaired sentence comprehension. However, comprehension of semantically irreversible long sentences (containing 10 words) was within the range of controls, indicating that verbal short-term memory was preserved. Additionally, IWA were assessed with tasks taken from LEMO 2.0 (Stadie et al., 2013) to rule out auditory comprehension deficits at the word level as an origin of impaired sentence comprehension. All IWA performed within the range of normal controls, indicating unimpaired pre-lexical and lexical processing of single words.

Control participants reported no history of neurological, language, or learning disorders. All participants were right-handed (Oldfield, 1971), native speakers of German, and had normal or corrected-to-normal vision and auditory acuity. If needed, participants kept on their glasses/contact lenses or hearing aids during the experiment and pre-tests.

The experiment was approved by the local ethics committee and informed consent was obtained from all participants.

5.2.2 Material

The experiment was an eye-tracking adaptation of Adani (2011). Material for the experiment consisted of number- and case-marked RCs that were presented auditorily to the participants while they watched short movie clips on a computer screen.

Sentence stimuli comprised target and filler sentences. Target sentences were *where*-questions introducing a right-branching SRC or ORC. All sentences were derived from semantically reversible actions of eight transitive verbs (e.g., waschen, *to wash*) combined with two animate noun phrases (e.g., Kamel, *camel*; Igel, *hedgehog*). All nouns were monomorphemic, mono- or bisyllabic, and denoted animals. Moreover, to make sure that case marking occurred only at the determiner, we used masculine strong nouns, as they did not gain a final *-n* or *-en* in accusative case. Altogether, 32 different nouns were used to create number- and case-marked RCs (8 feminine, 8 neuter, 16 masculine).

Target sentences were distributed across four conditions (see Table 5.2), which were created by crossing the factors RC type (SRC, ORC) and embedded constituent type (full DP, pronoun). For each of these conditions, case- and number-marked sentences were created. Each target structure was represented by 16 sentences, resulting in each 64 number- and case-marked RCs. Example target sentences with their approximate English gloss and translation are reported in 8 (a-h, see Table 5.2).

To create number-marked RCs, RC head contained feminine or neuter singular nouns (determiner *die* or *das*), while the embedded full DP or pronoun were masculine and plural-marked (determiner *die* or pronoun *sie*). Due to case syncretism, both noun phrases were ambiguous between nominative and accusative case, thus, case marking did not provide unambiguous information about sentence interpretation (see Table 5.2). However, verb inflection of the sentence-final verb disambiguated the syntactic structure. If the verb was singular (*wäscht*), it was in agreement with RC head, resulting in an SRC (8a and c). In case of plural marking (*waschen*), the verb agreed with the embedded constituent, that is, the sentence was an ORC (8e and g).

Table 5.2

Experimental design

RC type	Embedded constituent type	Type of disambiguating feature	Matrix clause	Relative pronoun	Embedded constituent	Verb
SRC	Full DP	Number (8a)	Wo ist das Kamel	das	die Igel	wäscht?
			Where is the$_{\text{nom sg, +NP}}$ camel	that$_{\text{nom/acc sg}}$	the$_{\text{nom/acc pl, +NP}}$ hedgehogs	washes$_{\text{sg}}$
			(Where is the camel that is washing the hedgehogs?)			
		Case (8b)	Wo ist der Hamster	der	den Frosch	wäscht?
			Where is the$_{\text{nom sg, +NP}}$ hamster	that$_{\text{nom sg}}$	the$_{\text{acc sg, +NP}}$ frog	washes$_{\text{sg}}$
			(Where is the hamster that is washing the frog?)			
	Pronoun	Number (8c)	Wo ist das Kamel	das	sie	wäscht?
			Where is the$_{\text{nom sg, +NP}}$ camel	that$_{\text{nom/acc sg}}$	they$_{\text{nom pl, -NP}}$/them$_{\text{acc pl, -NP}}$	washes$_{\text{sg}}$
			(Where is the camel that is washing them?)			
		Case (8d)	Wo ist der Hamster	der	ihn	wäscht?
			Where is the$_{\text{nom sg, +NP}}$ hamster	that$_{\text{nom sg}}$	him$_{\text{acc sg, -NP}}$	washes$_{\text{sg}}$
			(Where is the hamster that is washing him?)			

Table 5.2 (continued)

RC type	Embedded constituent type	Type of disambiguating feature	Matrix clause	Relative pronoun	Embedded constituent	Verb
ORC	Full DP	Number (8e)	Wo ist das Kamel	das	die Igel	waschen?
			Where is the$_{nom\ sg,\ +NP}$ camel	that$_{nom/acc\ sg}$	the$_{nom/acc\ pl,\ +NP}$ hedgehogs	wash$_{pl}$
			(Where is the camel that the hedgehogs are washing?)			
		Case (8f)	Wo ist der Hamster	den	der Frosch	wäscht?
			Where is the$_{nom\ sg,\ +NP}$ hamster	that$_{acc\ sg}$	the$_{nom\ sg,\ +NP}$ frog	washes$_{sg}$
			(Where is the hamster that the frog is washing?)			
	Pronoun	Number (8g)	Wo ist das Kamel	das	sie	waschen?
			Where is the$_{nom\ sg,\ +NP}$ camel	that$_{nom/acc\ sg}$	they$_{nom\ pl,\ -NP}$/them$_{acc\ pl,\ -NP}$	wash$_{pl}$
			(Where is the camel that they are washing?)			
		Case (8h)	Wo ist der Hamster	den	er	wäscht?
			Where is the$_{nom\ sg,\ +NP}$ hamster	that$_{acc\ sg}$	he$_{nom\ sg,\ -NP}$	washes$_{sg}$
			(Where is the hamster that he is washing?)			

Note. SRC = subject relative clause, ORC = object relative clause, DP = determiner phrase.

In case-marked RCs, both RC head and the embedded constituent contained masculine singular nouns, which made them unambiguously case-marked. Hence, case marking on the relative pronoun (*der* or *den*) provided cues to sentence interpretation (see Table 5.2). If the relative pronoun was marked for nominative case (*der*), the determiner of the embedded full DP or the pronoun carried accusative case (determiner *den* or pronoun *ihn*) and the sentence was an SRC (8b and d). If the relative pronoun was marked for accusative case (*den*), the embedded constituent was marked for nominative case (*der* or *er*), resulting in an ORC (8f and h).
Moreover, two different sets of 32 simple *where*-questions were used as filler items (e.g., Wo ist das Kamel mit der Wolke?, *Where is the camel with the cloud?*). Fillers always contained a feminine or neuter singular noun (in number-marked RCs) or a masculine noun (in case-marked RCs) followed by a prepositional phrase including an inanimate noun that referred to the symbol on one of the animals (see Figure 5.1). In total, each 96 number- and case-marked items (i.e., 64 targets and 32 fillers) were presented. The complete list of target and filler sentences can be found in Table A.1 and Table A.2 in the Appendix.

Figure 5.1
Sample picture of a visual scene

Within each sentence, RC head nouns and the embedded nouns did not differ significantly in lemma frequency, as measured by dlex (http://www.dlexdb.de; Heister et al., 2011), their age of acquisition, typicality, or familiarity ratings (Schröder et al., 2012; all $p > .2$, paired t-test, two-sided). Nouns within one target sentence did not share the initial phoneme. Moreover, we ensured that across target sentences the same verb never co-occurred with the same pair of nouns and that the same nouns were not paired more than once throughout the experiments.

The sentences were digitally recorded by a female native speaker of German in a sound proof booth, using Audacity software (version 2.0.5, audacityteam.org) and processed as follows. Since prosodic information has been shown to affect the interpretation of case-ambiguous sentences in German healthy speakers (Weber et al., 2006), we aimed at keeping SRCs and ORCs maximally similar. To achieve this, we selected from each SRC-ORC pair the sentence that included a rising accent on the RC head and a falling prosodic contour throughout the relative clause, which was lowest at the final verb. In a next step, the sentence-final verb (in number-marked RCs) or the relative pronoun and the embedded constituent (in case-marked RCs) were exchanged to create an ORC from a SRC and vice versa. Moreover, the silence between the offset of RC head and the onset of the relative pronoun was set to 400 ms.

For each target sentence, we determined the duration of the following constituents: matrix clause (including the 400 ms pause), relative pronoun, embedded constituent, and verb. Comparisons of the constituent durations in number-marked SRCs and ORCs did not differ significantly (all $p > .2$; paired t-test, two-sided). However, for case-marked RCs, the durations of the relative pronoun and the embedded constituent in SRCs and ORCs had to be manipulated using Praat software (version 5.3.77, Boersma & Weenink, 2014). Following the length manipulation, the statistical comparison of the durations revealed no significant differences across SRCs and ORCs (all $p > .05$; paired t-test, two-sided). The mean articulation rate in the final target recordings was 3.09 syllables per second ($SD = 0.30$). Lastly, maximum amplitude of all recordings was normalized to 1 dB using Audacity software.

Each sentence was paired with one short video clip of semantically reversible events performed by cartoon animals (Adani & Fritzsche, 2015). In each item, the arrangement of the animals was as follows: One animal of type A (e.g., camel) was presented on the left and on the right (referred to by the RC head noun). In the center, two or one animal (number- and case-marked RCs, respectively) of type B appeared (e.g., hedgehog; referred to by the embedded constituent). For example, a camel was washing two hedgehogs, which were in turn washing another camel (Figure 5.1). This scene was paired with one of the sentences in 8 (a-h). Hence, the answer to the interrogative RC always referred to one of the animals in the periphery. If a SRC was presented, the target picture was the agent animal (camel on the left in Figure 5.1), whereas in ORCs the patient animal was the target picture (camel on the right in Figure 5.1). Throughout the experiment, all animals carried a symbol to keep the visual material for target and filler items identical. However, only filler sentences required analyzing the symbol of one of the animals A to identify the target picture.

Within one visual scene, the area covered by the animals on the left, in the center, and on the right was equal, while keeping the animals' proportions natural. The pictures of the animals never overlapped, since all actions were performed using an instrument.

5.2.3 Procedure

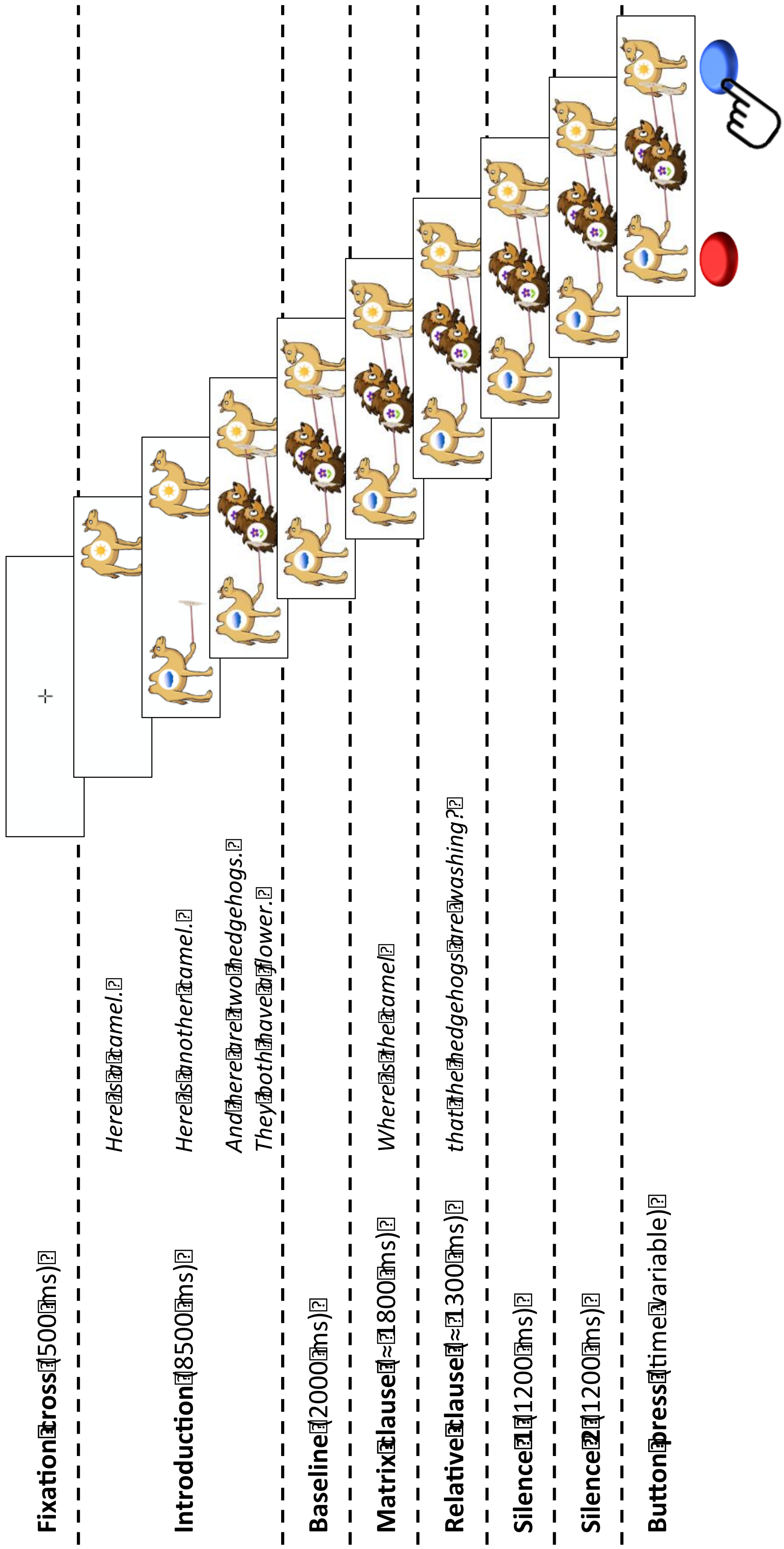
Participants performed an auditory referent-identification task via button press. They had to select the target animal, which was referred to by the RC head noun. In other words, participants had to determine whether the head noun was modified by a SRC or by an ORC. Two pushbuttons served as response devices: one for the outer left animal and one for the outer right animal. All participants used their non-dominant hand to press the buttons.

The experiments including number- and case-marked RCs were carried out within two separate sessions. The order of presentation of number- vs. case-marked RCs was counterbalanced across participants. Moreover, we made sure that there was at least a one-week interval between the two sessions.

For each type of disambiguating feature, two item lists were constructed such that each noun-verb combination was presented as SRC in one list and as ORC in the other list. Half of the participants were tested with one list, the other half with the other list. Within each list, the item order was pseudo-randomized. Moreover, the target position and action direction were controlled for within each list. Each of the two lists was also presented in reversed sequence to control for item order. An SMI RED250 eye tracker with a sampling rate of 60 Hz was used to collect the participants' eye movements (binocular tracking, gaze position accuracy: 0.40, tolerance for head movements: 40 × 40 × 20 cm), when the testing session took place at the University of Potsdam. Participants were seated in a dimly lit room at a distance of approximately 60 cm in front of a computer monitor (screen size: 22”, resolution: 1680 × 1050), connected to the eye-tracking device. When participants preferred to be tested at home, we used a portable SMI REDm eye-tracker (binocular tracking, gaze position accuracy: 0.50, tolerance for head movements: 32 × 21 × 25 cm), connected to a laptop (screen size: 17’’, resolution: 1600 × 900). Stimuli were presented with SMI Experiment Center software (version 3.4, SensoMotoric Instruments GmbH, 2014). For each item, a movie file was created using Adobe Flash Professional CS6 (version 12.0.2, Adobe Systems Incorporated, 2012). The structure of each item was as follows (Figure 5.2): Each item started with a fixation cross shown at the center of the screen for 500 ms to prepare participants for the presentation of the upcoming item. Then, the animals were introduced by naming them while they appeared on the screen one after another. Additionally, the center animals' symbol was mentioned during the introduction (see Figure 5.2). Animals in the center always appeared last to center participants' eye gaze before the animals began to move their instruments and heads. Then, the sentence was presented auditorily while the movie clip continued. As soon as the participant pressed a button and the presentation of the sentence was finished, the experimenter ended the item manually and thereby advanced the experiment to the next item. The maximum response time was set to 20 s after sentence onset. Responses exceeding this maximum were considered time-outs.

Figure 5.2

Trial structure and corresponding interval durations in milliseconds (English translation)



Prior to each experimental session, participants received a written description of the experimental procedure and the eye-tracking method. The eye-tracker was calibrated for each participant at the beginning of the experimental session. During a practice phase, participants were familiarized with the task and the experimental procedure. No participant needed to repeat the practice phase. Following this, calibration was repeated prior to the testing phase. Re-calibration was carried out between items if required. After each third of the items (i.e., 32 items), participants were given a break of 5–10 min, following which calibration was repeated.
The overall duration of one experimental session was about 50–60 min in controls, with a testing phase of approximately 35 min. In IWA, the experimental session took about 60–75 min.

5.2.4 Data analysis

For statistical analysis, we used R (R Development Core Team, 2014) and the lme4 package (D. Bates et al., 2015). With respect to response scoring, we differentiated between correct (i.e., selection of correct referent of RC head) and incorrect (i.e., selection of incorrect referent of RC head or time-outs) responses. Self-corrections were not accepted. Binary accuracy data were analyzed using generalized linear mixed models fit by maximum likelihood with a logit link function. To achieve model convergence, we included the "bobyqa" optimizer in the glmer function. Only items with correct responses in the referent-identification task entered the analysis of eye-movement data.
For the analysis of eye-gaze data, three visual Areas of Interest (AoI) were determined. The agent, the patient, and the center animals each formed an AoI. Fixations were calculated automatically by SMI BeGaze software (version 3.4, SensoMotoric Instruments GmbH, 2014). We measured the proportion of fixations on each AoI. As dependent variable, we calculated the proportion of looks to the patient animal (PLP).[7] As pointed out earlier, the target picture in case of an ORC was the patient animal. Hence, by taking PLP as the dependent variable used for analysis of gaze data, successful processing of ORCs was expressed by an increase in PLP. By contrast, since the agent animal was the target picture in SRCs, PLP should decline

[7] The PLP animal was calculated by dividing the looks to the patient animal by the sum of looks to the agent, patient, and center animals.

as soon as participants derived the correct sentence meaning. The PLP was aggregated across subjects and items for each of the following temporal Regions of Interest (RoIs) by grouping constituents of the target sentences: Baseline (1200 ms prior to sentence onset), Matrix clause (i.e., *where is*, RC head, 400 ms pause), and Relative clause (i.e., relative pronoun, embedded constituent, verb). The silence between sentence offset and the participant's button press was divided into two silence regions of 1200 ms each (Silence 1 and Silence 2) and a region including fixations later than 2400 ms after sentence offset (i.e., RoI called *>2400*). The temporal boundaries of each RoI were shifted 200 ms downstream to compensate for the time necessary for programming and executing eye movements (Allopenna et al., 1998; Altmann & Kamide, 2004).

For statistical analyses of eye-gaze data, we fit linear mixed effect models with maximum likelihood. For all analyses, we used subjects and items as random factors, while RoI (levels: Baseline, Matrix clause, Relative clause, Silence 1, Silence 2, >2400), RC type (levels: SRC, ORC), type of embedded constituent (levels: full DP, pronoun), and group (levels: controls, IWA) were treated as fixed factors.[8] Analyses of number- and case-marked RCs were performed separately.

5.3 Results

5.3.1 Number-marked RCs

Table 5.3 provides the groups' mean proportion of correct responses in the referent-identification task to give the raw accuracy scores. Six trials had to be excluded (0.3% of the total data points), because participants gave a response before the offset of the sentence-final verb, which provided the unambiguous cue to sentence interpretation. Moreover, eight time-outs (0.4% of the total data points), which were distributed almost equally across conditions, were scored as incorrect.

[8] For the factor RoI, we applied successive difference contrast coding. From the second RoI onwards, PLP in each region was compared to the preceding one. For the factor group, we used treatment contrast, coding control participants as baseline. Consequently, non-significant interactions between the factor group and another factor allowed us to assume that IWA were not behaving differently from controls with respect to this effect. All remaining factors were coded using sum contrast.

Table 5.3

Controls' and IWAs' mean proportion of correct responses in the referent-identification task. Standard deviations are provided in parentheses.

RC type	Embedded constituent type	Number-marked RCs		Case-marked RCs	
		Controls	IWA	Controls	IWA
SRC	Full DP	0.990 (0.097)	0.606 (0.490)	0.991 (0.097)	0.756 (0.431)
	Pronoun	0.984 (0.124)	0.509 (0.501)	0.978 (0.147)	0.688 (0.465)
ORC	Full DP	0.930 (0.255)	0.594 (0.493)	0.891 (0.313)	0.529 (0.501)
	Pronoun	0.984 (0.125)	0.712 (0.454)	0.962 (0.191)	0.550 (0.499)

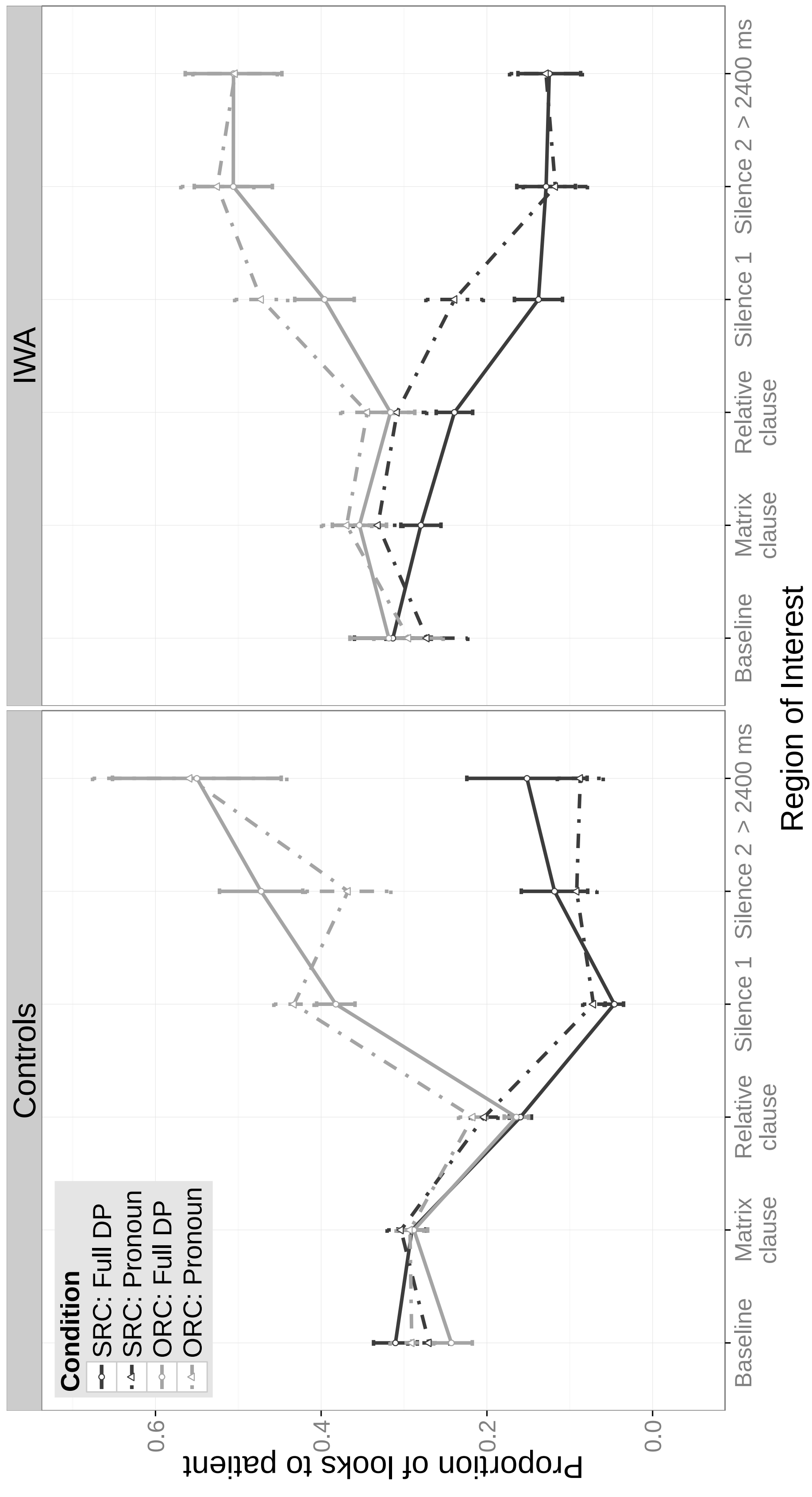
Note. RC = relative clause, IWA = individuals with aphasia, SRC = subject relative clause, ORC = object relative clause, DP = determiner phrase.

IWA performed overall significantly less accurately than controls ($p < .001$). There was a main effect of RC type ($p = .018$), which also interacted with the factor group ($p = .002$): While controls exhibited higher accuracy on SRCs as compared to ORCs, IWA displayed higher comprehension accuracy on ORCs than on SRCs. Importantly, the interaction between RC type and embedded constituent type was significant ($p = .02$): While accuracy for SRCs with full DPs and pronouns as embedded constituent was similar, both groups performed better in comprehending ORCs with pronouns as compared to full DPs. There was no significant three-way interaction between RC type, embedded constituent type, and group ($p = .249$), indicating that both groups showed this comprehension pattern. The complete model output including coefficient estimates, standard errors (*SE*), *z*-scores, and their corresponding *p*-values is provided in Table A.3 in the Appendix.

Figure 5.3 shows controls' and IWAs' eye-gaze data. Two items were excluded from the analysis altogether, because track loss across participants and items exceeded 50% during the analyzed temporal RoI. Moreover, 17 trials were excluded due to track loss of more than 50% during the analyzed RoI. This led us to exclude 4% of the data.

Figure 5.3

Controls' and IWAs' proportion of looks to the patient animal within the Regions of Interest for analysis in number-marked RCs, divided by condition (dark gray: SRC; light gray: ORC; solid: Full DP; dashed: Pronoun).



Analysis of participants' eye-gaze data yielded main effects of RoI, RC type, and group. For controls' correct responses, we found a main effect of RoI, with decreasing PLP at the relative clause ($p < .001$) and increasing PLP at Silence 1 ($p < .001$), indicating that participants tended to look away from the patient during the relative clause, but looked at the patient after sentence offset. The main effect of RC type ($p < .001$) indicated that control participants fixated on the patient animal in ORCs, but looked away from the patient animal in SRCs, as predicted. There was an interaction between RoI and RC type ($p < .001$), showing that PLP increased for ORCs and decreased for SRCs during Silence 1, i.e., after sentence offset. At Silence 2, PLP increased for sentences with full DPs, but not with pronouns, resulting in a significant interaction between RoI and embedded constituent type ($p = .001$). Importantly, the interaction between RC and embedded constituent type did not reach statistical significance at any critical RoI ($p > .05$).

In IWAs' correct responses, there was no decline in PLP during the relative clause, as evidenced by a significant RoI by group interaction ($p = .003$). Moreover, we found a three-way interaction between RoI, RC, and group during Silence 1 ($p = .003$) and Silence 2 ($p = .006$): At Silence 1, the change in PLP was lower in IWA as compared to controls in ORCs, but not in SRCs. At Silence 2, IWAs' PLP increased further for ORCs and decreased for SRCs, while PLP in controls increased in both RC conditions. In Table A.4 in the Appendix, the complete model output including coefficient estimates, *SE*, *t*-scores, and *p*-values is provided.

5.3.2 Case-marked RCs

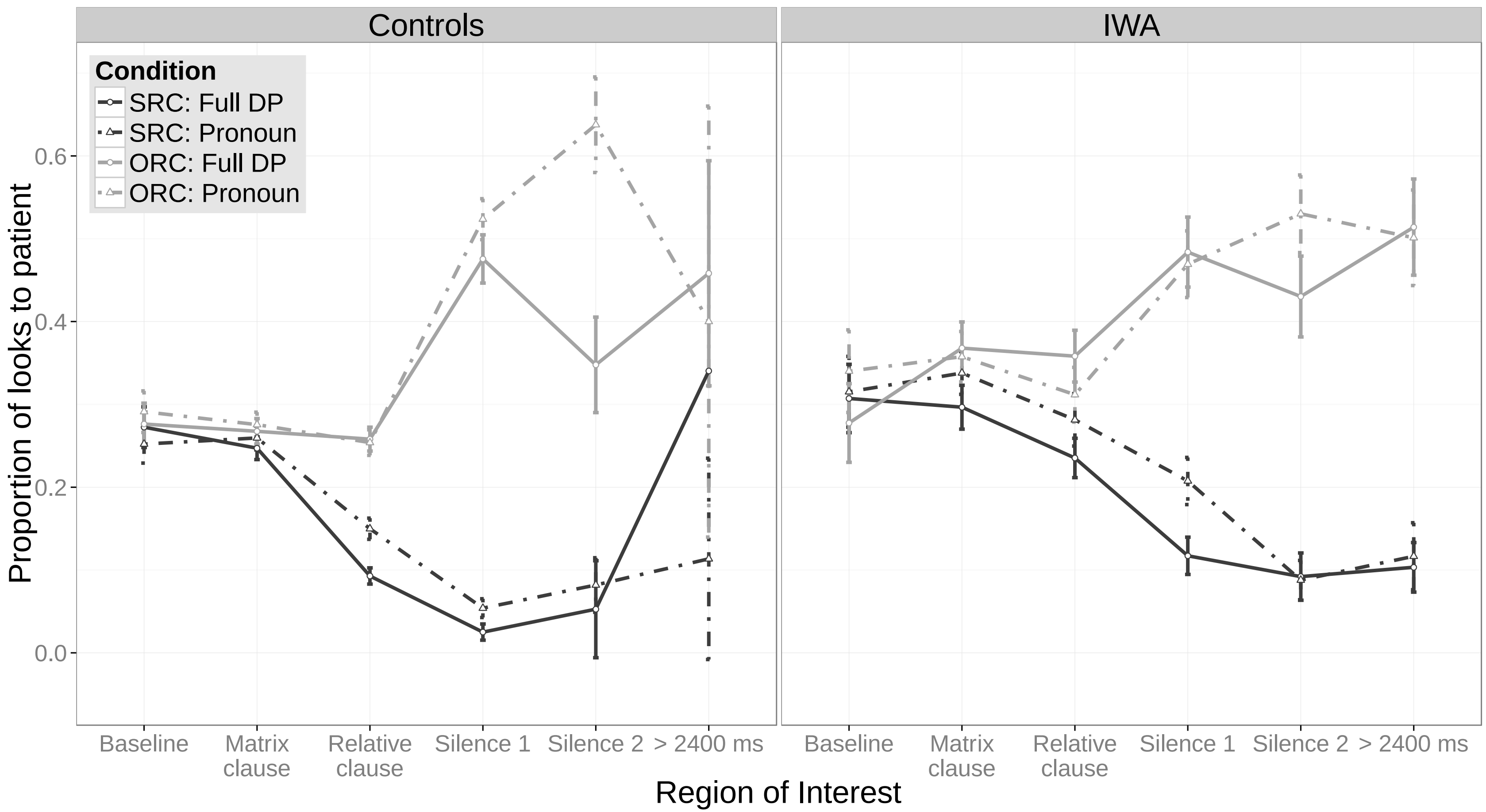
The groups' mean proportion of correct responses in the referent-identification task is given in Table 5.3. In four instances (0.2% of the total data points), time-outs were scored incorrect. Additionally, one trial was excluded (0.1% of the total data points) due to a response given prior to the offset of the relative pronoun, which provided the cue to sentence interpretation. As expected, IWA performed overall significantly less accurately than controls ($p < .001$). The effect of RC type was significant with SRCs being comprehended better than ORCs both in controls and IWA ($p < .001$), as the RC type by group interaction did not reach significance ($p = .07$). Moreover, there was an interaction between RC type and embedded constituent type ($p = .005$), which additionally interacted with the factor group ($p = .049$): While both groups performed as accurately on SRCs with full DPs and pronouns as embedded constituent, only controls' comprehension performance increased in ORCs with pronouns as compared to full DPs. In IWA, comprehension of ORCs was similar, irrespective of the embedded constituent type. The model output is provided in Table A.5 in the Appendix.

Figure 5.4 shows controls' and IWAs' eye-gaze data given a correct response in the referent-identification task. Altogether, nine trials had to be excluded (0.5% of the total data), because more than 50% of the data points during the analyzed temporal RoIs were missing.

Analyzing participants' eye movements, there were main effects of RoI and RC type, but not of group. Moreover, there were no significant interactions with the factor group. Therefore, the effects described below were applicable to both IWA and controls. Main effects of RoI revealed that PLP decreased at the relative clause ($p < .001$) and increased at Silence 1 ($p < .001$). This means that participants shifted their gaze away from the patient during the relative clause, but looked at the patient immediately after sentence offset. The main effect of RC type indicates that, as predicted, participants fixated on the patient animal differently depending on RC type ($p < .001$): They looked at the patient animal in ORCs, but looked away in SRCs. Moreover, we found an interaction between RoI and RC type: During the relative clause, PLP decreased for SRCs, but not for ORCs ($p < .001$), whereas there was an increase for ORCs during Silence 1, while PLP decreased further for SRCs ($p < .001$). This implies that the expected change in PLP started earlier for SRCs as compared to ORCs. Moreover, there was a three-way interaction between RoI, RC type, and embedded constituent type during Silence 2 ($p = .034$): PLP declined for ORCs with full DP and rose further for ORCs with pronouns, whereas PLP in the SRC conditions remained unchanged. In Table A.6 in the Appendix, the model output is provided.

Figure 5.4

Controls' and IWAs' proportion of looks to the patient animal within the Regions of Interest for analysis in case-marked RCs, divided by condition (dark gray: SRC; light gray: ORC; solid: Full DP; dashed: Pronoun).



5.4 Discussion

The present study tested the predictions of the RM approach (Costa et al., 2012; Grillo, 2008; Rizzi, 1990, 2013; Varlokosta, Nerantzini, Papadopoulou, et al., 2014) by targeting the offline and online processing of German RCs in healthy adults and IWA. A visual-world experiment embedded within an auditory referent-identification task was administered to assess whether RM can capture the comprehension patterns emerging during processing number- and case-marked RCs. Target sentences were SRCs and ORCs varying in the structural similarity between RC head and the embedded constituent with respect to the [+NP] feature (full DP vs. pronoun). By testing number- and case-marked RCs, we additionally manipulated the structural similarity of the elements involved with respect to the case, number, and gender features. We tested the occurrence of a subject-object asymmetry in the accuracy data and eye-gaze data. According to the RM approach, the subject-object asymmetry is caused by the presence of the embedded subject intervening between the moved object and its extraction site in ORCs, giving rise to a Minimality effect (Grillo, 2005, 2008, 2009). Moreover, within ORCs, we investigated whether pronouns as embedded subjects facilitate processing as compared to full DP subjects, thus, reducing the Minimality effect. Thereby, we examined Friedmann et al.'s (2009) extension of the RM account, assuming that structural dissimilarity of the moved object and the intervening subject with respect to the [+NP] feature facilitates ORC processing.

Table 5.4 summarizes the results from our study in relation to these hypotheses. By comparing the occurrence of a subject-object asymmetry and pronoun facilitation both in number- and case-marked RCs, we were additionally able to explore the predictions of Costa et al. (2012) that a higher degree of similarity in the internal feature structure results in greater Minimality effects. With respect to these hypotheses, we will discuss the subject-object asymmetry and pronoun facilitation, always relating them to the role of feature dissimilarity.

Table 5.4

Summary of the offline and online results with respect to the subject-object asymmetry, pronoun facilitation and feature dissimilarity as predicted by the RM approach.

Type of disambiguating feature	Subject-object asymmetry				Pronoun facilitation			
	Controls		IWA		Controls		IWA	
	Offline	Online	Offline	Online	Offline	Online	Offline	Online
Number	+	+	–	+	+	–	+	–
Case	+	+	+	+	+	(+)	–	–

Note. IWA = individuals with aphasia, + = consistent with predictions of RM approach, – = inconsistent with predictions of RM approach, (+) = effect is not unequivocally attributable to a pronoun facilitation.

5.4.1 Subject-object asymmetry

Given the theoretical framework of RM and findings from previous studies on RC processing in healthy speakers and IWA (e.g., Bader & Meng, 1999; Burchert et al., 2003; Caplan et al., 2007; Grillo, 2005, 2008, 2009), we predicted a processing advantage for SRCs over ORCs. Usually, the subject-object asymmetry is restricted to online measures of sentence processing in controls and does not occur in offline accuracy data (e.g., Bader & Meng, 1999; Burchert et al., 2003; Friederici et al., 1998; Friedmann et al., 2010; Mecklinger et al., 1995), as healthy speakers are assumed to activate the full array of morpho-syntactic features, which overrides the Minimality effect in ORCs in accuracy (Grillo, 2008). Yet, greater processing demands for ORCs are expressed by higher response latencies or reading and listening times (e.g., Bader & Meng, 1999; Caplan et al., 2007; Gordon et al., 2001, 2004). This indicates that even healthy speakers are susceptible to the Minimality effect in ORCs. Interestingly, though, we observed better comprehension of SRCs as compared to ORCs, both in number- and case-marked RCs. That means that there is evidence of a subject-object asymmetry even in our offline accuracy data. We attribute this result to the age group tested in our study. While in most published studies participants in their 20s and 30s took part in the experiments, our control group comprised healthy adults age-matched to IWA with a mean age of 58 years (range 38–75). Therefore, we assume that aging in healthy adults leads to higher susceptibility to Minimality effects, which is evident even in comprehension performance (compare DeDe, 2014; Obler et al., 1991). However, investigations of the influence of aging on Minimality effects and, within this context, on pronoun facilitation are still lacking. Results corroborating the aforementioned assumption would eventually extent the scope of the RM approach to sentence processing in healthy aging.

Considering controls' online data, we found the expected subject-object asymmetry, which is in line with findings from previous studies using a variety of online tasks (e.g., Bader & Meng, 1999; Caplan et al., 2007; Friederici et al., 1998; Gordon et al., 2001, 2004; Mecklinger et al., 1995). Evidence of faster processing of SRCs as compared to ORCs can be derived from the observation that participants entertain a subject-first interpretation of a temporally ambiguous sentence. This interpretation turns out to be correct in SRCs, but not in ORCs. In number-marked RCs, which are ambiguous between SRC and ORC until the sentence-final verb, we observed a decrease in PLP during the relative clause region, irrespective of RC type. This decrease indicates that participants interpret the RC head as being the agent and predict the subsequent DP to be the patient. However, upon hearing the inflection of the sentence-final verb in number-marked RCs, participants immediately shift their gaze towards the patient animal in ORCs, but not in SRCs, resulting in a diverging PLP after sentence offset. By contrast, the unambiguous cue to sentence interpretation is given earlier in case-marked RCs, namely at the relative pronoun. Consequently, there was a change in PLP already at the relative clause region, which was stronger in SRCs as compared to ORCs, as controls can use the case cue already before sentence offset. In comparing controls' online data upon visual inspection with respect to the different disambiguating features, we observed that the PLP in SRCs and ORCs diverges earlier in case- than in number-marked RCs. This finding is attributable to the earlier point of disambiguation in case-marked (i.e., relative pronoun) as compared to number-marked RCs (i.e., sentence-final verb). This response pattern supports the claim that healthy speaker can immediately make use of the morpho-syntactic cues and is in accordance with the prediction that number marking induces greater processing difficulties than case marking (Meng & Bader, 2000). Taken together, data from both offline and online processing of RCs in healthy speakers constitute evidence of a subject-object asymmetry and, thus, provide support for the RM approach (see Table 5.4).

Turning to the IWAs' results, they performed, as expected, less accurately than controls both in number- and case-marked RCs. However, IWA exhibited the expected asymmetry with better comprehension of SRCs as compared to ORCs in case-marked RCs. By contrast, unlike controls, IWA exhibited a reversed subject-object asymmetry in number-marked RCs, with significantly better comprehension of ORCs as compared to SRCs. Hence, the results from case-marked RCs indicate that IWA are susceptible to Minimality effects in ORCs (Grillo, 2005, 2008, 2009), in line with findings from earlier studies on RC comprehension in aphasia (Burchert et al., 2003; Friedmann et al., 2010; Garraffa & Grillo, 2008; Thompson et al., 2010). Yet, it should be noted that the unexpected effect of a reversed asymmetry in number-marked RCs could be ascribed to the marked increase in comprehension accuracy on ORCs with pronouns as embedded constituent as compared to all the other conditions. We will return to this issue when discussing the effect of pronoun facilitation. Considering only number-marked RCs with a full DP as embedded constituent, we found no asymmetry in comprehension of SRCs and ORCs, which is not in accordance with the RM account, but is still consistent with other experimental studies in aphasia reporting no subject-object asymmetry in RC comprehension (e.g., Nerantzini, Varlokosta, et al., 2014). One finding that merits discussion is the fact the IWAs' performance on SRCs was considerably low, as compared to 73% correct responses on average during pre-testing of sentence comprehension abilities (Burchert et al., 2011). This result suggests that IWA were not applying a heuristic strategy in comprehending SRCs during the experiment, such as the subject-first assumption (e.g., Bever, 1970; Grodzinsky, 1990). If they were relying on this strategy, their performance on SRCs should be at ceiling. Therefore, the low performance on SRCs implies that IWA are in fact processing the sentences. Yet, correct processing of number-marked RCs requires maintaining the temporarily ambiguous part of the sentence in memory until the sentence-final verb, when the sentence is disambiguated towards a SRC or an ORC. Consequently, it can be assumed that this late point of disambiguation results in low performance, possibly due to reduced processing capacities (Caplan et al., 2007). However, there was no further decline in comprehension accuracy for ORCs. Lower accuracy rates in number-marked SRCs as compared to ORCs stands in contrast to the observed subject-object asymmetry in case-marked RCs. In the following, we will relate this discrepancy (highlighted in Table 5.4) to the differences in structural dissimilarity in terms of morpho-syntactic features. But before, we will discuss the IWAs' online data with respect to the subject-object asymmetry in aphasia.

Turning towards the IWAs' eye movements, we found evidence of greater demands in processing ORCs as compared to SRCs, similar to the findings in controls. This finding is in line with the assumptions of the RM approach and previous results on online processing of RCs in IWA (Caplan et al., 2007). In number-marked RCs, IWA exhibited a subject-object asymmetry in the following manner. IWAs' change in PLP was smaller for ORCs as compared to controls, whereas PLP for SRCs changed at a similar rate in both groups. This means that, as soon as the number cue was provided through inflection of the sentence-final verb, IWA can employ it for deriving the correct meaning of SRCs at the same speed as controls. The fact that the increase in PLP for ORCs continued even during Silence 2 indicates that IWA take longer to process ORCs as compared to SRCs, thus, displaying a subject-object asymmetry in online processing. In case-marked RCs, the subject-object asymmetry is again attested by an initial subject-first interpretation, similar to controls. During the relative clause region, PLP decreased for SRCs, while there was no change in PLP for ORCs. This subject-first assumption is then supported by case marking in SRCs, but has to be overridden in ORCs. Thus, SRCs are processed faster than ORCs, which is in line with the RM account. Altogether, in accordance with the RM approach, IWAs' online data support the assumption of faster processing of SRCs as compared to ORCs.

Summarizing the IWAs' results with respect to the hypothesis of a subject-object asymmetry, we observed higher comprehension accuracy on SRCs than on ORCs in case-marked RCs, but not in number-marked RCs. By contrast, similar to control participants, IWA exhibited a subject-object asymmetry in the online data for both case- and number-marked RCs. Yet, this raises the question of why the subject-object asymmetry is expressed differently as a function of the disambiguating morpho-syntactic features in aphasia. Considering the formal definition of RM, a subject-object asymmetry would be expected regardless of the morpho-syntactic feature involved in the RCs, since an intervening element is present between the moved object and its extraction site both in number- and case-marked RCs. However, following the extension of the RM approach to neurolinguistic research (Grillo, 2005, 2008, 2009), and subsequently refined based on research in language acquisition and psycholinguistics (Adani et al., 2010; Costa et al., 2012), speakers need to activate and/or maintain the full set of features in order to distinguish the moved constituent from the intervener. This entails that greater similarity results in stronger Minimality effects (Costa et al., 2012). Transferring this notion to German RCs, we can attribute the presence of a subject-object asymmetry only in case-marked sentences to the low degree of featural distinctiveness: In case-marked ORCs, the moved object and the intervening subject are structurally similar with regard to the number (both singular) and the gender (both masculine) features, whereas they differ only in the feature specification of case (accusative/nominative). Consequently, the moved and the intervening elements in case-marked ORCs can only be distinguished in terms of the case feature. Yet, due to reduced processing capacities (Grillo, 2008), IWA do not have available the full set of morpho-syntactic features. This, in turn, increases the Minimality effect in case-marked ORCs, causing a subject-object asymmetry. By contrast, the object and subject in number-marked ORCs carry varying specifications for all relevant morpho-syntactic features in German (number: singular/plural, gender: feminine or neuter/masculine, case: accusative/nominative). Hence, even though processing capacities in IWA are reduced and even if they can activate or maintain just a subset of morpho-syntactic features in their syntactic representation, they can distinguish the moved and the intervening elements in number-marked ORCs based even on an impoverished representation. Therefore, we did not observe a decrease in comprehension performance on number-marked ORCs as compared to SRCs. Moreover, this explanatory approach underscores the relevance of features such as case, number, and gender within the RM approach (Adani et al., 2010; Belletti et al., 2012). Yet, in this context the question arises of why the results from the offline and online data diverge in number-marked RCs. We conjecture that, even though, the presence of an intervening element in ORCs causes a disadvantage in the online processing of ORCs, this disadvantage does not take effect on comprehension performance in number-marked RCs, due to the aforementioned high degree of structural dissimilarity between the subject and the object.

5.4.2 Pronoun facilitation in ORC processing

With regard to pronoun facilitation within ORCs, we find evidence of this effect in the controls' accuracy data, which supports the predictions of the RM approach (Friedmann et al., 2009). Even though controls' comprehension accuracy for both number- and case-marked ORCs was relatively high, accuracy on ORCs with a pronoun as embedded subject was higher compared to a full DP subject. This finding suggests that even unimpaired adult speakers benefit from structural dissimilarity of the moved and the embedded element in ORCs in terms of the [+NP] feature. Moreover, the results are in accordance with previous findings of faster self-paced reading times in ORCs with pronouns than with full DPs as embedded subjects (Gordon et al., 2001, 2004; Reali & Christiansen, 2007). In addition, the lacking impact of pronouns on comprehension accuracy in SRCs demonstrates that feature dissimilarity is crucial only if an element intervenes in a syntactic relation, which is only the case in ORCs.

In contrast to the controls' offline data, pronoun facilitation is not unequivocally manifested in the online data, neither in number-marked nor in case-marked RCs. This result is inconsistent with findings from self-paced reading studies (Gordon et al., 2001, 2004; Reali & Christiansen, 2007; Warren & Gibson, 2002). Based on these studies, facilitative effects of pronouns were supposed to be expressed in the eye-gaze data in terms of a faster rise of the PLP once participants derive the correct meaning of ORCs. However, in number-marked RCs, there was no interaction between RC type and embedded constituent type at any RoI, indicating that there was no pronoun facilitation. A possible explanation for the absence of the facilitative effect of pronouns in number-marked ORCs could be that, at the stage when the embedded subject (full DP or pronoun) is processed, the disambiguating cue to sentence interpretation has not yet been provided. Consequently, pronoun facilitation cannot take effect.[9] In case-marked RCs, we observed a strong decrease in PLP for ORCs with full DPs, absent in ORCs with pronouns as embedded subject, but only at Silence 2 (i.e., between 1200 and 2400 ms after sentence offset). Thus, if any, the pronoun facilitation occurred only late in processing case-marked ORCs, contrary to our predictions. One possible explanation attributes this finding to

[9] We thank an anonymous reviewer for pointing out this possibility.

uncertainty regarding sentence interpretation in ORCs when the moved object and the intervening subject are both full DPs (i.e., when they are structurally similar in the [+NP] feature). Hence, even though this effect could be interpreted as pronoun facilitation, these considerations should be regarded with caution, as the effect occurs relatively late after sentence offset. At that time, most control participants had already given their offline response. Thus, we suppose that this result does not clearly signify pronoun facilitation. Similarly, Contemori and Marinis (2014) reported no facilitative effect of dissimilarity in the number feature in children's online processing of ORCs in terms of self-paced listening times. They speculated that the facilitation effect occurs late and is therefore present only in the offline accuracy data. Consequently, further research is needed to clarify which methods in sentence processing research are suitable to detect this effect. Since we observed no effect of pronoun facilitation in IWAs' online data either, we will limit the following discussion about pronoun facilitation to the offline results.

Considering IWAs' accuracy data from the referent-identification task, we obtained varying effects of pronouns on ORC comprehension in number- and case-marked RCs (highlighted in Table 5.4). While we observed a strong facilitative effect of pronouns in comprehending number-marked ORCs, there was no pronoun facilitation in case-marked ORCs. Therefore, only offline data from number-marked RCs appear to be in accordance with Friedmann et al.'s (2009) adaptation of the RM account, which assumes that pronouns in the embedded subject position facilitate ORC comprehension. According to Friedmann et al., pronoun facilitation should occur regardless of the morpho-syntactic feature disambiguating the syntactic structure. The offline data from case-marked RCs in turn are inconsistent with the predictions of RM. Nevertheless, the lack of pronoun facilitation in case-marked ORCs is in line with findings from Greek-speaking IWA (Varlokosta, Nerantzini, Papadopoulou, et al., 2014). Hence, the differential facilitative effect of pronouns on case- and number-marked ORC comprehension requires further explanation. As pointed out earlier, the moved and the intervening constituents in case-marked ORCs are structurally more similar than in number-marked ORCs. We suspect that the varying degrees of structural similarity do not only affect the occurrence of a Minimality effect in IWA, but also cause the different effects of pronouns in German ORCs. This claim is based on the hypothesis by Costa et al. (2012) that the higher the similarity between the constituents the stronger the Minimality effect. This follows from the assumption that IWA suffer from reductions in processing capacities, which impede the activation and maintenance of the full set of features associated with the moved and the intervening elements (Grillo, 2005, 2008, 2009). Consequently, we conjecture that adding another feature with varying specifications (in this case [+NP]) improves ORC processing only if the other features structurally differ as well. In other words, IWA can only detect the dissimilarity in the [+NP] feature if a high number of features are structurally dissimilar. With regard to German ORCs, this means that IWA can distinguish the moved and the intervening elements more easily in number-marked ORCs as compared to case-marked ORCs, because the internal feature structure differ more strongly in the former sentence type. However, adding the distinct [+NP] feature to case-marked ORCs does not sufficiently increase the structural dissimilarity for IWA to distinguish the moved and the intervening elements. Consequently, pronouns do not facilitate comprehension of case-marked ORCs. Thus, we conclude that the internal structure of the constituents modulates not only Minimality effects (Costa et al., 2012), but also affects the facilitative effect of pronouns.

One implication of the current proposal is that IWAs' sentence comprehension performance is dependent on the internal feature structure of the DPs (Adani et al., 2010, 2014). However, further research is needed to further investigate this feature-based approach to sentence comprehension difficulties in aphasia. Since the features that are relevant to the internal feature structure of DPs are language specific, findings from cross-linguistic studies can contribute to an extension of this approach. In investigating languages in which the DP's internal feature structure involves not only case, number, and gender but for example also animacy (e.g., in Slavic languages), the effect of varying degrees of feature dissimilarity can be explored further. Since the degree of dissimilarity can be manipulated more freely in these languages, it is conceivable to determine whether IWAs' comprehension performance improves gradually if the degree of featural dissimilarity increases. Furthermore, the current proposal would predict that, due to reduced processing capacities, IWA require a higher degree of feature dissimilarity to improve sentence comprehension. Consequently, approaches to the treatment of sentence comprehension deficits in aphasia need to take into account this factor. Treatment material can be created hierarchically by decreasing the degree of structural similarity (cf. Stegenwallner-Schütz & Adani, 2017, for an analogous proposal for the therapy of developmental disorders). This means that comprehension of semantically reversible RCs should be structured as follows: number-marked RCs before case-marked RCs and within number- and case-marked RCs, ORCs with dissimilar [+NP] features before ORCs with similar [+NP] features. Adopting the Complexity Account of Treatment Efficacy (CATE; e.g., Thompson et al., 2003), treatment of sentence comprehension deficits could also focus on the most complex structure (i.e., case-marked ORCs with two full DPs), with the prospect of generalized improvements in the comprehension of less complex structures. Hence, we believe that morpho-syntactic features are important in considering sentence comprehension patterns in aphasia. Further research will therefore contribute to a better understanding of the role of feature dissimilarity in sentence processing.

5.4.3 Conclusion

In the present study, we investigated whether the RM approach predicts offline and online comprehension of RCs in healthy speakers and IWA. Our results largely support the theoretical framework of RM. While the results are mostly compatible with the hypothesis that the presence of an intervening element in ORCs causes processing difficulties (Grillo, 2008), pronouns do not generally facilitate ORC processing as hypothesized by Friedmann et al. (2009). We propose that the internal feature structure of the moved and the intervening element in RCs has to be taken into account when considering Minimality effects and pronoun facilitation in aphasia (Costa et al., 2012; Varlokosta, Nerantzini, Papadopoulou, et al., 2014), lending support for the importance of morpho-syntactic features in sentence processing (Adani et al., 2010). Our proposal suggests that, due to processing resource reductions, IWA require a high degree of structural dissimilarity in terms of morpho-syntactic features in order to overcome the syntactic comprehension deficit.

5.5 Acknowledgements

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6 WHAT MATTERS IN PROCESSING GERMAN OBJECT RELATIVE CLAUSES IN APHASIA – TIMING OR MORPHO-SYNTACTIC CUES?[10]

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ABSTRACT

Background: It is a well-established finding that individuals with aphasia have difficulties in using morpho-syntactic cues to determine the meaning of non-canonical sentences, such as object relative clauses (ORCs). While non-brain-damaged speakers can process ORCs disambiguated through unambiguous case marking more easily than number marking (i.e. subject-verb agreement), there is still much debate concerning the varying impact of case and number cues on sentence processing in aphasia.

Aims: The objective of the present study is to investigate the use of case and number marking as cues to sentence interpretation and to test the predictions of the Relativized Minimality approach. Within this account, dissimilarity in the number specification of the subject and object is assumed to facilitate ORC processing in aphasia, while case is not.

Methods & Procedures: Combining the visual-world eye-tracking methodology with an auditory referent-identification task, we measured offline and online sentence processing in German-speaking individuals with aphasia and in a group of control participants. ORCs were disambiguated through case or number marking, whereby case occurred at different points of disambiguation: case marking at (1) the relative pronoun, (2) the following noun phrase, or (3) number marking on the sentence-final verb. Thereby, we were able to control for number dissimilarity of the

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subject and object in ORCs, with number specification being similar in case-marked ORCs and dissimilar in number-marked ORCs.

Outcome & Results: We found that both participant groups exhibit a general processing advantage for case- over number-disambiguated ORCs. Moreover, case-marked ORCs disambiguated at different positions within the sentence were processed similarly in term of accuracy, reaction times or online processing speed.

Conclusions: These results support the assumption that case marking can be used more successfully to derive sentence meaning as compared to number marking – regardless of the timing of disambiguation. Future research is needed to further disentangle the status of case and number in the computation of Minimality.

6.1 Introduction

Many studies have shown that individuals with aphasia (IWA) have great difficulties in auditory comprehension of object relative clauses (ORCs) (Burchert et al., 2003; Caplan et al., 2007; Caramazza & Zurif, 1976; Garraffa & Grillo, 2008; among others). This selective deficit in comprehending non-canonical sentences was at first associated only with Broca's aphasia (e.g., Caramazza & Zurif, 1976; Schwartz et al., 1980). Later studies, though, revealed that individuals with other types of aphasia also exhibit impaired sentence comprehension (e.g., Caramazza & Miceli, 1991; Goodglass et al., 1979; Hanne et al., 2015; Martin & Blossom-Stach, 1986). In head-initial languages, non-canonical ORCs are assumed to involve syntactic movement of the object. According to Generative Grammar, the head noun of the relative clause (*the boy* in example 1) is moved from its argument position in the embedded clause (marked by underscores) and is assigned the thematic role of patient by the relative clause verb (*is kissing*) (e.g., Chomsky, 1995; Haegeman, 1994). Hence, to derive the correct sentence meaning, the syntactic dependency must be established between the moved object and its extraction site.

(1) I see [the boy] who [the girl] is kissing ____

IWAs' difficulties in comprehending ORCs have been attested in different tasks and in different languages (sentence-picture verification: German: Burchert et al., 2003; self-paced listening: English: Caplan et al., 2007; sentence-picture matching: Hebrew: Friedmann, 2008; Russian: Friedmann et al., 2010; English: Grodzinsky, 1989; Greek: Terzi & Nanousi, 2018). In binary choice tasks, such as sentence-picture matching, IWA usually perform within chance range on ORCs, but mostly above chance on subject-extracted relative clauses (SRCs), the canonical counterpart of ORCs (e.g., Friedmann, 2008; Friedmann et al., 2010; Grodzinsky, 1989). In contrast to IWA, healthy non-brain-damaged speakers comprehend both SRCs and ORCs at ceiling (Burchert et al., 2003; Nerantzini, Varlokosta, et al., 2014). However, healthy speakers experience a processing cost while processing ORCs in online tasks, such as self-paced listening and reading (Caplan et al., 2007; Gordon et al., 2001; Mak et al., 2002, 2006), eye-tracking while listening and reading (Dickey & Thompson, 2009; Traxler et al., 2002), as well as in event-related potentials studies (Friederici et al., 1998; Mecklinger et al., 1995).

6.1.1 Relativized Minimality

Even though processing of ORCs has been investigated intensively in IWA and healthy speakers, uncertainty remains about what causes the processing difficulties. Since ORC processing is associated with higher processing costs in both groups, it appears that a unitary explanatory approach could potentially elucidate the underlying processes responsible for these difficulties. One recent approach that has been proposed in this direction is the Generalized Minimality approach (Friedmann et al., 2009; Garraffa & Grillo, 2008; Grillo, 2005, 2008, 2009), which uses the concept of Relativized Minimality (Rizzi, 1990) as a metric of syntactic complexity. This account offers a linguistically motivated explanation of IWAs' selective comprehension deficit for non-canonical sentences, which has been studied increasingly in the past years (e.g., Engel et al., 2018; Grillo, 2005, 2008, 2009; Nerantzini, Papadopoulou, et al., 2014; Sheppard et al., 2015; Varlokosta, Nerantzini, Papadopoulou, et al., 2014). Within this approach, it is claimed that the embedded subject in ORCs (*the girl* in example (1)) causes processing difficulties, because it has to be crossed when the syntactic dependency is established between the moved object (*the boy* in example (1)) and its extraction site. This means that the embedded subject intervenes between the object and its base position causing a so-called Minimality effect (borrowing the term from Adelt et al., 2017; Grillo, 2005, 2009; Varlokosta, Nerantzini, Papadopoulou, et al., 2014). Following the argumentation proposed by Grillo (2008), the syntactic processing system of both healthy speakers and IWA relies on this universal principle. As the syntactic processing system in healthy speakers is intact, they can distinguish the moved object and the embedded subject based on the morpho-syntactic features, yielding unimpaired sentence comprehension. Still, the presence of the intervening subject triggers a Minimality effect, causing ORC processing to be more demanding which can be usually detected via online measures of sentence processing. By contrast, following Grillo (2005, 2008), IWA are assumed to be more susceptible to the Minimality effect as compared to healthy adults. Therefore, IWAs' difficulties in processing ORCs can be observed in both offline and online measures.

Across languages and populations, it has been shown that the occurrence of the Minimality effect is modulated by the degree of similarity between the moved object and the embedded subject (e.g., Adani et al., 2010; Adelt et al., 2017; Belletti et al., 2012; Friedmann et al., 2017; Haendler et al., 2015; Haendler & Adani, 2018; Terzi & Nanousi, 2018). This means that processing of ORCs becomes less demanding when the verb's arguments are specified differently in terms of features such as number, case, or gender (for English: Adani et al., 2014; for German: Adelt et al., 2017; for Hebrew: Belletti et al., 2012, among others). Importantly, not every feature's dissimilarity impacts the strength of the Minimality effect (Friedmann et al., 2017). According to Belletti et al. (2012) and Friedmann et al. (2017), Minimality effects are argued to be selective in that only features triggering movement to the subject position enter the computation. Following the argumentation proposed by Belletti et al. (2012), features have to be realized in the agreement morphology of the tensed verb to count as syntactically active feature. This means that features only have an impact on the degree of similarity when they attract movement of the VP-embedded subject to the subject position in order to agree with the inflected verb.

As languages differ in their reliance on morpho-syntactic markings to determine sentence meaning, language-specific properties have to be considered when explaining the role of morphological information in sentence processing. Since verbs in German, the language under investigation in this study, are marked for person and number, but only number information is provided as a morpho-syntactic cue on the verb arguments, it can be hypothesised that merely dissimilarity of the number feature should impact the strength of the Minimality effect. In addition to the number cue, noun phrases in German are also marked for case, thus, also case information can be employed for sentence comprehension. However, case is assigned by verb or nouns (Haider, 2010) and does not trigger syntactic movement. Hence, following Belletti et al. (2012), case is not considered to be a syntactically active feature in German. As a result, comparing the processing of ORCs with varying case and number cues provides an interesting test case to study the predictions of the Relativized Minimality account, as recently put forward by Belletti et al. (2012) and Friedmann et al. (2017).

Unambiguous case marking of nominative and accusative occurs on the relative pronoun and determiners of masculine nouns (see examples 2 and 3). In example (2), the relative pronoun is marked for accusative case (*den*), thus, the RC head is assigned the thematic role of patient. In contrast, in example (3), the relative pronoun is ambiguous with respect to case marking due to case syncretism (*die* denotes both nominative and accusative case). However, the embedded subject is masculine and, hence, its determiner carries nominative case (*der*). Consequently, case marking provides a cue to assign the thematic agent role to the embedded subject and the patient role to the RC head noun. In example (4), case marking of both the relative pronoun (*die*) and the determiner of the embedded subject (*das*) is ambiguous between nominative and accusative case. Sentence meaning in example (4) can be inferred from verb inflection of the sentence-final verb, since German verbs are inflected for person and number and agree with the embedded subject.

(2) Das ist der Junge, **den** das Mädchen küsst[11]
This is the boy who$_{acc,\ 3sg}$ the$_{nom,\ 3sg}$ girl kisses$_{3sg}$
This is the boy who the girl is kissing

(3) Das ist das Mädchen, das **der** Junge küsst
This is the girl who$_{nom/acc,\ 3sg}$ the$_{nom,\ 3sg}$ boy kisses$_{3sg}$
This is the girl who the boy is kissing

(4) Das sind die Jungen, die das Mädchen **küsst**
These are the boys$_{3pl}$ who$_{nom/acc,\ 3pl}$ the girl$_{nom/acc,\ 3sg}$ kisses$_{3sg}$
These are the boys who the girl is kissing

Considering these examples in terms of Relativized Minimality, ORCs with different number information on the moved object and the embedded subject (as in number-disambiguated ORCs in (4)) are expected to be easier to process as compared to ORCs with both subject and object being singular/plural (as in case-disambiguated ORCs in (2) or (3)). Conversely, as case is not considered to be a movement-triggering feature in German, differences in case marking of subject and object in ORCs should not result in better comprehension of ORCs. This prediction is supported by findings provided by Friedmann et al. (2017) on Hebrew-speaking

[11] Due to case syncretism, *das Mädchen* can be either nominative or accusative case. Since the preceding relative pronoun is already unambiguously marked for accusative case, the embedded subject can only carry nominative case.

IWA. In Hebrew, the definite direct object is marked structurally by the case marker "et" preceding the object noun phrase. Similar to German, case dissimilarity in Hebrew does not enter the computation of Minimality. Employing a sentence-picture-matching task, Friedmann et al. found chance-level performance on non-canonical active sentences, which indicates that although IWA are sensitive to the presence of the case marker, they cannot make proper use of overt case marking to derive the correct sentence meaning.

As can be seen from examples (2), (3), and (4), disambiguation through case and number markings occurs at different positions within ORCs (marked in boldface). Case marking can provide cues to sentence meaning immediately when hearing or reading the relative pronoun (2, henceforth *immediate disambiguation*) or the determiner of the embedded subject (3, *early disambiguation*). However, number marking disambiguates the interpretation only at the end of the sentence of the finite verb (4, *late disambiguation)*. Consequently, in addition to Minimality effects, the relative position of case and number cues can have an impact on sentence processing in healthy speakers and IWA, resulting in a gradual increase in difficulty during ORC processing.

By comparing case and number marking as cues to sentence interpretation in German, it is possible to investigate the use of both morpho-syntactic markers as cues to sentence interpretation and examine the predictions of the Relativized Minimality account. In the following, we will describe results from studies comparing the effects of case and number markings on sentence processing in German-speaking healthy adults and IWA.

6.1.2 Impaired and unimpaired processing of case and number marking in German

With respect to differences in the processing of case and number markers, there is evidence that healthy speakers prefer to assign a subject-first interpretation to temporarily ambiguous sentences (e.g., Friederici et al., 1998; Meng & Bader, 2000; among others). Previous studies showed that recovery from this initial misinterpretation is more difficult in number-disambiguated sentences (cf. example 4) as compared to case-disambiguated sentences (cf. examples 2 and 3) (Friederici

et al., 1998; Meng & Bader, 2000), even if disambiguation through case marking is accomplished later than through number marking (Meng & Bader, 2000).[12]
Investigating temporarily ambiguous relative clauses with the same morphological cue appearing at different disambiguation points revealed that comprehension of case-marked sentences in healthy speakers is more accurate in early disambiguated (examples 3) than in immediately disambiguated sentences (example 2). Regarding online ERP data, Friederici et al. (1998) reported a P600 component induced by the disambiguating cue (i.e. a positive-going waveform around 600 ms after the critical word). This component is argued to reflect a sentence reanalysis effect when readers have to replace the expected canonical subject-first interpretation with the less preferred non-canonical object-first interpretation. While this component occurred immediately after the disambiguation point in immediate case-disambiguated and late number-disambiguated ORCs, it was observed only sentence-finally at the verb in the early case condition. The authors interpret this delay to be caused by the use of masculine singular nouns as the embedded subject. Since the nominative case form of masculine singular nouns is ambiguous to dative singular feminine nouns, it is argued that participants had to defer the syntactic reanalysis to the end of the sentence. Taken together, German healthy adults experience lower processing costs associated with the reanalysis of case-marked ORCs compared to number-marked ORCs (Friederici et al., 1998; Meng & Bader, 2000). A similar processing advantage for case-marked sentences has been reported for typically-developing, seven-year-old German-speaking children (Arosio et al., 2012). Moreover, this pattern was observed in other case-marked languages: Guasti, Stavrakaki, and Arosio (2008) found an advantage of case over number marking in Greek, despite the fact that disambiguation through case occurs later than by number in Greek sentences.
In German-speaking IWA, processing of case and number markings has not been extensively tested, and those who did provide contradicting results.

[12] In German object-extracted *wh*-questions (i), the disambiguating case cue (i.e. nominative case on the determiner of the embedded subject) occurs later than the number cue in (ii) (i.e. subject-verb agreement between the verb and the embedded subject):

i.	Welche Vertreterin	hat	**der** Minister	kritisiert?
	Which delegate$_{NOM/ACC,\ 3SG}$	has$_{SG}$	the minister$_{NOM,\ 3SG}$	criticised?
	Which delegate has the minister criticised?			
ii.	Welche Vertreterin	**haben**	die Minister	kritisiert?
	Which delegate$_{NOM/ACC,\ 3SG}$	have$_{PL}$	the ministers$_{NOM,\ 3PL}$	criticised?
	Which delegate have the ministers criticised?			

Burchert et al. (2003) studied IWAs' comprehension of semantically reversible sentences (actives, RCs, cleft sentences) using a sentence-picture verification task. Comprehension of all case-marked, non-canonical sentences was above chance, whereas the performance level on number-marked, non-canonical sentences was at chance. This finding implies that IWAs' sentence processing performance benefits more from case marking compared to number marking. Furthermore, the results suggest that IWA were sensitive to morpho-syntactic markers, as performance levels ranged between above and within chance, except for one participant. Below-chance performance, however, would indicate that IWA were interpreting non-canonical sentences as if they had a canonical word order, resulting in the application of a linear, subject-first strategy (see also Friedmann et al., 2010). In accordance with Bates, Friederici, and Wulfeck (1987), the finding of more impaired comprehension of number- than case-marked sentences can be attributed to the fact that, in case-marked languages such as German, case is a more reliable cue for sentence meaning than number, as case provides direct information about the assignment of the agent and patient role.

More recently, Hanne et al. (2015) investigated processing of case- and number-marked canonical and non-canonical active sentences both using a sentence-picture matching task and collecting eye-gaze data to gain insights into IWAs' online sentence processing. Contrary to the results reported by Burchert et al. (2003), the offline data revealed that IWA comprehended non-canonical number-marked sentences more accurately than case-marked sentences. However, the authors did not report a statistical significance of this difference. Regarding online data, they concluded that IWA could process unambiguous case and number cues correctly as soon as they became available, even though processing was delayed as compared to control participants. This suggested that IWA processed case and number markings at the point of the disambiguation. Hanne et al. (2015) reported contradictory results to previous studies in healthy German adults (Friederici et al., 1998; Meng & Bader, 2000) and IWA (Burchert et al., 2003). Yet, they did not clearly discuss what caused this discrepancy. Similar to studies reporting a processing advantage of case over number marking, they ascribed their findings to factors such as the reliability of morpho-syntactic cues.

Unlike Burchert et al. (2003) and Hanne et al. (2015), Adelt et al. (2017) reported comparably impaired processing of case- (see example 2) and number-disambiguated ORCs (example 4) in IWA. In addition to the manipulation of the disambiguating morpho-syntactic cue, the authors varied the dissimilarity in terms of the lexical restriction feature (i.e. full noun phrase vs. pronoun) of the verb argument to investigate the feature-driven approach of Relativized Minimality. Interestingly, IWA benefited from dissimilar specifications of lexical restriction only in number-disambiguated ORCs. Following the argumentation of Belletti et al. (2012), this finding lends support to the notion that only number dissimilarity has an impact on sentence processing in German.

Taken together, there is only little and inconclusive data on the comparison of case and number marking in IWAs' processing of German sentences. Thus, it remains unclear whether IWA exhibit a processing advantage either for case or for number marking. Furthermore, the question arises as to whether these morpho-syntactic markers differ with respect to their status in syntactic processing or whether the processing difference can be attributed to varying points of disambiguation.

6.1.3 Aims and hypotheses

In the current study, we aimed to investigate the impact of case and number cues during sentence processing of German-speaking healthy adults and IWA using offline and online measures by means of an eye-tracking experiment. Particularly, we considered the explanation that ORC processing is affected by the relative position of disambiguating case and number information (i.e. immediate, early or late disambiguation) (e.g., Friederici et al., 1998; Hanne et al., 2015). Moreover, we studied the prediction of the Relativized Minimality approach that processing of number-disambiguated ORCs is easier as compared to case-disambiguated ORCs due to number dissimilarity of the moved object and the embedded subject (Belletti et al., 2012; Friedmann et al., 2017). Towards this end, we examined temporarily ambiguous ORCs with varying disambiguation points, whereby disambiguation was obtained through case or number marking. Disambiguation of ORCs was accomplished either through case marking occurring at the relative pronoun (immediate disambiguation), at the determiner of the embedded subject (early disambiguation), or through number information in the sentence-final position at the finite verb (late disambiguation). By comparing case marking occurring at two different points of disambiguation, we were able to investigate the impact of timing.

Moreover, through the manipulation of number dissimilarity between the verb arguments, we could evaluate the predictions of Relativized Minimality.

So far, comparing sentence processing of the same disambiguating morpho-syntactic cue at different points within the sentence has not been undertaken in IWA. Moreover, such an investigation in aphasia has not yet been done considering data obtained from online methods, such as eye tracking. The present study utilised the visual-world paradigm (Tanenhaus et al., 1995), which has been found to be a suitable method to study sentence processing in aphasia (e.g., Adelt et al., 2017; Dickey et al., 2007; Hanne et al., 2015). Moreover, the visual-world paradigm is particularly suitable to investigate at which point in the time course of a sentence morpho-syntactic cues are used to resolve sentence meaning (Huettig et al., 2011). In our study, we combined the eye-tracking method with an auditory referent-identification task, which has been proven useful in studying the offline comprehension of relative clauses in IWA (Adelt et al., 2017; Nerantzini, Papadopoulou, et al., 2014; Varlokosta, Nerantzini, Papadopoulou, et al., 2014).

Based on previous research findings, we outline the following hypotheses: For healthy adults, offline comprehension of ORCs is at ceiling regardless of the disambiguating cue and the point of disambiguation. Since the controls' syntactic processing system is intact, we assumed that they will use the morpho-syntactic cues as soon as they become available (due to incremental sentence processing, e.g., Hanne et al., 2015; Schriefers et al., 1995) and do not have to rely on feature dissimilarity in terms of Relativized Minimality. Thus, response latencies as well as the change in the proportion of looks to the target picture are time-bound to the point of disambiguation with responses and fixations on the target picture occurring earlier in immediately case-marked compared to early case-marked ORCs, which are in turn processed faster than number-marked ORCs. Hence, in controls, we expect that sentence processing will be impacted by the varying timing of disambiguation. This means that earlier points of disambiguation result in earlier and possibly more efficient reanalysis.

For IWA, we expect impaired offline comprehension performance in all conditions in terms of lower accuracy rates and slower reaction times compared to healthy controls. If IWA were sensitive to dissimilarity of the number feature, we would expect more preserved comprehension performance on number-marked as compared to case-marked ORCs, a result which would be in line with the Relativized

Minimality approach. Moreover, comprehension accuracy and processing speed (in terms of reaction times and proportion of looks to the target picture) would be comparable in immediately and early disambiguated case-marked sentences, as the subject and object do not differ in number marking in both conditions. Concerning eye-movement data, we expect that the occurrence of Minimality effects is evidenced by a smaller or more delayed rise in looks to the target at the point of disambiguation (cf. Adelt et al., 2017; Sheppard et al., 2015). In contrast, if sentence processing in IWA was merely determined by timing, comprehension of case-marked ORCs would be better preserved than that of number-marked ORCs, which would comply with the predicted processing advantage of case-disambiguated sentences in controls. In addition, we predict that IWAs' processing of morpho-syntactic cues is delayed, as shown in previous studies (e.g., Burkhardt et al., 2008; Love et al., 2008). Therefore, we expect a delayed increase in the proportion of looks to the target picture as compared to controls (e.g., Dickey et al., 2007; Hanne et al., 2015).

6.2 Methods

6.2.1 Participants

We tested two groups of participants: Ten IWA (3 females) and 35 neurologically unimpaired adults as controls (19 females). Both participant groups were matched for age (M_{IWA} = 58.1, range = 43–75, M_{CONTROLS} = 58.4, range = 38–75, $t(13.9) = -0.1$, $p = .94$, independent t-test, two-tailed) and years of education (M_{IWA} = 14.6, M_{CONTROLS} = 16.0, t $(24.5) = -1.9$, $p = .06$, independent t-test, two-tailed). Table 6.1 provides demographic and neurological data about IWA. The Aachen Aphasia Test (Huber et al., 1983) was conducted to determine the type and severity of aphasia. To be included in the study, IWA had to demonstrate deficits in comprehending non-canonical sentences, assessed with a German sentence comprehension test (Burchert, Lorenz, Schröder, De Bleser, & Stadie, 2011).

Table 6.1

Participants with aphasia: Demographic and neurological data

Subject	Gender	Age (years)	Years of education	Years post-onset	Etiology	Localization	Handedness[1]	Aphasia type[2]	Severity (standard nine)[2]
P01	F	49	11.5	20	Ischemic CVA	L	R	Broca	Mild (6.0)
P02	M	60	15.0	2	Ischemic CVA	L	R	Broca	Moderate (4.8)
P03	M	62	17.0	20	Hemorrhagic CVA	R	L	Broca	Moderate (4.8)
P04	F	46	17.0	2	Ischemic CVA	L	R	Broca	Moderate (4.6)
P05	M	70	13.5	2	Ischemic CVA	L	R	Broca	Moderate (4.2)
P06	F	43	13.0	15	Ischemic CVA	L	R	Anomic	Mild (6.8)
P07	M	64	15.0	4	Ischemic CVA	L	R	Anomic	Mild (6.4)
P08	M	51	13.5	14	Ischemic CVA	L	R	Anomic	Mild (5.8)
P09	M	61	15.5	12	Ischemic CVA	L	R	Anomic	Mild (5.6)
P10	M	75	15.0	2	Ischemic CVA	L	R	Non-classifiable	Mild (6.6)

[1]Edinburgh Handedness Inventory (Oldfield, 1971), [2]Aachen Aphasia Test (Huber et al., 1983).

Note. F = female, M = male, CVA = cerebral vascular accident, L = left, R = right.

Control participants reported no history of neurological, language, or learning disorders. All participants were native speakers of German and (except for P03) right-handed, as evidenced by the Edinburgh Handedness Inventory (Oldfield, 1971). Moreover, all participants had normal or corrected-to-normal vision and auditory acuity. If needed, participants kept on their glasses/contact lenses or hearing aids during the experiment and pre-testing.

The local ethics committee approved the experiment and informed consent was obtained from all participants.

6.2.2 Materials

The material consisted of relative clause sentences that were presented auditorily and short video clips that were shown on a computer screen.

6.2.2.1 Target sentences

Sentence stimuli consisted of 48 ORCs as target sentences and 48 SRCs as filler sentences, yielding a total of 96 items.[13] All sentences were derived from eight transitive verbs denoting semantically reversible actions (e.g., kitzeln, *to tickle*), which were combined with two animate nouns (e.g., Esel, *donkey*; Hahn, *rooster*). All 32 nouns (8 feminine, 8 neuter, 16 masculine) were monomorphemic, mono- or bisyllabic, and denoted animals. Masculine nouns were always strong nouns, as they did not gain a final *-n* or *-en* in accusative case. Consequently, case marking occurred only on the determiner.

Target sentences were *where*-questions introducing a right-branching ORC. They were distributed across three conditions using different disambiguating points and cues: immediate disambiguation through case marking of the relative pronoun (5a), early disambiguation through case marking of the determiner of the embedded subject (5b), and late disambiguation through number marking of the sentence-final verb (5c). Each target structure was represented by 16 sentences. Table 6.2 presents an example of each target condition with its approximate English gloss and translation.

[13] The complete list of target and filler sentences can be found in Table B.1 in the Appendix.

Table 6.2

Experimental design

Condition	Sentence
Case – Immediate (5a)	Wo ist der Esel, **den** gerade der Hahn kitzelt? Where is the$_{nom\ sg}$ donkey that$_{acc\ sg}$ currently the$_{nom\ sg}$ rooster tickles$_{sg}$ *(Where is the donkey that the cock is currently tickling?)*
Case – Early (5b)	Wo ist das Schaf, das gerade **der** Igel kitzelt? Where is the$_{nom\ sg}$ sheep, that$_{nom/acc\ sg}$ currently the$_{nom\ sg}$ hedgehog tickles$_{sg}$ *(Where is the sheep that the hedgehog is currently tickling?)*
Number – Late (5c)	Wo ist das Reh, das gerade die Frösche kitzel**n**? Where is the$_{nom\ sg}$ deer, that$_{nom/acc\ sg}$ currently the$_{nom/acc\ pl}$ frogs tickle$_{pl}$ *(Where is the deer that the frogs are currently tickling?)*

Note. The disambiguation points are indicated in bold.

To create ORCs disambiguated immediately by case (5a), both noun phrases comprised masculine nouns in the singular. Both the relative pronoun and the determiner of the embedded subject were unambiguously case-marked: While the relative pronoun was marked for accusative case (*den*), the determiner was in nominative case (*der*). In ORCs disambiguated early by case (5b), the head of the relative clause contained a feminine or neuter noun in the singular, while the embedded subject referred to a masculine singular noun. Since the nominative and accusative forms of feminine and neuter relative pronouns are identical *(die* or *das*), these sentences were ambiguous between an SRC or ORC reading up to the determiner of the embedded subject. The determiner was unambiguously marked for nominative case (*der*). In ORCs disambiguated late through number (5c), the RC head contained feminine or neuter singular nouns (relative pronoun *die* or *das*). The noun in the embedded subject was masculine and plural-marked (determiner *die*). Verb inflection of the sentence-final verb disambiguated the syntactic structure. The verb was marked for plural (*waschen*), thus agreeing in person and number with the embedded subject.

Within each target sentence, the two nouns did not differ significantly in terms of their lemma frequency, as available from the German dlex database (www.dlexdb.de; Heister et al., 2011), their age of acquisition, typicality, and familiarity ratings (Schröder et al., 2012) (all $p > .39$, paired t-test, two-tailed).

Throughout the experiment, the same verb never co-occurred with the same pair of nouns and the same nouns were not paired more than once. Moreover, we ensured that within the same sentence nouns differed in their initial phoneme.

All sentences were recorded by a female native German speaker in a soundproof booth, using Audacity (version 2.0.5, audacityteam.org). Target sentences had a mean length of 4314 ms (*SD* = 136), with a mean speech rate of 3.26 syllables per second (*SD* = 0.26). Maximum amplitude of all sound files was normalised to −1 dB.

6.2.2.2 Filler sentences

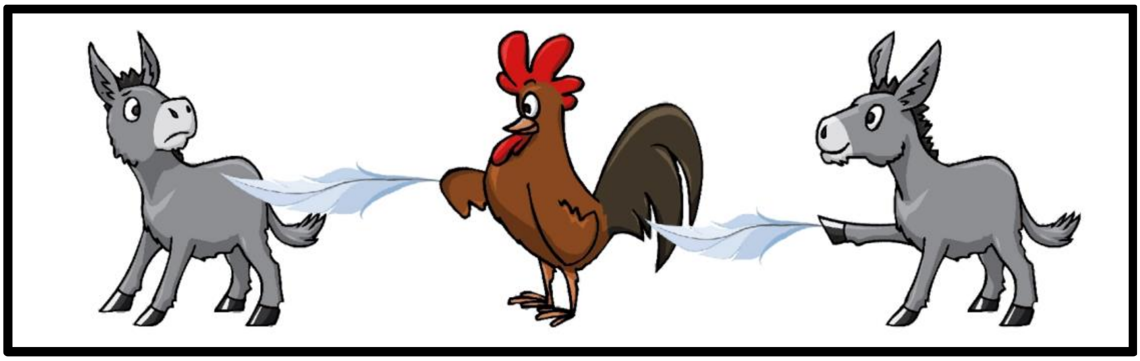
SRC equivalents of the target sentences were administered as fillers, resulting in three filler conditions, each represented by 16 sentences: SRCs disambiguated at the relative pronoun, SRCs disambiguated at the embedded object, and SRCs disambiguated at the sentence-final verb.

6.2.2.3 Video clips

Each sentence was paired with a short movie clip depicting semantically reversible events performed by cartoon animals. In each item, the animals were arranged as follows: One animal of type A (e.g., donkey) was presented on the left and on the right (referred to by the RC head noun). In the centre, an animal of type B appeared (e.g., rooster; referred to by the embedded noun phrase). In case-marked sentences, one animal of type B was presented, while there were two animals of type B in number-marked sentences. For example, a donkey was tickling a rooster, while the rooster was tickling another donkey (Figure 6.1). This scene was paired with the sentences in (5). Within one visual scene, all animals were of approximately the same size. All actions were performed with an instrument to ensure that the pictures of the animals did not overlap.

Figure 6.1

Sample of the visual display and auditory stimulus



Introduction: Hier ist ein Esel. Hier ist noch ein Esel. Und hier ist ein Hahn.
(Here is a donkey. Here is another donkey. And here is a rooster.)

Target sentence: Wo ist der Esel, den gerade der Hahn kitzelt?
(Where is the donkey that the rooster is currently tickling?)

6.2.3 Procedure

In an experimental setup previously applied by Adelt et al. (2017), participants performed an auditory referent-identification task. They had to select the picture which was referred to by the RC head noun as quickly and correctly as possible via button press with their non-dominant hand. Two pushbuttons served as response device, since the answer to the interrogative RC always referred to the outer left or outer right animal in the visual scene. In ORCs, the patient animal (donkey on the left in Figure 6.1) was the target picture (i.e. the correct response), whereas the agent animal (donkey on the right in Figure 6.1) was the distractor picture (i.e. the incorrect response).

Two lists were constructed such that the noun-verb combinations in the early case condition in the first list were presented in the number condition in the second list and vice versa. Items in the immediate case condition were presented in both lists. Half of the participants were exposed to one list and the other half were exposed to the other list. The order of items was pseudo-randomised within each list, while controlling for the target position. Moreover, we balanced the action direction (i.e. the spatial position of the agent animal in relation to the patient animal), which could go either from left to right or from right to left. Each item list was also presented in reversed sequence to control for item order.

We employed an SMI RED250 eye tracker with a sampling rate of 60 Hz to collect the participants' eye movements (binocular tracking, gaze position accuracy: 0.4°, tolerance for head movements: 40 × 40 × 20 cm), when the testing session took place at the laboratory. Participants were seated in a dimly lit room at a distance of approximately 60 cm in front of a computer monitor (screen size: 22'', resolution: 1680 × 1050), connected to the eye-tracking device. A portable SMI REDm eye-tracker (binocular tracking, gaze position accuracy: 0.5°, tolerance for head movements: 32 × 21 × 25 cm), connected to a laptop (screen size: 17'', resolution: 1600 × 900), was used when participants preferred to be tested at home. Stimuli were presented with SMI Experiment Center software (version 3.4, SensoMotoric Instruments GmbH, 2014).

For each item, a movie file was created using Adobe Flash Professional CS6 (version 12.0.2, Adobe Systems Incorporated, 2012). The structure of each item was as follows: Prior to each item, a fixation cross was shown at the centre of the screen for 500 ms. During the preamble of 6500 ms, the animals were named while they appeared on the screen one after another (see Figure 6.1). Animals in the middle of the scene always appeared last to centre participants' eye gaze before the animals began to move their instruments and heads for 2000 ms. Then, the sentence was presented auditorily, while the movie clip continued. After participants gave their response, presentation of the next item started. The movie clip ended 20 s after sentence onset. Hence, responses given later than this were considered missing data. At the beginning of the experimental session, the eye-tracker was calibrated for each participant. During a practice phase, all participants were familiarised with the task and the experimental procedure. Following this, calibration was repeated and the testing phase began. Re-calibration was carried out between items if required. After a block of 32 items, participants were given a break, following which calibration was repeated.

6.2.4 Data analysis

For statistical analysis, we used R (R Development Core Team, 2014) and the lmerTest package (Kuznetsova et al., 2017). To score the responses, we differentiated between correct and incorrect responses. If participants gave multiple responses, we always scored the first one. Reaction times were calculated as the time needed to give a response after sentence onset. For controls, only trials with correct responses in the referent-identification task entered the analysis of reaction time and eye-gaze data due to the small number of incorrect responses. In IWA, reaction times and eye-gaze data were analysed separately for correct and incorrect offline responses.

For the analysis of eye-gaze data, we determined two visual Areas of Interest (AoI): one for the target and one for the distractor picture. Fixations were calculated automatically by means of SMI BeGaze software (version 3.4, SensoMotoric Instruments GmbH, 2014). We measured the proportion of fixations on each AoI. Our dependent variable was the proportion of looks to the target picture (PLT).[14] PLT was aggregated across subjects and items for each of the following temporal Regions of Interest (RoI): "Where is", RC head, Pause, Relative pronoun (including the adverb *gerade*), Embedded subject (divided into two parts), Verb. The silence after sentence offset was divided into three silence regions of 600 ms each (Silence 1, 2, and 3) and a region including fixations later than 1800 ms after sentence offset (called *>1800*). After aggregation, PLT was transformed into empirical logit including prior weights following the procedure proposed by Barr (2008). Each RoI had a length of approximately 600 ms, whereby the temporal boundaries of each RoI were shifted 200 ms downstream to compensate for the time necessary for programming and executing eye movements (Allopenna et al., 1998; Altmann & Kamide, 2004).

Binary accuracy data were analysed using generalised linear mixed models fit by maximum likelihood with a logit link function. For statistical analyses of logarithmically transformed reaction times and eye-gaze data, we fit linear mixed-effect models with maximum likelihood. RoI, condition and group were treated as fixed factors. For all analyses, subjects and items were included as random intercepts. By-subject random slopes were added in the analyses, as long as they significantly improved model fit compared to an alternative model without them, indicated by log-likelihood comparisons. For the factor RoI, we applied successive difference contrast coding. From the second RoI onwards, PLT in each region was compared to the preceding one. For the factor group, we used treatment contrast, coding control participants as baseline. Hence, significant interactions between any

[14] PLT was calculated by dividing the looks to the target picture by the sum of looks to the target and distractor pictures.

factor and the factor group allowed us to infer that IWA were behaving differently from controls with respect to this effect. The factor condition was coded using Helmert contrast, thereby contrasting the second level (case – early) with the first (case – immediate), and the third (number – late) with the average of the first two, resulting in a comparison of case and number. The complete model outputs of all analyses including coefficient estimates, standard errors (*SE*), *z*- and *t*-scores, and their corresponding *p*-values, which were calculated based on Satterthwaite's approximation, are provided in Tables B.2-B.6 in the Appendix.

6.3 Results

6.3.1 Offline data – accuracy and reaction times

Table 6.3 provides the groups' mean proportion of correct responses in the referent-identification task to give the raw accuracy scores.

Table 6.3

Controls' and IWAs' mean proportion of correct responses in the referent-identification task. Standard deviations are provided in parentheses.

	Accuracy	
Condition	Controls	IWA
Case – Immediate	0.951 (0.261)	0.551 (0.499)
Case – Early	0.962 (0.190)	0.616 (0.488)
Number – Late	0.879 (0.326)	0.510 (0.502)

Note. IWA = individuals with aphasia

As expected, IWA performed significantly less accurately than controls ($p < .001$, see Table B.2). We found no significant effect within case conditions ($p = .348$), which also did not interact with the factor group ($p = .987$). This indicates that both participant groups show similar comprehension accuracy in both case conditions. In contrast, there was a significant difference between the case and number conditions in controls ($p < .001$), with higher accuracy on ORCs disambiguated by case compared to number. Moreover, this contrast interacted with the factor group

($p < .001$): Post-hoc analysis of this interaction revealed that IWAs' comprehension accuracy in the case and number conditions did not differ significantly ($p = .112$).

Additionally, we analysed IWAs' mean proportion of correct responses on the referent-identification task using the binomial statistic. This allowed us to compare the group's performance to chance for each condition. Comparison to chance revealed that comprehension of immediately case-disambiguated ($z = 1.27$, $p = .2$) and late number-disambiguated ORCs ($z = 0.24$, $p = .81$) was within chance range, whereas performance on early case-disambiguated ORCs was above chance ($z = 2.93$, $p < .01$).

In Table 6.4, we provide mean reaction times. Overall, response latencies were significantly longer in IWA than in controls ($p < .001$, see Table B.3). We found no significant effect within case conditions ($p = .146$) and no interaction with the factor group ($p = .754$): Both groups exhibited comparable response latencies for ORCs in the immediate and early case conditions. With respect to the contrast between case and number, we found significantly longer reaction times in ORCs disambiguated by number in controls ($p < .001$) and IWA ($p = .03$). However, this effect was pronounced less strongly in IWA, as indicated by a significant condition by group interaction ($p = .002$). A separate model fit to the IWAs' reaction time data and including accuracy as a predictor revealed no effect of accuracy, showing that IWA were slower than controls irrespective of response accuracy (see Table B.4).

Table 6.4

Controls' and IWAs' reaction times by accuracy in the referent-identification task. Standard deviations are provided in parentheses.

	Controls	IWA	
Condition	Correct	Correct	Incorrect
Case – Immediate	4774 (791)	6505 (1828)	6503 (1578)
Case – Early	4858 (817)	6454 (1897)	6668 (2164)
Number – Late	5330 (860)	6866 (2218)	6813 (2368)

Note. IWA = individuals with aphasia

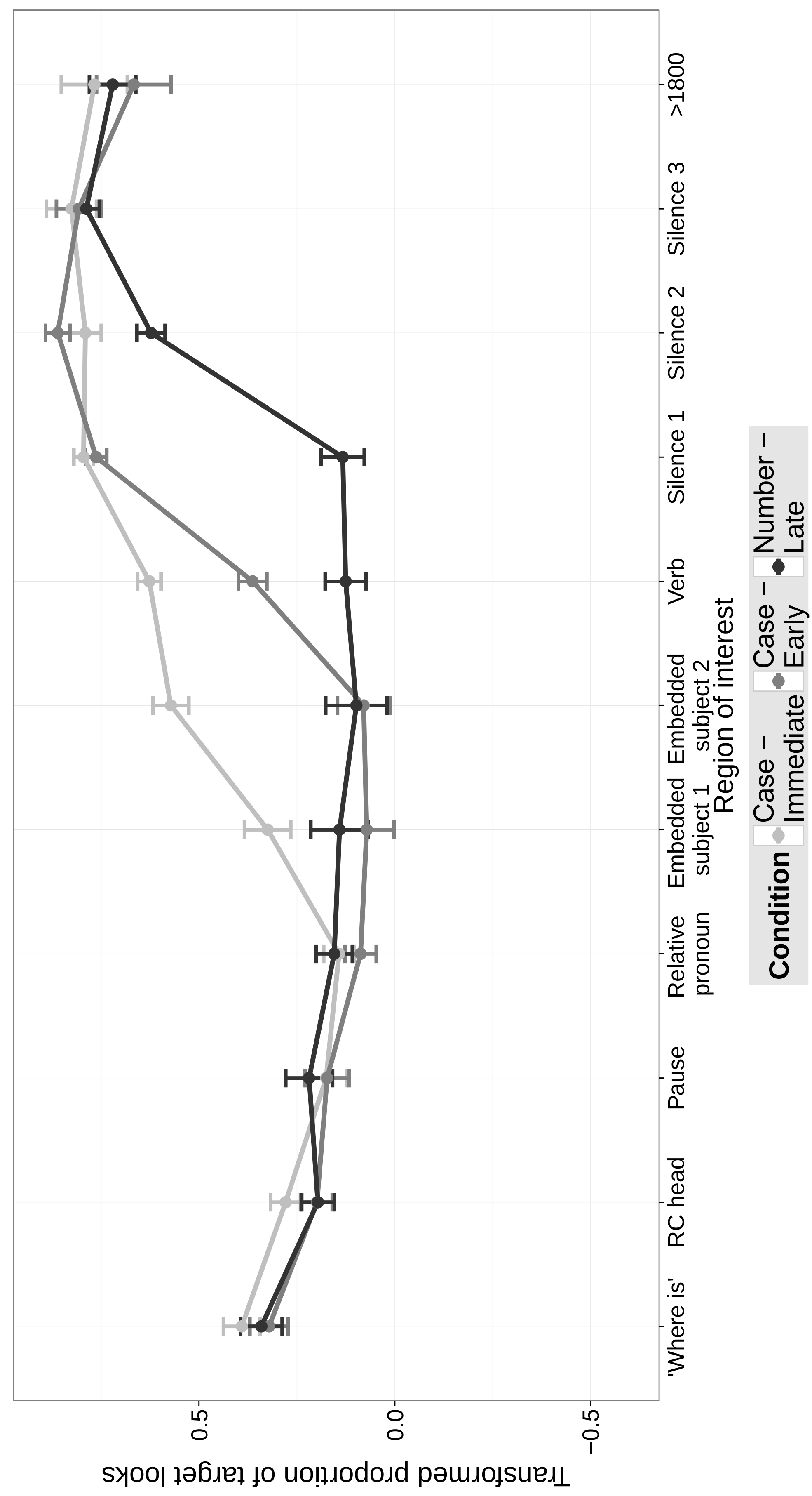
6.3.2 Online data – eye movements

Figures 6.2 and 6.3 display the controls' and IWAs' eye-gaze data. For controls, we only present online data when the offline response was correct, whereas we divide the IWAs' online data with respect to response accuracy. Due to track loss of more than 50% during the analysed RoI, 10 individual items (i.e. less than 1% of the data) had to be excluded from the analysis.

For controls' correct responses, we found a main effect of RoI, with decreasing PLT at the RC head ($p < .001$, see Table B.5). Moreover, PLT increased significantly at the verb and at Silence 1 and 2 ($p = .006$, $p < .001$, and $p < .001$, respectively). This indicates that control participants tended to look at the distractor picture at the beginning of the sentence but looked at the target at the end and after sentence offset. With respect to the main effect of condition, we found a significant difference in PLT within case conditions ($p = .005$), as well as between case and number conditions ($p < .001$). Furthermore, there was a significant interaction between RoI and the condition factor (immediate vs. early case condition): During the regions Embedded subject 1 and 2 (RoI5-4: $p = .022$, RoI6-5: $p = .017$), the increase in PLT was stronger in immediately case-disambiguated ORCs compared to early case-disambiguated ORCs. In contrast, at the verb and at Silence 1 (RoI7-6: $p = .016$, RoI8-7: $p = .004$), the pattern was reversed, with a stronger increase in PLT in the early case condition compared to the immediate case condition. Moreover, the difference between case and number interacted with RoI: PLT increased significantly faster in ORCs in the case conditions during Silence 1 (RoI8-7: $p < .001$). Conversely, the rise in PLT was stronger in number-marked ORCs as compared to case-marked ORCs during Silence 2 and 3 (RoI9-8: $p < .001$, RoI10-9: $p = .033$).

Figure 6.2

Controls' proportion of target looks (transformed to empirical logit) within the Regions of Interest for analysis, divided by condition.

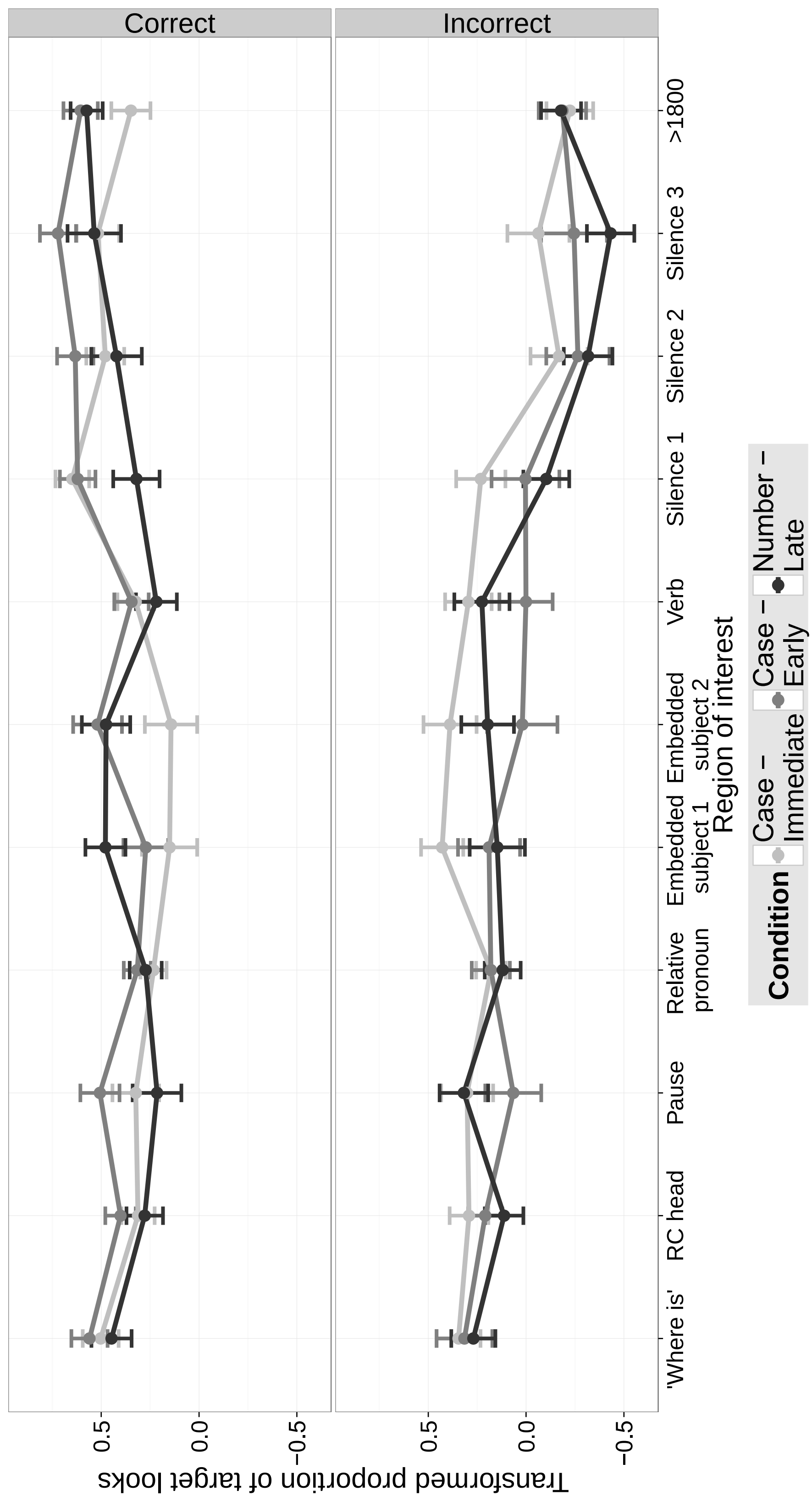


As indicated by a significant RoI by group interaction, there was no increase in the overall PLT at the verb in IWAs' correct responses, contrary to controls (RoI7-6: $p = .042$). However, PLT in IWA increased significantly at Silence 1 (RoI8-7: $p = .007$). Moreover, while PLT increased strongly in controls at Silence 2, it remained unchanged in IWA, as shown by significant RoI by group interactions (RoI9-8: $p = .026$). Furthermore, the factors group and the contrast within case conditions interacted significantly ($p < .001$): There was an overall higher PLT in the early case condition compared to the immediate case condition in IWA, whereas the pattern was reversed in controls. However, the group factor did not interact with the condition factor with respect to the contrast between case and number ($p = .129$), indicating that PLT was higher in case-disambiguated than in number-disambiguated ORCs in controls, whereby IWA did not differ significantly. Additionally, RoI, the contrast between case conditions, and group interacted significantly: At the Embedded subject 2, PLT remained stable in the immediate case condition in IWA as well as in the early case condition in controls, while it increased in the respective other case condition (RoI6-5: $p = .049$). Moreover, PLT rose at the verb region for immediately case-disambiguated ORCs and slightly decreased for early case-disambiguated ORCs, whereas PLT in controls increased in both case conditions, albeit more strongly in early case-disambiguated ORCs (RoI7-6: $p = .018$).

Comparing IWAs' correct and incorrect responses resulted in a significant effect of accuracy, with higher PLT in correct than incorrect responses ($p < .001$, see Table B.6). In correct responses, we found main effects of RoI, with decreasing PLT at the RC head ($p = .03$) and increasing PLT at Silence 1 ($p = .007$). Furthermore, accuracy interacted with the factor RoI: While PLT rose at Silence 1 in correct responses, it decreased in incorrect responses (RoI8-7: $p = .008$). Moreover, PLT remained stable in correct responses at Silence 2, whereas it significantly decreased in incorrect trials (RoI9-8: $p = .04$). Additionally, the interaction between condition regarding both case conditions and accuracy ($p < .001$) indicates that PLT was higher in the immediate compared to the early case condition in incorrect responses, whereas this difference was found to be in the opposite direction in IWAs' correct responses.

Figure 6.3

IWAs' proportion of target looks (transformed to empirical logit) within the Regions of Interest for analysis, divided by condition and response accuracy in the referent-identification task.



6.4 Discussion

The present study investigated offline and online processing of non-canonical ORCs in German-speaking healthy adults and IWA by measuring accuracy data, reaction times, and eye-movements. Therefore, we administered a visual-world experiment embedded within an auditory referent-identification task. We hereby intended to evaluate whether processing of case- and number-disambiguated ORCs is affected by Relativized Minimality (Belletti et al., 2012; Friedmann et al., 2017; Rizzi, 1990). This approach predicts that processing of ORCs involving dissimilar number specification of the embedded subject and the moved object (as in number-disambiguated ORCs) is less demanding as compared to ORCs with identical number marking of subject and object (as in case-marked ORCs). Furthermore, we considered that sentence processing is influenced by the relative position of the disambiguation point, yielding processing of case-disambiguated ORCs easier as compared to number-disambiguated ORCs because of the earlier occurrence of the case cue within the sentence. Within case-disambiguated ORCs, this account predicts more accurate and faster processing of immediately than of early disambiguated ORCs. All target ORCs were temporarily ambiguous and varied with respect to specific morpho-syntactic cues (case vs. number). Additionally, case disambiguated the sentence at two different positions. Thus, we were able to determine whether a processing advantage is restricted to one type of morpho-syntactic cues or whether ORC processing is determined by timing. In the following, we will first discuss the results for healthy adults, before reviewing the findings from IWA.

6.4.1 Healthy adults

Given the findings from previous studies on ORC processing in healthy speakers, higher demands in processing ORCs were expected to be observed in reaction time and eye-gaze data, but not in terms of accuracy (Caplan et al., 2007; Dickey & Thompson, 2009). Interestingly, though, while participants scored at ceiling on both types of case-disambiguated ORCs in the referent-identification task, we found a significant drop in performance in number-disambiguated ORCs. Similarly, controls responded faster in case- than in number-marked ORCs, with no significant difference between immediately and early case-disambiguated ORCs. Contrary to the hypothesis proposed by Friederici et al. (1998) that sentence processing is determined by the varying length of the ambiguity in temporarily ambiguous sentences, we observed no significant difference in accuracy rates and response times between immediate and early disambiguation through case marking. Rather, the general processing advantage of case over number marking can be attributed to the fact that case information is a more reliable cue than number to reanalyse the initial misinterpretation of temporarily ambiguous ORCs (Wulfeck et al., 1991), as case marking provides direct information about who did what to whom. An alternative hypothesis to explain more accurate and faster responses in case-marked ORCs has been proposed by Meng and Bader (2000) and Arosio et al. (2012), which is based on the diagnosis and repair model developed by Fodor and Inoue (2000). Since healthy speakers assume a subject-initial reading of temporarily ambiguous sentences (see, for example, Bader & Meng, 1999), they have to reanalyse the structure as soon as they encounter the morpho-syntactic cue indicating the non-canonical syntactic structure. Following Fodor and Inoue (2000), participants include the disambiguating phrase into the structure they have built until this point. However, this syntactic structure results in ungrammaticality, which has to be resolved through reanalysis. According to Fodor and Inoue (2000), the case advantage is attributed to the fact that case provides an effective cue for how to rebuild the structure. In contrast, revising number-disambiguated ORCs is more demanding, because number information is only given after both verb arguments have already been integrated into the structure (see Arosio et al., 2012, for a detailed analyses of the individual steps during reanalysis). This processing advantage of earlier as opposed to late morphological cues to reanalysis is also supported by findings in studies investigating artificial language learning in adults (Pozzan & Trueswell, 2015) and language acquisition (Trueswell et al., 2012).[15]

In this context, the analysis of the online eye-gaze data further corroborates this assumption. The significant decrease in PLT during the ambiguous parts of the sentence (i.e. during the RC head) indicates that control participants initially entertain a subject-first interpretation. However, this interpretation turns out to be incorrect in ORCs as soon as the disambiguating cue is presented. With respect to the difference between varying disambiguation points, our online data suggest that

[15] We thank an anonymous reviewer for raising this issue and pointing out the similarities between our results and language learning in children and adults.

reanalysing case-marked ORCs is easier compared to number-marked ORCs. This is evidenced by the differential rising patterns in PLT after the disambiguating cue is provided. In the immediate case conditions, the increase in PLT occurs immediately after the disambiguating region (i.e. following the relative pronoun), indicating that participants start to fixate on the target picture as soon as the relevant morpho-syntactic cue becomes available (i.e. incremental sentence processing; e.g., Hanne et al., 2015; Schriefers et al., 1995). Yet, due to the presence of the adverb "gerade" between the case-marked relative pronoun and the determiner of the embedded subject, it is not possible to unequivocally determine the exact processing speed of case information. In early disambiguated ORCs, participants appear to defer their decision until the complete presentation of the embedded subject, as evidenced by a rising PLT at the verb region. Moreover, the increase in PLT in number-marked ORCs is delayed by one temporal RoI (i.e. by about 600 ms[16]). If number marking was processed at the same speed as case marking at the relative pronoun, PLT should rise significantly after the sentence-final verb was presented. Contrary to this prediction, we observed a significant increase in PLT only 600 ms after sentence offset. In accordance with Sekerina, Campanelli, and Van Dyke (2016), this late but great increase in PLT might also reflect repair processes after encountering the sentence-final verb. Once healthy speakers have realised that their initial interpretation of number-marked ORCs is incorrect, they seem to verify their reanalysed interpretation before giving the offline response.

Taken together, our data corroborate the hypothesis that case and number differ regarding the ease with which the misanalysed syntactic structure can be fixed. Since we found hardly any difference between immediately and early disambiguated case-marked ORCs, our data suggest that the processing advantage of case over number marking is not an artefact due to an earlier disambiguation point. Hence, healthy speakers can make direct use of morpho-syntactic cues to determine sentence meaning, which causes faster and less effortful processing of case compared to number marking.

[16] Please note that due to aggregation across RoIs the time intervals for analysing the eye-movement data were 600 ms long. A more fine-grained analysis with time as a continuous variable would provide additional insight into the time course of processing case and number information in healthy speakers.

6.4.2 IWA

In line with our predictions, participants with aphasia performed less accurately and responded more slowly than healthy controls across all conditions. Similar to controls, IWA displayed no significant difference between immediately and early case-disambiguated ORCs. However, unlike controls, IWAs' comprehension was equally impaired in ORCs disambiguated by case and number marking, resulting in a non-significant difference between these two conditions. This finding replicates results reported by Adelt et al. (2017), who found comparable accuracy rates on these types of sentences. Moreover, our findings cannot be traced back to the application of a linear subject-first strategy, as comprehension accuracy ranged within or above chance in all conditions. In line with the findings reported by Friedmann et al. (2010), this indicates that IWA are sensitive to morpho-syntactic cues. In contrast to Friedmann et al., we observed above-chance performance on early case-disambiguated ORCs. This result points towards the IWAs', albeit fragile, ability to make successful use of the case cue when the relative pronoun is ambiguous with respect to case marking and the embedded subject is unambiguously marked for nominative case. This finding can be captured neither by the Relativized Minimality approach nor by an account suggesting that IWAs' sentence comprehension benefits from earlier disambiguation within the sentence.

Considering reaction times, like in controls, response latencies did not differ between immediately and early case-disambiguated ORCs, whereas responses to number-marked ORCs took significantly longer than to case-marked ORCs. Although accuracy and reaction time data do not show a clear and uniform pattern, there is some evidence in our offline data that case and number have a differential impact on processing ORCs. Taken together, our offline accuracy and reaction time data support the previous finding of better preserved comprehension of case marking compared to number marking in aphasia (Burchert et al., 2003). Moreover, our results extend those reported by Hanne et al. (2015), although they report less impaired performance on number-marked than on case-marked sentences. These diverging results can be attributed to the fact that Hanne et al. (2015) investigated non-canonical active sentences with object-verb-subject word order, while we presented IWA with ORCs with object-subject-verb order. Due to the verb being at the second position of the active sentence, it can be integrated into the syntactic structure before the verb arguments (cf. Fodor & Inoue, 2000), making a reanalysis unnecessary. By contrast, in German ORCs, the verb is presented sentence-finally after both verb arguments have been processed and integrated into the syntactic structure. Hence, the relative position of the verb (and thereby also the number cue) compared to the verb arguments appears to be crucial.

Regarding IWAs' eye-gaze data, we found no evidence of an online processing advantage neither for case nor for number. Other than in controls, we did not observe a time-bound increase in PLT associated with the point of disambiguation in IWA, which implies that IWA do not process disambiguating morpho-syntactic cues incrementally. This missing effect might be ascribed to the fact that IWA seem to delay their decision until sentence offset, as evidenced by a significant increase in PLT at Silence 1. This finding is in line with the results reported by Hanne et al. (2015) and Schumacher et al. (2015), who provide evidence of delayed integration of morpho-syntactic cues in the processing of non-canonical German sentences. Obviously, this delay affects all ORCs to the same degree, as the conditions do not differ significantly.

One finding that merits discussion is the rise in PLT at the second embedded subject region in early case-disambiguated ORCs, while PLT remained stable in immediately case-disambiguated ORCs. Interestingly, though, this effect was in the opposite direction in controls. It can be argued that, contrary to controls, IWA cannot make use of case information in the immediate condition, because it occurs too early. However, the PLT increase following the presentation of the unambiguously case-marked subject implies that IWA are capable of incremental sentence processing to some extent in early disambiguated ORCs. This may also explain why ORCs in the early case condition were comprehended slightly more accurately compared to the other conditions. Furthermore, in line with the observation of within and above chance performance in the offline task, online eye-gaze data support the assumption that IWA do not pursue a subject-first strategy for interpreting non-canonical ORCs. Even though there was a significant decrease in PLT at the RC head noun, indicating an initial subject-first interpretation, IWA displayed a general advantage for the target picture throughout the sentence. This finding speaks against a subject-first bias, as PLT should decline more strongly if IWA were applying such a heuristic strategy.

The finding of slightly more accurate and faster processing of case-marked compared to number-marked ORCs implies that IWA do not benefit from number dissimilarity in number-marked ORCs – contrary to the predictions of the Relativized Minimality approach (Belletti et al., 2012; Friedmann et al., 2017). IWA seem to have particular difficulties in comprehending number-marked ORCs. However, unlike Friedmann et al. (2017), we argue that IWA can make use of unambiguous case marking to distinguish the moved object and the embedded subject in case-marked ORCs. Hence, similar to controls, IWA seem to rank unambiguous case marking (particularly of the subject) higher during sentence processing as compared to the potential effect of number dissimilarity. Yet, this conclusion does not unequivocally disprove the Relativized Minimality account. Although this account predicts better preserved sentence comprehension in case of a higher degree of feature dissimilarity, it does not argue against the effect of other factors such as the length of ambiguity. Hence, future research is needed to further disentangle the status of case and number in the computation of Minimality. Clearly, future studies should compare similarly difficult syntactic structures with case and number cues at the same position within the sentence in order to rule out any other confounds. Since we observed no significant differences between both types of case-marked ORCs in terms of accuracy and response times in IWA, there is evidence that case and number constitute distinct types of morpho-syntactic cues. This finding can be explained by Fodor and Inoue's (2000) diagnosis and repair model. The data suggest that IWA, like controls, might be sensitive to the effectiveness of morpho-syntactic cues in the reanalysis of syntactic structures. As pointed out by Fodor and Inoue, case is assumed to be a more informative cue regarding reanalysis, since the case cue is provided before both verb arguments are integrated into the syntactic structure. Conversely, the number cue occurs after the integration of the verb arguments, rendering it a less informative cue.

Besides the discussion about the differential effect of case and number marking, our data additionally contribute to the issue of erroneous online sentence processing in aphasia. In ORCs comprehended incorrectly, we observed an overall decrease in PLT starting after the end of the sentence. This suggests that IWA do not pursue a guessing strategy. If IWA were guessing, the eye-gaze pattern would not vary as a function of accuracy in the referent-identification task. Instead, since the increase in PLT in correct responses and the decrease in incorrect responses occur at the same time, we hypothesise that as soon as the presentation of the sentence is finished, IWA either fixate on the target picture, resulting in an accurate sentence interpretation, or they shift their gaze towards the distractor picture, which leads to an incorrect subject-first interpretation. Although the effect occurs after sentence offset in all conditions of non-canonical sentences, we conclude that incorrect responses are the result of delayed misinterpretations of morpho-syntactic cues. Successful processing is intermittently disrupted due to reduced processing capacities devoted to sentence processing in aphasia, which is in accordance with the intermittent deficiency account proposed by Hanne, Sekerina, Vasishth, Burchert, and De Bleser (2011). Following this account, IWA have to resort to heuristics to determine sentence meaning. Consequently, treatment of impaired sentence processing (Mapping Treatment; e.g., Kiran et al., 2012; Schwartz et al., 1994; Treatment of Underlying Forms; e.g., Stadie et al., 2008; Thompson & Shapiro, 2005) should focus on the sensitivity to morpho-syntactic cues to improve comprehension of non-canonical sentences in aphasia.

To conclude, we investigated the processing of German case- and number-disambiguated ORCs in healthy speakers and IWA. Altogether, our results support the assumption that case and number cues affect sentence processing differently and that case-marked sentences are easier to process than number-marked sentences, which can be attributed to the fact that case provides a more effective cue to sentence processing as compared to number.

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APPENDIX A

FEATURE DISSIMILARITIES IN THE PROCESSING OF GERMAN RELATIVE CLAUSES IN APHASIA

Table A.1

Full list of target sentences and their English translation

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
SRC	Full DP	Number	1	Wo ist die Ente, die die Käfer fängt? *Where is the duck that is catching the beetles?*
				Wo ist das Schaf, das die Hähne fängt? *Where is the sheep that is catching the roosters?*
				Wo ist die Kuh, die die Panther kämmt? *Where is the cow that is combing the panthers?*
				Wo ist das Küken, das die Tiger kämmt? *Where is the chick that is combing the tigers?*
				Wo ist das Kamel, das die Hamster kitzelt? *Where is the camel that is tickling the hamsters?*
				Wo ist die Maus, die die Vögel kitzelt? *Where is the mouse that is tickling the birds?*
				Wo ist die Biene, die die Igel misst? *Where is the bee that is measuring the hedgehogs?*
				Wo ist das Pony, das die Frösche misst? *Where is the pony that is measuring the frogs?*
				Wo ist das Reh, das die Füchse ruft? *Where is the deer that is calling the foxes?*
				Wo ist die Ziege, die die Hunde ruft? *Where is the goat that is calling the dogs?*
				Wo ist die Robbe, die die Krebse schlägt? *Where is the seal that is hitting the crabs?*
				Wo ist das Schwein, das die Fische schlägt? *Where is the pig that is hitting the fish?*
				Wo ist die Eule, die die Esel sticht? *Where is the owl that is poking the donkeys?*
				Wo ist das Zebra, das die Wölfe sticht? *Where is the zebra that is poking the wolves?*
				Wo ist die Katze, die die Dinos wäscht? *Where is the cat that is washing the dinosaurs?*
				Wo ist das Lama, das die Haie wäscht? *Where is the lama that is washing the sharks?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
SRC	Full DP	Number	2	Wo ist die Katze, die die Füchse fängt? *Where is the cat that is catching the foxes?*
				Wo ist das Lama, das die Krebse fängt? *Where is the lama that is catching the crabs?*
				Wo ist die Maus, die die Hamster kämmt? *Where is the mouse that is combing the hamsters?*
				Wo ist das Zebra, das die Esel kämmt? *Where is the zebra that is combing the donkeys?*
				Wo ist die Biene, die die Fische kitzelt? *Where is the bee that is tickling the fish?*
				Wo ist das Schwein, das die Wölfe kitzelt? *Where is the pig that is tickling the wolves?*
				Wo ist das Kamel, das die Panther misst? *Where is the camel that is measuring the panthers?*
				Wo ist die Ziege, die die Käfer misst? *Where is the goat that is measuring the beetles?*
				Wo ist die Kuh, die die Tiger ruft? *Where is the cow that is calling the tigers?*
				Wo ist das Küken, das die Dinos ruft? *Where is the chick that is calling the dinosaurs?*
				Wo ist die Ente, die die Igel schlägt? *Where is the duck that is hitting the hedgehogs?*
				Wo ist das Pony, das die Haie schlägt? *Where is the pony that is hitting the sharks?*
				Wo ist das Reh, das die Vögel sticht? *Where is the deer that is poking the birds?*
				Wo ist die Robbe, die die Hähne sticht? *Where is the seal that is poking the roosters?*
				Wo ist die Eule, die die Frösche wäscht? *Where is the owl that is washing the frogs?*
				Wo ist das Schaf, das die Hunde wäscht? *Where is the sheep that is washing the dogs?*
SRC	Full DP	Case	1	Wo ist der Igel, der den Käfer fängt? *Where is the hedgehog that is catching the beetle?*
				Wo ist der Tiger, der den Hund fängt? *Where is the tiger that is catching the dog?*
				Wo ist der Hamster, der den Fuchs kämmt? *Where is the hamster that is combing the fox?*
				Wo ist der Panther, der den Hahn kämmt? *Where is the panther that is combing the rooster?*
				Wo ist der Esel, der den Fisch kitzelt? *Where is the donkey that is tickling the fish?*
				Wo ist der Fuchs, der den Panther kitzelt? *Where is the fox that is tickling the panther?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist der Krebs, der den Esel misst? *Where is the crab that is measuring the donkey?*
				Wo ist der Wolf, der den Frosch misst? *Where is the wolf that is measuring the frog?*
				Wo ist der Frosch, der den Wolf ruft? *Where is the frog that is calling the wolf?*
				Wo ist der Hai, der den Vogel ruft? *Where is the shark that is calling the bird?*
				Wo ist der Dino, der den Igel schlägt? *Where is the dinosaur that is hitting the hedgehog?*
				Wo ist der Hund, der den Krebs schlägt? *Where is the dog that is hitting the crab?*
				Wo ist der Hahn, der den Dino sticht? *Where is the rooster that is poking the dinosaur?*
				Wo ist der Käfer, der den Hai sticht? *Where is the beetle that is poking the shark?*
				Wo ist der Fisch, der den Hamster wäscht? *Where is the fish that is washing the hamster?*
				Wo ist der Vogel, der den Tiger wäscht? *Where is the bird that is washing the tiger?*
SRC	Full DP	Case	2	Wo ist der Hahn, der den Esel fängt? *Where is the rooster that is catching the donkey?*
				Wo ist der Wolf, der den Fuchs fängt? *Where is the wolf that is catching the fox?*
				Wo ist der Esel, der den Hund kämmt? *Where is the donkey that is combing the dog?*
				Wo ist der Tiger, der den Vogel kämmt? *Where is the tiger that is combing the bird?*
				Wo ist der Hund, der den Igel kitzelt? *Where is the dog that is tickling the hedgehog?*
				Wo ist der Vogel, der den Hai kitzelt? *Where is the bird that is tickling the shark?*
				Wo ist der Hai, der den Panther misst? *Where is the shark that is measuring the panther?*
				Wo ist der Käfer, der den Fisch misst? *Where is the beetle that is measuring the fish?*
				Wo ist der Dino, der den Tiger ruft? *Where is the dinosaur that is calling the tiger?*
				Wo ist der Igel, der den Hahn ruft? *Where is the hedgehog that is calling the rooster?*
				Wo ist der Fisch, der den Käfer schlägt? *Where is the fish that is hitting the beetle?*
				Wo ist der Fuchs, der den Hamster schlägt? *Where is the fox that is hitting the hamster?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist der Hamster, der den Wolf sticht? *Where is the hamster that is poking the wolf?*
				Wo ist der Krebs, der den Frosch sticht? *Where is the crab that is poking the frog?*
				Wo ist der Frosch, der den Dino wäscht? *Where is the frog that is washing the dinosaur?*
				Wo ist der Panther, der den Krebs wäscht? *Where is the panther that is washing the crab?*
SRC	Pronoun	Number	1	Wo ist die Maus, die sie fängt? *Where is the mouse that is catching them?*
				Wo ist das Reh, das sie fängt? *Where is the deer that is catching them?*
				Wo ist die Eule, die sie kämmt? *Where is the owl that is combing them?*
				Wo ist das Lama, das sie kämmt? *Where is the lama that is combing them?*
				Wo ist die Kuh, die sie kitzelt? *Where is the cow that is tickling them?*
				Wo ist das Zebra, das sie kitzelt? *Where is the zebra that is tickling them?*
				Wo ist die Katze, die sie misst? *Where is the cat that is measuring them?*
				Wo ist das Schwein, das sie misst? *Where is the pig that is measuring them?*
				Wo ist das Kamel, das sie ruft? *Where is the camel that is calling them?*
				Wo ist die Robbe, die sie ruft? *Where is the seal that is calling them?*
				Wo ist die Biene, die sie schlägt? *Where is the bee that is hitting them?*
				Wo ist das Schaf, das sie schlägt? *Where is the sheep that is hitting them?*
				Wo ist das Küken, das sie sticht? *Where is the chick that is poking them?*
				Wo ist die Ziege, die sie sticht? *Where is the goat that is poking them?*
				Wo ist die Ente, die sie wäscht? *Where is the duck that is washing them?*
				Wo ist das Pony, das sie wäscht? *Where is the pony that is washing them?*
SRC	Pronoun	Number	2	Wo ist die Biene, die sie fängt? *Where is the bee that is catching them?*
				Wo ist das Pony, das sie fängt? *Where is the pony that is catching them?*

Table A.1 (continued)

Condition RC type	 Embedded constituent type	 Disambi-guating feature	 List	 Item English translation
				Wo ist die Katze, die sie kämmt? *Where is the cat that is combing them?*
				Wo ist das Reh, das sie kämmt? *Where is the deer that is combing them?*
				Wo ist das Küken, das sie kitzelt? *Where is the chick that is tickling them?*
				Wo ist die Ziege, die sie kitzelt? *Where is the goat that is tickling them?*
				Wo ist die Maus, die sie misst? *Where is the mouse that is measuring them?*
				Wo ist das Zebra, das sie misst? *Where is the zebra that is measuring them?*
				Wo ist die Ente, die sie ruft? *Where is the duck that is calling them?*
				Wo ist das Schaf, das sie ruft? *Where is the sheep that is calling them?*
				Wo ist die Eule, die sie schlägt? *Where is the owl that is hitting them?*
				Wo ist das Lama, das sie schlägt? *Where is the lama that is hitting them?*
				Wo ist die Kuh, die sie sticht? *Where is the cow that is poking them?*
				Wo ist das Schwein, das sie sticht? *Where is the pig that is poking them?*
				Wo ist das Kamel, das sie wäscht? *Where is the camel that is washing them?*
				Wo ist die Robbe, die sie wäscht? *Where is the seal that is washing them?*
SRC	Pronoun	Case	1	Wo ist der Esel, der ihn fängt? *Where is the donkey that is catching him?*
				Wo ist der Fuchs, der ihn fängt? *Where is the fox that is catching him?*
				Wo ist der Hund, der ihn kämmt? *Where is the dog that is combing him?*
				Wo ist der Vogel, der ihn kämmt? *Where is the bird that is combing him?*
				Wo ist der Hai, der ihn kitzelt? *Where is the shark that is tickling him?*
				Wo ist der Igel, der ihn kitzelt? *Where is the hedgehog that is tickling him?*
				Wo ist der Fisch, der ihn misst? *Where is the fish that is measuring him?*
				Wo ist der Panther, der ihn misst? *Where is the panther that is measuring him?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist der Hahn, der ihn ruft? *Where is the rooster that is calling him?*
				Wo ist der Tiger, der ihn ruft? *Where is the tiger that is calling him?*
				Wo ist der Hamster, der ihn schlägt? *Where is the hamster that is hitting him?*
				Wo ist der Käfer, der ihn schlägt? *Where is the beetle that is hitting him?*
				Wo ist der Frosch, der ihn sticht? *Where is the frog that is poking him?*
				Wo ist der Wolf, der ihn sticht? *Where is the wolf that is poking him?*
				Wo ist der Dino, der ihn wäscht? *Where is the dinosaur that is washing him?*
				Wo ist der Krebs, der ihn wäscht? *Where is the crab that is washing him?*
SRC	Pronoun	Case	2	Wo ist der Hund, der ihn fängt? *Where is the dog that is catching him?*
				Wo ist der Käfer, der ihn fängt? *Where is the beetle that is catching him?*
				Wo ist der Fuchs, der ihn kämmt? *Where is the fox that is combing him?*
				Wo ist der Hahn, der ihn kämmt? *Where is the rooster that is combing him?*
				Wo ist der Fisch, der ihn kitzelt? *Where is the fish that is tickling him?*
				Wo ist der Panther, der ihn kitzelt? *Where is the panther that is tickling him?*
				Wo ist der Esel, der ihn misst? *Where is the donkey that is measuring him?*
				Wo ist der Frosch, der ihn misst? *Where is the frog that is measuring him?*
				Wo ist der Vogel, der ihn ruft? *Where is the bird that is calling him?*
				Wo ist der Wolf, der ihn ruft? *Where is the wolf that is calling him?*
				Wo ist der Igel, der ihn schlägt? *Where is the hedgehog that is hitting him?*
				Wo ist der Krebs, der ihn schlägt? *Where is the crab that is hitting him?*
				Wo ist der Dino, der ihn sticht? *Where is the dinosaur that is poking him?*
				Wo ist der Hai, der ihn sticht? *Where is the shark that is poking him?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist der Hamster, der ihn wäscht? *Where is the hamster that is washing him?*
				Wo ist der Tiger, der ihn wäscht? *Where is the tiger that is washing him?*
ORC	Full DP	Number	1	Wo ist die Katze, die die Füchse fangen? *Where is the cat that the foxes are catching?*
				Wo ist das Lama, das die Krebse fangen? *Where is the lama that the crabs are catching?*
				Wo ist die Maus, die die Hamster kämmen? *Where is the mouse that the hamsters are combing?*
				Wo ist das Zebra, das die Esel kämmen? *Where is the zebra that the donkeys are combing?*
				Wo ist die Biene, die die Fische kitzeln? *Where is the bee that the fish are tickling?*
				Wo ist das Schwein, das die Wölfe kitzeln? *Where is the pig that the wolves are tickling?*
				Wo ist das Kamel, das die Panther messen? *Where is the camel that the panthers are measuring?*
				Wo ist die Ziege, die die Käfer messen? *Where is the goat that the beetles are measuring?*
				Wo ist die Kuh, die die Tiger rufen? *Where is the cow that the tigers are calling?*
				Wo ist das Küken, das die Dinos rufen? *Where is the chick that the dinosaurs are calling?*
				Wo ist die Ente, die die Igel schlagen? *Where is the duck that the hedgehogs are hitting?*
				Wo ist das Pony, das die Haie schlagen? *Where is the pony that the sharks are hitting?*
				Wo ist das Reh, das die Vögel stechen? *Where is the deer that the birds are poking?*
				Wo ist die Robbe, die die Hähne stechen? *Where is the seal that the roosters are poking?*
				Wo ist die Eule, die die Frösche waschen? *Where is the owl that the frogs are washing?*
				Wo ist das Schaf, das die Hunde waschen? *Where is the sheep that the dogs are washing?*
ORC	Full DP	Number	2	Wo ist die Ente, die die Käfer fangen? *Where is the duck that the beetles are catching?*
				Wo ist das Schaf, das die Hähne fangen? *Where is the sheep that the roosters are catching?*
				Wo ist die Kuh, die die Panther kämmen? *Where is the cow that the panthers are combing?*
				Wo ist das Küken, das die Tiger kämmen? *Where is the chick that the tigers are combing?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist das Kamel, das die Hamster kitzeln? *Where is the camel that the hamsters are tickling?*
				Wo ist die Maus, die die Vögel kitzeln? *Where is the mouse that the birds are tickling?*
				Wo ist die Biene, die die Igel messen? *Where is the bee that the hedgehogs are measuring?*
				Wo ist das Pony, das die Frösche messen? *Where is the pony that the frogs are measuring?*
				Wo ist das Reh, das die Füchse rufen? *Where is the deer that the foxes are calling?*
				Wo ist die Ziege, die die Hunde rufen? *Where is the goat that the dogs are calling?*
				Wo ist die Robbe, die die Krebse schlagen? *Where is the seal that the crabs are hitting?*
				Wo ist das Schwein, das die Fische schlagen? *Where is the pig that the fish are hitting?*
				Wo ist die Eule, die die Esel stechen? *Where is the owl that the donkeys are poking?*
				Wo ist das Zebra, das die Wölfe stechen? *Where is the zebra that the wolves are poking?*
				Wo ist die Katze, die die Dinos waschen? *Where is the cat that the dinosaurs are washing?*
				Wo ist das Lama, das die Haie waschen? *Where is the lama that the sharks are washing?*
ORC	Full DP	Case	1	Wo ist der Hahn, den der Esel fängt? *Where is the rooster that the donkey is catching?*
				Wo ist der Wolf, den der Fuchs fängt? *Where is the wolf that the fox is catching?*
				Wo ist der Esel, den der Hund kämmt? *Where is the donkey that the dog is combing?*
				Wo ist der Tiger, den der Vogel kämmt? *Where is the tiger that the bird is combing?*
				Wo ist der Hund, den der Igel kitzelt? *Where is the dog that the hedgehog is tickling?*
				Wo ist der Vogel, den der Hai kitzelt? *Where is the bird that the shark is tickling?*
				Wo ist der Hai, den der Panther misst? *Where is the shark that the panther is measuring?*
				Wo ist der Käfer, den der Fisch misst? *Where is the beetle that the fish is measuring?*
				Wo ist der Dino, den der Tiger ruft? *Where is the dinosaur that the tiger is calling?*
				Wo ist der Igel, den der Hahn ruft? *Where is the hedgehog that the rooster is calling?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist der Fisch, den der Käfer schlägt? *Where is the fish that the beetle is hitting?*
				Wo ist der Fuchs, den der Hamster schlägt? *Where is the fox that the hamster is hitting?*
				Wo ist der Hamster, den der Wolf sticht? *Where is the hamster that the wolf is poking?*
				Wo ist der Krebs, den der Frosch sticht? *Where is the crab that the frog is poking?*
				Wo ist der Frosch, den der Dino wäscht? *Where is the frog that the dinosaur is washing?*
				Wo ist der Panther, den der Krebs wäscht? *Where is the panther that the crab is washing?*
ORC	Full DP	Case	2	Wo ist der Igel, den der Käfer fängt? *Where is the hedgehog that the beetle is catching?*
				Wo ist der Tiger, den der Hund fängt? *Where is the tiger that the dog is catching?*
				Wo ist der Hamster, den der Fuchs kämmt? *Where is the hamster that the fox is combing?*
				Wo ist der Panther, den der Hahn kämmt? *Where is the panther that the rooster is combing?*
				Wo ist der Esel, den der Fisch kitzelt? *Where is the donkey that the fish is tickling?*
				Wo ist der Fuchs, den der Panther kitzelt? *Where is the fox that the panther is tickling?*
				Wo ist der Krebs, den der Esel misst? *Where is the crab that the donkey is measuring?*
				Wo ist der Wolf, den der Frosch misst? *Where is the wolf that the frog is measuring?*
				Wo ist der Frosch, den der Wolf ruft? *Where is the frog that the wolf is calling?*
				Wo ist der Hai, den der Vogel ruft? *Where is the shark that the bird is calling?*
				Wo ist der Dino, den der Igel schlägt? *Where is the dinosaur that the hedgehog is hitting?*
				Wo ist der Hund, den der Krebs schlägt? *Where is the dog that the crab is hitting?*
				Wo ist der Hahn, den der Dino sticht? *Where is the rooster that the dinosaur is poking?*
				Wo ist der Käfer, den der Hai sticht? *Where is the beetle that the shark is poking?*
				Wo ist der Fisch, den der Hamster wäscht? *Where is the fish that the hamster is washing?*
				Wo ist der Vogel, den der Tiger wäscht? *Where is the bird that the tiger is washing?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
ORC	Pronoun	Number	1	Wo ist die Biene, die sie fangen? *Where is the bee that they are catching?*
				Wo ist das Pony, das sie fangen? *Where is the pony that they are catching?*
				Wo ist die Katze, die sie kämmen? *Where is the cat that they are combing?*
				Wo ist das Reh, das sie kämmen? *Where is the deer that they are combing?*
				Wo ist das Küken, das sie kitzeln? *Where is the chick that they are tickling?*
				Wo ist die Ziege, die sie kitzeln? *Where is the goat that they are tickling?*
				Wo ist die Maus, die sie messen? *Where is the mouse that they are measuring?*
				Wo ist das Zebra, das sie messen? *Where is the zebra that they are measuring?*
				Wo ist die Ente, die sie rufen? *Where is the duck that they are calling?*
				Wo ist das Schaf, das sie rufen? *Where is the sheep that they are calling?*
				Wo ist die Eule, die sie schlagen? *Where is the owl that they are hitting?*
				Wo ist das Lama, das sie schlagen? *Where is the lama that they are hitting?*
				Wo ist die Kuh, die sie stechen? *Where is the cow that they are poking?*
				Wo ist das Schwein, das sie stechen? *Where is the pig that they are poking?*
				Wo ist das Kamel, das sie waschen? *Where is the camel that they are washing?*
				Wo ist die Robbe, die sie waschen? *Where is the seal that they are washing?*
ORC	Pronoun	Number	2	Wo ist die Maus, die sie fangen? *Where is the mouse that they are catching?*
				Wo ist das Reh, das sie fangen? *Where is the deer that they are catching?*
				Wo ist die Eule, die sie kämmen? *Where is the owl that they are combing?*
				Wo ist das Lama, das sie kämmen? *Where is the lama that they are combing?*
				Wo ist die Kuh, die sie kitzeln? *Where is the cow that they are tickling?*
				Wo ist das Zebra, das sie kitzeln? *Where is the zebra that they are tickling?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist die Katze, die sie messen? *Where is the cat that they are measuring?*
				Wo ist das Schwein, das sie messen? *Where is the pig that they are measuring?*
				Wo ist das Kamel, das sie rufen? *Where is the camel that they are calling?*
				Wo ist die Robbe, die sie rufen? *Where is the seal that they are calling?*
				Wo ist die Biene, die sie schlagen? *Where is the bee that they are hitting?*
				Wo ist das Schaf, das sie schlagen? *Where is the sheep that they are hitting?*
				Wo ist das Küken, das sie stechen? *Where is the chick that they are poking?*
				Wo ist die Ziege, die sie stechen? *Where is the goat that they are poking?*
				Wo ist die Ente, die sie waschen? *Where is the duck that they are washing?*
				Wo ist das Pony, das sie waschen? *Where is the pony that they are washing?*
ORC	Pronoun	Case	1	Wo ist der Hund, den er fängt? *Where is the dog that he is catching?*
				Wo ist der Käfer, den er fängt? *Where is the beetle that he is catching?*
				Wo ist der Fuchs, den er kämmt? *Where is the fox that he is combing?*
				Wo ist der Hahn, den er kämmt? *Where is the rooster that he is combing?*
				Wo ist der Fisch, den er kitzelt? *Where is the fish that he is tickling?*
				Wo ist der Panther, den er kitzelt? *Where is the panther that he is tickling?*
				Wo ist der Esel, den er misst? *Where is the donkey that he is measuring?*
				Wo ist der Frosch, den er misst? *Where is the frog that he is measuring?*
				Wo ist der Vogel, den er ruft? *Where is the bird that he is calling?*
				Wo ist der Wolf, den er ruft? *Where is the wolf that he is calling?*
				Wo ist der Igel, den er schlägt? *Where is the hedgehog that he is hitting?*
				Wo ist der Krebs, den er schlägt? *Where is the crab that he is hitting?*

Table A.1 (continued)

Condition				
RC type	**Embedded constituent type**	**Disambi-guating feature**	**List**	**Item** **English translation**
				Wo ist der Dino, den er sticht? *Where is the dinosaur that he is poking?*
				Wo ist der Hai, den er sticht? *Where is the shark that he is poking?*
				Wo ist der Hamster, den er wäscht? *Where is the hamster that he is washing?*
				Wo ist der Tiger, den er wäscht? *Where is the tiger that he is washing?*
ORC	Pronoun	Case	2	Wo ist der Esel, den er fängt? *Where is the donkey that he is catching?*
				Wo ist der Fuchs, den er fängt? *Where is the fox that he is catching?*
				Wo ist der Hund, den er kämmt? *Where is the dog that he is combing?*
				Wo ist der Vogel, den er kämmt? *Where is the bird that he is combing?*
				Wo ist der Hai, den er kitzelt? *Where is the shark that he is tickling?*
				Wo ist der Igel, den er kitzelt? *Where is the hedgehog that he is tickling?*
				Wo ist der Fisch, den er misst? *Where is the fish that he is measuring?*
				Wo ist der Panther, den er misst? *Where is the panther that he is measuring?*
				Wo ist der Hahn, den er ruft? *Where is the rooster that he is calling?*
				Wo ist der Tiger, den er ruft? *Where is the tiger that he is calling?*
				Wo ist der Hamster, den er schlägt? *Where is the hamster that he is hitting?*
				Wo ist der Käfer, den er schlägt? *Where is the beetle that he is hitting?*
				Wo ist der Frosch, den er sticht? *Where is the frog that he is poking?*
				Wo ist der Wolf, den er sticht? *Where is the wolf that he is poking?*
				Wo ist der Dino, den er wäscht? *Where is the dinosaur that he is washing?*
				Wo ist der Krebs, den er wäscht? *Where is the crab that he is washing?*

Table A.2

Full list of filler sentences and their English translation

Condition	Item *English translation*
Number	Wo ist das Zebra mit dem Baum? *Where is the zebra with the tree?*
	Wo ist die Kuh mit der Wolke? *Where is the cow with the cloud?*
	Wo ist das Kamel mit dem Baum? *Where is the camel with the tree?*
	Wo ist die Ziege mit dem Baum? *Where is the goat with the tree?*
	Wo ist das Pony mit dem Stift? *Where is the pony with the pen?*
	Wo ist das Schaf mit dem Mond? *Where is the sheep with the moon?*
	Wo ist die Ente mit dem Eis? *Where is the duck with the ice?*
	Wo ist die Ziege mit dem Drachen? *Where is the goat with the kite?*
	Wo ist die Eule mit der Sonne? *Where is the owl with the sun?*
	Wo ist das Reh mit dem Eis? *Where is the deer with the ice?*
	Wo ist das Schaf mit dem Herz? *Where is the sheep with the heart?*
	Wo ist die Robbe mit dem Schuh? *Where is the seal with the shoe?*
	Wo ist das Lama mit der Blume? *Where is the lama with the flower?*
	Wo ist das Reh mit der Sonne? *Where is the deer with the sun?*
	Wo ist die Robbe mit dem Buch? *Where is the seal with the book?*
	Wo ist die Eule mit der Tasse? *Where is the owl with the cup?*
	Wo ist das Zebra mit dem Baum? *Where is the zebra with the tree?*
	Wo ist die Katze mit der Sonne? *Where is the cat with the sun?*
	Wo ist das Schwein mit dem Ball? *Where is the pig with the ball?*
	Wo ist die Biene mit dem Eis? *Where is the bee with the ice?*
	Wo ist die Kuh mit der Tasse? *Where is the cow with the cup?*
	Wo ist das Kamel mit dem Ball? *Where is the camel with the ball?*

Table A.2 (continued)

Condition	Item ***English translation***
	Wo ist die Maus mit dem Eis? *Where is the mouse with the ice?*
	Wo ist das Küken mit dem Mond? *Where is the chick with the moon?*
	Wo ist das Lama mit dem Buch? *Where is the lama with the book?*
	Wo ist die Ente mit dem Buch? *Where is the duck with the book?*
	Wo ist das Pony mit dem Ballon? *Where is the pony with the balloon?*
	Wo ist die Katze mit dem Apfel? *Where is the cat with the apple?*
	Wo ist die Maus mit dem Buch? *Where is the mouse with the book?*
	Wo ist das Schwein mit der Blume? *Where is the pig with the flower?*
	Wo ist das Küken mit dem Buch? *Where is the chick with the book?*
	Wo ist die Biene mit dem Herz? *Where is the bee with the heart?*
Case	Wo ist der Krebs mit dem Stift? *Where is the crab with the pen?*
	Wo ist der Dino mit dem Mond? *Where is the dinosaur with the moon?*
	Wo ist der Hamster mit dem Eis? *Where is the hamster with the ice?*
	Wo ist der Panther mit der Sonne? *Where is the panther with the sun?*
	Wo ist der Igel mit dem Herz? *Where is the hedgehog with the heart?*
	Wo ist der Dino mit der Wolke? *Where is the dinosaur with the cloud?*
	Wo ist der Käfer mit dem Schuh? *Where is the beetle with the shoe?*
	Wo ist der Wolf mit der Blume? *Where is the wolf with the flower?*
	Wo ist der Frosch mit dem Herz? *Where is the frog with the heart?*
	Wo ist der Käfer mit dem Drachen? *Where is the beetle with the kite?*
	Wo ist der Wolf mit dem Stern? *Where is the wolf with the star?*
	Wo ist der Tiger mit dem Mond? *Where is the tiger with the moon?*
	Wo ist der Hamster mit der Wolke? *Where is the hamster with the cloud?*

Table A.2 (continued)

Condition	**Item** ***English translation***
	Wo ist der Vogel mit dem Ballon? *Where is the bird with the balloon?*
	Wo ist der Hund mit dem Drachen? *Where is the dog with the kite?*
	Wo ist der Hahn mit dem Mond? *Where is the rooster with the moon?*
	Wo ist der Fuchs mit dem Eis? *Where is the fox with the ice?*
	Wo ist der Krebs mit dem Herz? *Where is the crab with the heart?*
	Wo ist der Fisch mit der Wolke? *Where is the fish with the cloud?*
	Wo ist der Esel mit dem Stern? *Where is the donkey with the star?*
	Wo ist der Hai mit der Sonne? *Where is the shark with the sun?*
	Wo ist der Frosch mit dem Herz? *Where is the frog with the heart?*
	Wo ist der Tiger mit dem Herz? *Where is the tiger with the heart?*
	Wo ist der Panther mit dem Stern? *Where is the panther with the star?*
	Wo ist der Vogel mit dem Apfel? *Where is the bird with the apple?*
	Wo ist der Esel mit dem Mond? *Where is the donkey with the moon?*
	Wo ist der Hund mit der Sonne? *Where is the dog with the sun?*
	Wo ist der Fisch mit dem Buch? *Where is the fish with the book?*
	Wo ist der Igel mit dem Baum? *Where is the hedgehog with the tree?*
	Wo ist der Hai mit dem Apfel? *Where is the shark with the apple?*
	Wo ist der Fuchs mit dem Ball? *Where is the fox with the ball?*
	Wo ist der Hahn mit dem Apfel? *Where is the rooster with the apple?*

Table A.3

Model output – accuracy in referent-identification task on number-marked RCs

Fixed effect	Coefficient	*SE*	*z*-value	*p*-value
(Intercept)	4.077	0.275	14.837	< .001
RC	0.521	0.221	2.357	.018
Embedded constituent	-0.265	0.221	-1.197	.231
Group	-3.608	0.328	-10.985	< .001
RC : Embedded constituent	0.516	0.221	2.332	.020
RC : Group	-0.737	0.235	-3.134	.002
Embedded constituent : Group	0.231	0.235	0.980	.327
RC : Embedded constituent : Group	-0.271	0.235	-1.153	.249

Note. SE = standard error, RC = relative clause.

Table A.4

Model output – eye movements in number-marked RCs

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
(Intercept)	0.262	0.019	14.134	< .001
RoI2-1	0.011	0.012	0.919	.358
RoI3-2	-0.107	0.012	-8.661	< .001
RoI4-3	0.049	0.013	3.907	< .001
RoI5-4	0.019	0.022	0.866	.387
RoI6-5	0.057	0.043	1.332	.183
RC	-0.088	0.008	-10.705	< .001
Embedded constituent	-0.001	0.008	-0.145	.884
Group	0.064	0.031	2.097	.044
RoI2-1 : RC	-0.013	0.012	-1.038	.299
RoI3-2 : RC	-0.008	0.012	-0.666	.506
RoI4-3 : RC	-0.169	0.013	-13.399	< .001
RoI5-4 : RC	0.019	0.021	0.882	.378
RoI6-5 : RC	-0.061	0.043	-1.430	.153
RoI2-1 : Embedded constituent	0.009	0.012	0.705	.481
RoI3-2 : Embedded constituent	-0.020	0.012	-1.607	.108

Table A.4 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RoI4-3 : Embedded constituent	0.005	0.013	0.431	.667
RoI5-4 : Embedded constituent	0.054	0.021	2.537	.011
RoI6-5 : Embedded constituent	-0.018	0.043	-0.416	.678
RC : Embedded constituent	0.001	0.008	0.137	.891
RoI2-1 : Group	-0.027	0.025	-1.051	.293
RoI3-2 : Group	0.076	0.025	3.019	.003
RoI4-3 : Group	-0.040	0.026	-1.571	.116
RoI5-4 : Group	-0.019	0.033	-0.584	.559
RoI6-5 : Group	-0.063	0.053	-1.186	.236
RC : Group	0.007	0.011	0.626	.531
Embedded constituent : Group	-0.010	0.011	-0.919	.358
RoI2-1 : RC : Embedded constituent	-0.010	0.012	-0.804	.421
RoI3-2 : RC : Embedded constituent	0.005	0.012	0.380	.704
RoI4-3 : RC : Embedded constituent	0.005	0.013	0.357	.721
RoI5-4 : RC : Embedded constituent	-0.027	0.021	-1.269	.204
RoI6-5 : RC : Embedded constituent	0.034	0.043	0.806	.421
RoI2-1 : RC : Group	-0.021	0.025	-0.817	.414
RoI3-2 : RC : Group	0.008	0.025	0.320	.749
RoI4-3 : RC : Group	0.075	0.026	2.929	.003
RoI5-4 : RC : Group	-0.090	0.032	-2.762	.006
RoI6-5 : RC : Group	0.065	0.053	1.226	.220
RoI2-1 : Embedded constituent : Group	-0.029	0.025	-1.150	.250
RoI3-2 : Embedded constituent : Group	0.012	0.025	0.466	.642
RoI4-3 : Embedded constituent : Group	-0.025	0.026	-0.969	.333
RoI5-4 : Embedded constituent : Group	-0.014	0.032	-0.420	.675
RoI6-5 : Embedded constituent : Group	0.019	0.053	0.350	.726
RC : Embedded constituent : Group	-0.001	0.011	-0.139	.890
RoI2-1 : RC : Embedded constituent : Group	-0.007	0.025	-0.264	.791
RoI3-2 : RC : Embedded constituent : Group	-0.006	0.025	-0.245	.807
RoI4-3 : RC : Embedded constituent : Group	0.000	0.026	-0.005	.996
RoI5-4 : RC : Embedded constituent : Group	0.043	0.032	1.335	.182

Table A.4 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RoI6-5 : RC : Embedded constituent : Group	-0.046	0.053	-0.870	.384

Note. SE = standard error, RoI = Region of Interest, RC = relative clause.

Table A.5

Model output – accuracy in referent-identification task on case-marked RCs

Fixed effect	Coefficient	*SE*	*z*-value	*p*-value
(Intercept)	3.985	0.326	12.239	< .001
RC	0.828	0.193	4.280	< .001
Embedded constituent	-0.098	0.193	-0.508	.612
Group	-3.363	0.454	-7.410	< .001
RC : Embedded constituent	0.537	0.193	2.786	.005
RC : Group	-0.386	0.213	-1.814	.070
Embedded constituent : Group	0.164	0.212	0.774	.439
RC : Embedded constituent : Group	-0.418	0.212	-1.971	.049

Note. SE = standard error, RC = relative clause.

Table A.6

Model output – eye movements in case-marked RCs

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
(Intercept)	0.266	0.026	10.318	<.001
RoI2-1	-0.010	0.013	-0.804	.422
RoI3-2	-0.073	0.013	-5.853	<.001
RoI4-3	0.071	0.014	5.163	<.001
RoI5-4	0.009	0.028	0.308	.759
RoI6-5	0.069	0.095	0.726	.468
RC	-0.103	0.017	-6.212	<.001
Embedded constituent	0.000	0.017	-0.020	.984
Group	0.052	0.038	1.355	.183
RoI2-1 : RC	0.001	0.013	0.091	.927
RoI3-2 : RC	-0.058	0.013	-4.642	<.001

Table A.6 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RoI4-3 : RC	-0.159	0.014	-11.617	<.001
RoI5-4 : RC	0.011	0.028	0.405	.685
RoI6-5 : RC	0.123	0.095	1.299	.194
RoI2-1 : Embedded constituent	-0.007	0.013	-0.533	.594
RoI3-2 : Embedded constituent	-0.008	0.013	-0.645	.519
RoI4-3 : Embedded constituent	-0.005	0.014	-0.334	.738
RoI5-4 : Embedded constituent	-0.048	0.028	-1.745	.081
RoI6-5 : Embedded constituent	0.169	0.095	1.779	.075
RC : Embedded constituent	0.018	0.017	1.091	.275
RoI2-1 : Group	0.037	0.026	1.459	.145
RoI3-2 : Group	0.029	0.025	1.157	.247
RoI4-3 : Group	-0.045	0.026	-1.719	.086
RoI5-4 : Group	-0.036	0.037	-0.960	.337
RoI6-5 : Group	-0.030	0.100	-0.300	.764
RC : Group	0.005	0.018	0.302	.763
Embedded constituent : Group	-0.007	0.018	-0.398	.690
RoI2-1 : RC : Embedded constituent	-0.010	0.013	-0.829	.407
RoI3-2 : RC : Embedded constituent	-0.015	0.013	-1.165	.244
RoI4-3 : RC : Embedded constituent	0.021	0.014	1.536	.125
RoI5-4 : RC : Embedded constituent	0.059	0.028	2.127	.034
RoI6-5 : RC : Embedded constituent	-0.016	0.095	-0.169	.866
RoI2-1 : RC : Group	-0.025	0.026	-0.963	.336
RoI3-2 : RC : Group	0.043	0.025	1.708	.088
RoI4-3 : RC : Group	0.038	0.026	1.467	.143
RoI5-4 : RC : Group	-0.048	0.037	-1.295	.195
RoI6-5 : RC : Group	-0.123	0.100	-1.233	.218
RoI2-1 : Embedded constituent : Group	0.017	0.026	0.678	.498
RoI3-2 : Embedded constituent : Group	0.016	0.025	0.626	.532
RoI4-3 : Embedded constituent : Group	-0.014	0.026	-0.546	.585
RoI5-4 : Embedded constituent : Group	0.043	0.037	1.171	.242
RoI6-5 : Embedded constituent : Group	-0.145	0.100	-1.450	.147

Table A.6 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RC : Embedded constituent : Group	-0.021	0.018	-1.185	.236
RoI2-1 : RC : Embedded constituent : Group	-0.015	0.026	-0.605	.545
RoI3-2 : RC : Embedded constituent : Group	0.004	0.025	0.178	.859
RoI4-3 : RC : Embedded constituent : Group	-0.025	0.026	-0.964	.335
RoI5-4 : RC : Embedded constituent : Group	-0.003	0.037	-0.083	.934
RoI6-5 : RC : Embedded constituent : Group	-0.018	0.100	-0.180	.857

Note. SE = standard error, RoI = Region of Interest, RC = relative clause.

APPENDIX B

WHAT MATTERS IN PROCESSING GERMAN OBJECT RELATIVE CLAUSES IN APHASIA – TIMING OR MORPHO-SYNTACTIC CUES?

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist der Panther, den gerade der Käfer schlägt? *Where is the panther that the beetle is currently hitting?*
				Wo ist der Fisch, den gerade der Hund sticht? *Where is the fish that the dog is currently poking?*
				Wo ist der Käfer, den gerade der Vogel sticht? *Where is the beetle that the bird is currently poking?*
				Wo ist der Fuchs, den gerade der Igel wäscht? *Where is the fox that the hedgehog is currently washing?*
				Wo ist der Hamster, den gerade der Frosch wäscht? *Where is the hamster that the frog is currently washing?*
Target	Case	Early	1	Wo ist die Katze, die gerade der Fuchs fängt? *Where is the cat that the fox is currently catching?*
				Wo ist das Schwein, das gerade der Esel fängt? *Where is the pig that the donkey is currently catching?*
				Wo ist die Eule, die gerade der Tiger kämmt? *Where is the owl that the tiger is currently combing?*
				Wo ist das Küken, das gerade der Hund kämmt? *Where is the chick that the dog is currently combing?*
				Wo ist die Biene, die gerade der Panther kitzelt? *Where is the bee that the panther is currently tickling?*
				Wo ist das Schaf, das gerade der Igel kitzelt? *Where is the sheep that the hedgehog is currently tickling?*
				Wo ist das Kamel, das gerade der Dino misst? *Where is the camel that the dinosaur is currently measuring?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist die Ziege, die gerade der Käfer misst? *Where is the goat that the beetle is currently measuring?*
				Wo ist die Maus, die gerade der Vogel ruft? *Where is the mouse that the bird is currently calling?*
				Wo ist das Reh, das gerade der Hamster ruft? *Where is the deer that the hamster is currently calling?*
				Wo ist das Pony, das gerade der Frosch schlägt? *Where is the pony that the frog is currently hitting?*
				Wo ist die Robbe, die gerade der Krebs schlägt? *Where is the seal that the crab is currently hitting?*
				Wo ist die Kuh, die gerade der Wolf sticht? *Where is the cow that the wolf is currently poking?*
				Wo ist das Zebra, das gerade der Hai sticht? *Where is the zebra that the shark is currently poking?*
				Wo ist die Ente, die gerade der Fisch wäscht? *Where is the duck that the fish is currently washing?*
				Wo ist das Lama, das gerade der Hahn wäscht? *Where is the lama that the rooster is currently washing?*
Target	Case	Early	2	Wo ist die Maus, die gerade der Hamster fängt? *Where is the mouse that the hamster is currently catching?*
				Wo ist das Pony, das gerade der Hund fängt? *Where is the pony that the dog is currently catching?*
				Wo ist die Ente, die gerade der Fuchs kämmt? *Where is the duck that the fox is currently combing?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist das Lama, das gerade der Panther kämmt? *Where is the lama that the panther is currently combing?*
				Wo ist das Reh, das gerade der Frosch kitzelt? *Where is the deer that the frog is currently tickling?*
				Wo ist die Ziege, die gerade der Tiger kitzelt? *Where is the goat that the tiger is currently tickling?*
				Wo ist die Biene, die gerade der Fisch misst? *Where is the bee that the fish is currently measuring?*
				Wo ist das Zebra, das gerade der Igel misst? *Where is the zebra that the hedgehog is currently measuring?*
				Wo ist die Kuh, die gerade der Esel ruft? *Where is the cow that the donkey is currently calling?*
				Wo ist das Schaf, das gerade der Hahn ruft? *Where is the sheep that the rooster is currently calling?*
				Wo ist die Katze, die gerade der Hai schlägt? *Where is the cat that the shark is currently hitting?*
				Wo ist das Schwein, das gerade der Wolf schlägt? *Where is the pig that the wolf is currently hitting?*
				Wo ist die Eule, die gerade der Krebs sticht? *Where is the owl that the crab is currently poking?*
				Wo ist das Küken, das gerade der Dino sticht? *Where is the chick that the dinosaur is currently poking?*
				Wo ist das Kamel, das gerade der Vogel wäscht? *Where is the camel that the bird is currently washing?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist die Robbe, die gerade der Käfer wäscht? *Where is the seal that the beetle is currently washing?*
Target	Number	Late	1	Wo ist die Maus, die gerade die Hamster fangen? *Where is the mouse that the hamsters are currently catching?*
				Wo ist das Pony, das gerade die Hunde fangen? *Where is the pony that the dogs are currently catching?*
				Wo ist die Ente, die gerade die Füchse kämmen? *Where is the duck that the foxes are currently combing?*
				Wo ist das Lama, das gerade die Panther kämmen? *Where is the lama that the panthers are currently combing?*
				Wo ist das Reh, das gerade die Frösche kitzeln? *Where is the deer that the frogs are currently tickling?*
				Wo ist die Ziege, die gerade die Tiger kitzeln? *Where is the goat that the tigers are currently tickling?*
				Wo ist die Biene, die gerade die Fische messen? *Where is the bee that the fish are currently measuring?*
				Wo ist das Zebra, das gerade die Igel messen? *Where is the zebra that the hedgehogs are currently measuring?*
				Wo ist die Kuh, die gerade die Esel rufen? *Where is the cow that the donkeys are currently calling?*
				Wo ist das Schaf, das gerade die Hähne rufen? *Where is the sheep that the roosters are currently calling?*
				Wo ist die Katze, die gerade die Haie schlagen? *Where is the cat that the sharks are currently hitting?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist das Schwein, das gerade die Wölfe schlagen? *Where is the pig that the wolves are currently hitting?*
				Wo ist die Eule, die gerade die Krebse stechen? *Where is the owl that the crabs are currently poking?*
				Wo ist das Küken, das gerade die Dinos stechen? *Where is the chick that the dinosaurs are currently poking?*
				Wo ist das Kamel, das gerade die Vögel waschen? *Where is the camel that the birds are currently washing?*
				Wo ist die Robbe, die gerade die Käfer waschen? *Where is the seal that the beetles are currently washing?*
Target	Number	Late	2	Wo ist die Katze, die gerade die Füchse fangen? *Where is the cat that the foxes are currently catching?*
				Wo ist das Schwein, das gerade die Esel fangen? *Where is the pig that the donkeys are currently catching?*
				Wo ist die Eule, die gerade die Tiger kämmen? *Where is the owl that the tigers are currently combing?*
				Wo ist das Küken, das gerade die Hunde kämmen? *Where is the chick that the dogs are currently combing?*
				Wo ist die Biene, die gerade die Panther kitzeln? *Where is the bee that the panthers are currently tickling?*
				Wo ist das Schaf, das gerade die Igel kitzeln? *Where is the sheep that the hedgehogs are currently tickling?*
				Wo ist das Kamel, das gerade die Dinos messen? *Where is the camel that the dinosaurs are currently measuring?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist die Ziege, die gerade die Käfer messen? *Where is the goat that the beetle are currently measuring?*
				Wo ist die Maus, die gerade die Vögel rufen? *Where is the mouse that the birds are currently calling?*
				Wo ist das Reh, das gerade die Hamster rufen? *Where is the deer that the hamsters are currently calling?*
				Wo ist das Pony, das gerade die Frösche schlagen? *Where is the pony that the frogs are currently hitting?*
				Wo ist die Robbe, die gerade die Krebse schlagen? *Where is the seal that the crabs are currently hitting?*
				Wo ist die Kuh, die gerade die Wölfe stechen? *Where is the cow that the wolves are currently poking?*
				Wo ist das Zebra, das gerade die Haie stechen? *Where is the zebra that the sharks are currently poking?*
				Wo ist die Ente, die gerade die Fische waschen? *Where is the duck that the fish are currently washing?*
				Wo ist das Lama, das gerade die Hähne waschen? *Where is the lama that the roosters are currently washing?*
Filler	Case	Immediate	1 & 2	Wo ist der Hahn, der gerade den Käfer fängt? *Where is the rooster that is currently catching the beetle?*
				Wo ist der Igel, der gerade den Krebs fängt? *Where is the hedgehog that is currently catching the crab?*
				Wo ist der Dino, der gerade den Hahn kämmt? *Where is the dinosaur that is currently combing the rooster?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist der Käfer, der gerade den Igel kämmt? *Where is the beetle that is currently combing the hedgehog?*
				Wo ist der Vogel, der gerade den Dino kitzelt? *Where is the bird that is currently tickling the dinosaur?*
				Wo ist der Wolf, der gerade den Fisch kitzelt? *Where is the wolf that is currently tickling the fish?*
				Wo ist der Hamster, der gerade den Panther misst? *Where is the hamster that is currently measuring the panther?*
				Wo ist der Tiger, der gerade den Frosch misst? *Where is the tiger that is currently measuring the frog?*
				Wo ist der Fisch, der gerade den Hai ruft? *Where is the fish that is currently calling the shark?*
				Wo ist der Krebs, der gerade den Wolf ruft? *Where is the crab that is currently calling the wolf?*
				Wo ist der Esel, der gerade den Vogel schlägt? *Where is the donkey that is currently hitting the bird?*
				Wo ist der Fuchs, der gerade den Hund schlägt? *Where is the fox that is currently hitting the dog?*
				Wo ist der Frosch, der gerade den Hamster sticht? *Where is the frog that is currently poking the hamster?*
				Wo ist der Panther, der gerade den Fuchs sticht? *Where is the panther that is currently poking the fox?*
				Wo ist der Hai, der gerade den Tiger wäscht? *Where is the shark that is currently washing the tiger?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist der Hund, der gerade den Esel wäscht? *Where is the dog that is currently washing the donkey?*
Filler	Case	Early	1	Wo ist die Kuh, die gerade den Igel fängt? *Where is the cow that is currently catching the hedgehog?*
				Wo ist das Reh, das gerade den Krebs fängt? *Where is the deer that is currently catching the crab?*
				Wo ist die Katze, die gerade den Hahn kämmt? *Where is the cat that is currently combing the rooster?*
				Wo ist das Zebra, das gerade den Käfer kämmt? *Where is the zebra that is currently combing the beetle?*
				Wo ist das Lama, das gerade den Vogel kitzelt? *Where is the lama that is currently tickling the bird?*
				Wo ist die Maus, die gerade den Fuchs kitzelt? *Where is the mouse that is currently tickling the fox?*
				Wo ist die Ente, die gerade den Hund misst? *Where is the duck that is currently measuring the dog?*
				Wo ist das Schaf, das gerade den Wolf misst? *Where is the sheep that is currently measuring the wolf?*
				Wo ist das Pony, das gerade den Fisch ruft? *Where is the pony that is currently calling the fish?*
				Wo ist die Robbe, die gerade den Hai ruft? *Where is the seal that is currently calling the shark?*
				Wo ist die Eule, die gerade den Esel schlägt? *Where is the owl that is currently hitting the donkey?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist das Kamel, das gerade den Hamster schlägt? *Where is the camel that is currently hitting the hamster?*
				Wo ist das Schwein, das gerade den Panther sticht? *Where is the pig that is currently poking the panther?*
				Wo ist die Ziege, die gerade den Frosch sticht? *Where is the goat that is currently poking the frog?*
				Wo ist die Biene, die gerade den Dino wäscht? *Where is the bee that is currently washing the dinosaur?*
				Wo ist das Küken, das gerade den Tiger wäscht? *Where is the chick that is currently washing the tiger?*
Filler	Case	Early	2	Wo ist die Ente, die gerade den Hahn fängt? *Where is the duck that is currently catching the rooster?*
				Wo ist das Schaf, das gerade den Käfer fängt? *Where is the sheep that is currently catching the beetle?*
				Wo ist die Kuh, die gerade den Dino kämmt? *Where is the cow that is currently combing the dinosaur?*
				Wo ist das Reh, das gerade den Igel kämmt? *Where is the deer that is currently combing the hedgehog?*
				Wo ist das Kamel, das gerade den Fisch kitzelt? *Where is the camel that is currently tickling the fish?*
				Wo ist die Robbe, die gerade den Hund kitzelt? *Where is the seal that is currently tickling the dog?*
				Wo ist die Maus, die gerade den Frosch misst? *Where is the mouse that is currently measuring the frog?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist das Schwein, das gerade den Vogel misst? *Where is the pig that is currently measuring the bird?*
				Wo ist das Lama, das gerade den Krebs ruft? *Where is the lama that is currently calling the crab?*
				Wo ist die Ziege, die gerade den Panther ruft? *Where is the goat that is currently calling the panther?*
				Wo ist die Biene, die gerade den Tiger schlägt? *Where is the bee that is currently hitting the tiger?*
				Wo ist das Küken, das gerade den Fuchs schlägt? *Where is the chick that is currently hitting the fox?*
				Wo ist die Katze, die gerade den Esel sticht? *Where is the cat that is currently poking the donkey?*
				Wo ist das Pony, das gerade den Hamster sticht? *Where is the pony that is currently poking the hamster?*
				Wo ist die Eule, die gerade den Hai wäscht? *Where is the owl that is currently washing the shark?*
				Wo ist das Zebra, das gerade den Wolf wäscht? *Where is the zebra that is currently washing the wolf?*
Filler	Number	Late	1	Wo ist die Ente, die gerade die Hähne fängt? *Where is the duck that is currently catching the roosters?*
				Wo ist das Schaf, das gerade die Käfer fängt? *Where is the sheep that is currently catching the beetles?*
				Wo ist die Kuh, die gerade die Dinos kämmt? *Where is the cow that is currently combing the dinosaurs?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist das Reh, das gerade die Igel kämmt? *Where is the deer that is currently combing the hedgehogs?*
				Wo ist das Kamel, das gerade die Fische kitzelt? *Where is the camel that is currently tickling the fish?*
				Wo ist die Robbe, die gerade die Hunde kitzelt? *Where is the seal that is currently tickling the dogs?*
				Wo ist die Maus, die gerade die Frösche misst? *Where is the mouse that is currently measuring the frogs?*
				Wo ist das Schwein, das gerade die Vögel misst? *Where is the pig that is currently measuring the birds?*
				Wo ist das Lama, das gerade die Krebse ruft? *Where is the lama that is currently calling the crabs?*
				Wo ist die Ziege, die gerade die Panther ruft? *Where is the goat that is currently calling the panthers?*
				Wo ist die Biene, die gerade die Tiger schlägt? *Where is the bee that is currently hitting the tigers?*
				Wo ist das Küken, das gerade die Füchse schlägt? *Where is the chick that is currently hitting the foxes?*
				Wo ist die Katze, die gerade die Esel sticht? *Where is the cat that is currently poking the donkey?*
				Wo ist das Pony, das gerade die Hamster sticht? *Where is the pony that is currently poking the hamsters?*
				Wo ist die Eule, die gerade die Haie wäscht? *Where is the owl that is currently washing the sharks?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist das Zebra, das gerade die Wölfe wäscht? *Where is the zebra that is currently washing the wolves?*
Filler	Number	Late	2	Wo ist die Kuh, die gerade die Igel fängt? *Where is the cow that is currently catching the hedgehogs?*
				Wo ist das Reh, das gerade die Krebse fängt? *Where is the deer that is currently catching the crabs?*
				Wo ist die Katze, die gerade die Hähne kämmt? *Where is the cat that is currently combing the roosters?*
				Wo ist das Zebra, das gerade die Käfer kämmt? *Where is the zebra that is currently combing the beetles?*
				Wo ist das Lama, das gerade die Vögel kitzelt? *Where is the lama that is currently tickling the birds?*
				Wo ist die Maus, die gerade die Füchse kitzelt? *Where is the mouse that is currently tickling the foxes?*
				Wo ist die Ente, die gerade die Hunde misst? *Where is the duck that is currently measuring the dogs?*
				Wo ist das Schaf, das gerade die Wölfe misst? *Where is the sheep that is currently measuring the wolves?*
				Wo ist das Pony, das gerade die Fische ruft? *Where is the pony that is currently calling the fish?*
				Wo ist die Robbe, die gerade die Haie ruft? *Where is the seal that is currently calling the sharks?*
				Wo ist die Eule, die gerade die Esel schlägt? *Where is the owl that is currently hitting the donkeys?*

Table B.1 (continued)

Condition				
Type	**Feature**	**Disambiguation point**	**List**	**Item** ***English translation***
				Wo ist das Kamel, das gerade die Hamster schlägt? *Where is the camel that is currently hitting the hamsters?*
				Wo ist das Schwein, das gerade die Panther sticht? *Where is the pig that is currently poking the panthers?*
				Wo ist die Ziege, die gerade die Frösche sticht? *Where is the goat that is currently poking the frogs?*
				Wo ist die Biene, die gerade die Dinos wäscht? *Where is the bee that is currently washing the dinosaurs?*
				Wo ist das Küken, das gerade die Tiger wäscht? *Where is the chick that is currently washing the tiger?*

Table B.2

Model output – accuracy in referent-identification task

Fixed effect	Coefficient	*SE*	*z*-value	*p*-value
(Intercept)	3.465	0.257	13.507	< .001
Immediate – Early	0.148	0.158	0.938	.348
Case – Number	-0.491	0.075	-6.535	< .001
Group	-3.204	0.460	-6.967	< .001
Immediate – Early : Group	0.003	0.198	0.016	.987
Case – Number : Group	0.379	0.102	3.719	< .001

Note. SE = standard error

Table B.3

Model output – response time in referent-identification task for correct responses in controls and IWA

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
(Intercept)	8.506	0.022	378.814	<.001
Immediate – Early	0.010	0.007	-1.476	.146
Case – Number	0.035	0.004	9.912	<.001
Group	0.266	0.048	5.591	<.001
Immediate – Early : Group	-0.004	0.013	-0.314	.754
Case – Number : Group	-0.024	0.007	-3.284	.002

Note. SE = standard error

Table B.4

Model output – response time in referent-identification task for correct and incorrect responses in IWA

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
(Intercept)	8.767	0.070	125.423	<.001
Immediate – Early	-0.010	0.011	-0.907	.366
Case – Number	0.014	0.007	2.186	.030
Accuracy	-0.005	0.015	-0.350	.727
Immediate – Early : Accuracy	0.031	0.017	1.798	.073
Case – Number : Accuracy	-0.007	0.010	-0.654	.513

Note. SE = standard error

Table B.5

Model output – eye movements of correct responses in controls and IWA

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
(Intercept)	0.425	0.025	16.964	<.001
RoI2-1	-0.131	0.035	-3.776	<.001
RoI3-2	-0.039	0.034	-1.141	.254
RoI4-3	-0.061	0.034	-1.793	.073
RoI5-4	0.060	0.038	1.553	.120
RoI6-5	0.081	0.044	1.851	.064
RoI7-6	0.115	0.041	2.776	.006
RoI8-7	0.187	0.037	5.051	<.001
RoI9-8	0.195	0.038	5.076	<.001
RoI10-9	0.079	0.055	1.458	.145
RoI11-10	-0.054	0.082	-0.659	.510
Immediate – Early	-0.059	0.021	-2.861	.005
Case – Number	-0.045	0.012	-3.831	<.001
Group	-0.002	0.047	-0.037	.971
RoI2-1 : Immediate – Early	-0.003	0.041	-0.063	.950
RoI3-2 : Immediate – Early	0.030	0.040	0.755	.450
RoI4-3 : Immediate – Early	-0.019	0.040	-0.466	.642

Table B.5 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RoI5-4 : Immediate – Early	-0.104	0.045	-2.297	.022
RoI6-5 : Immediate – Early	-0.124	0.052	-2.391	.017
RoI7-6 : Immediate – Early	0.114	0.047	2.407	.016
RoI8-7 : Immediate – Early	0.118	0.041	2.867	.004
RoI9-8 : Immediate – Early	0.055	0.046	1.186	.236
RoI10-9 : Immediate – Early	-0.029	0.072	-0.399	.690
RoI11-10 : Immediate – Early	-0.013	0.110	-0.114	.909
RoI2-1 : Case – Number	-0.006	0.025	-0.235	.815
RoI3-2 : Case – Number	0.024	0.025	0.949	.343
RoI4-3 : Case – Number	-0.002	0.025	-0.072	.943
RoI5-4 : Case – Number	-0.030	0.028	-1.056	.291
RoI6-5 : Case – Number	-0.055	0.032	-1.706	.088
RoI7-6 : Case – Number	-0.047	0.031	-1.522	.128
RoI8-7 : Case – Number	-0.094	0.028	-3.328	<.001
RoI9-8 : Case – Number	0.148	0.028	5.319	<.001
RoI10-9 : Case – Number	0.076	0.035	2.136	.033
RoI11-10 : Case – Number	0.005	0.053	0.087	.931
RoI2-1 : Group	-0.051	0.086	-0.590	.555
RoI3-2 : Group	0.054	0.086	0.628	.530
RoI4-3 : Group	-0.022	0.082	-0.263	.792
RoI5-4 : Group	-0.026	0.086	-0.301	.764
RoI6-5 : Group	0.005	0.099	0.045	.964
RoI7-6 : Group	-0.199	0.098	-2.037	.042
RoI8-7 : Group	0.042	0.092	0.462	.644
RoI9-8 : Group	-0.211	0.095	-2.228	.026
RoI10-9 : Group	0.022	0.106	0.206	.837
RoI11-10 : Group	-0.013	0.125	-0.100	.921
Immediate – Early : Group	0.129	0.030	4.238	<.001
Case – Number : Group	0.030	0.019	1.541	.129
RoI2-1 : Immediate – Early : Group	0.019	0.102	0.192	.848
RoI3-2 : Immediate – Early : Group	0.005	0.103	0.052	.959

Table B.5 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RoI4-3 : Immediate – Early : Group	-0.039	0.098	-0.394	.694
RoI5-4 : Immediate – Early : Group	0.123	0.104	1.179	.238
RoI6-5 : Immediate – Early : Group	0.236	0.120	1.966	.049
RoI7-6 : Immediate – Early : Group	-0.274	0.116	-2.371	.018
RoI8-7 : Immediate – Early : Group	-0.139	0.107	-1.301	.193
RoI9-8 : Immediate – Early : Group	0.043	0.112	0.389	.697
RoI10-9 : Immediate – Early : Group	0.055	0.130	0.420	.674
RoI11-10 : Immediate – Early : Group	0.047	0.158	0.299	.765
RoI2-1 : Case – Number : Group	0.007	0.063	0.117	.907
RoI3-2 : Case – Number : Group	-0.064	0.062	-1.037	.300
RoI4-3 : Case – Number : Group	0.076	0.059	1.284	.199
RoI5-4 : Case – Number : Group	0.121	0.062	1.957	.050
RoI6-5 : Case – Number : Group	0.025	0.071	0.358	.720
RoI7-6 : Case – Number : Group	-0.052	0.071	-0.729	.466
RoI8-7 : Case – Number : Group	0.016	0.068	0.235	.814
RoI9-8 : Case – Number : Group	-0.091	0.069	-1.317	.188
RoI10-9 : Case – Number : Group	-0.054	0.075	-0.719	.472
RoI11-10 : Case – Number : Group	0.064	0.086	0.749	.454

Note. RoI = Region of Interest, SE = standard error

Table B.6

Model output – eye movements of correct and incorrect responses in IWA

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
(Intercept)	0.410	0.041	9.897	<.001
RoI2-1	-0.176	0.079	-2.232	.026
RoI3-2	0.018	0.080	0.227	.821
RoI4-3	-0.076	0.076	-1.009	.313
RoI5-4	0.025	0.078	0.320	.749
RoI6-5	0.085	0.090	0.944	.345
RoI7-6	-0.083	0.089	-0.936	.349

Table B.6 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RoI8-7	0.225	0.084	2.690	.007
RoI9-8	-0.016	0.087	-0.188	.850
RoI10-9	0.085	0.092	0.924	.356
RoI11-10	-0.087	0.095	-0.916	.360
Immediate – Early	0.066	0.026	2.564	.012
Case – Number	-0.013	0.015	-0.890	.375
Accuracy	-0.309	0.029	-10.613	<.001
RoI2-1 : Immediate – Early	0.020	0.093	0.217	.828
RoI3-2 : Immediate – Early	0.051	0.095	0.534	.593
RoI4-3 : Immediate – Early	-0.061	0.091	-0.665	.506
RoI5-4 : Immediate – Early	0.021	0.095	0.223	.824
RoI6-5 : Immediate – Early	0.107	0.110	0.977	.328
RoI7-6 : Immediate – Early	-0.168	0.106	-1.585	.113
RoI8-7 : Immediate – Early	-0.034	0.099	-0.341	.733
RoI9-8 : Immediate – Early	0.113	0.103	1.101	.271
RoI10-9 : Immediate – Early	0.034	0.110	0.309	.757
RoI11-10 : Immediate – Early	0.024	0.115	0.210	.833
RoI2-1 : Case – Number	0.001	0.057	0.023	.982
RoI3-2 : Case – Number	0.040	0.058	-0.699	.484
RoI4-3 : Case – Number	0.065	0.054	1.184	.237
RoI5-4 : Case – Number	0.093	0.055	1.687	.092
RoI6-5 : Case – Number	-0.032	0.064	-0.504	.614
RoI7-6 : Case – Number	-0.091	0.064	-1.423	.155
RoI8-7 : Case – Number	-0.068	0.061	-1.107	.268
RoI9-8 : Case – Number	0.059	0.064	0.916	.360
RoI10-9 : Case – Number	0.011	0.067	0.161	.872
RoI11-10 : Case – Number	0.068	0.068	1.002	.317
RoI2-1 : Accuracy	0.086	0.116	0.742	.458
RoI3-2 : Accuracy	0.010	0.117	0.084	.933
RoI4-3 : Accuracy	0.008	0.112	0.067	.946
RoI5-4 : Accuracy	0.061	0.116	0.529	.597

Table B.6 (continued)

Fixed effect	Coefficient	*SE*	*t*-value	*p*-value
RoI6-5 : Accuracy	-0.139	0.130	-1.062	.288
RoI7-6 : Accuracy	0.056	0.132	0.421	.674
RoI8-7 : Accuracy	-0.345	0.132	-2.621	.009
RoI9-8 : Accuracy	-0.277	0.135	-2.057	.040
RoI10-9 : Accuracy	-0.086	0.139	-0.613	.540
RoI11-10 : Accuracy	0.111	0.142	0.777	.437
Immediate – Early : Accuracy	-0.144	0.035	-4.117	<.001
Case – Number : Accuracy	-0.010	0.020	-0.504	.614
RoI2-1 : Immediate – Early : Accuracy	-0.488	0.142	-0.344	.731
RoI3-2 : Immediate – Early : Accuracy	-0.121	0.143	-0.850	.396
RoI4-3 : Immediate – Early : Accuracy	0.177	0.138	1.286	.199
RoI5-4 : Immediate – Early : Accuracy	-0.152	0.143	-1.061	.289
RoI6-5 : Immediate – Early : Accuracy	-0.174	0.162	-1.069	.285
RoI7-6 : Immediate – Early : Accuracy	0.220	0.163	1.353	.176
RoI8-7 : Immediate – Early : Accuracy	0.054	0.162	0.335	.738
RoI9-8 : Immediate – Early : Accuracy	-0.057	0.168	-0.341	.733
RoI10-9 : Immediate – Early : Accuracy	-0.060	0.175	-0.346	.729
RoI11-10 : Immediate – Early : Accuracy	0.075	0.178	0.421	.674
RoI2-1 : Case – Number : Accuracy	-0.026	0.082	-0.310	.756
RoI3-2 : Case – Number : Accuracy	0.131	0.082	1.592	.111
RoI4-3 : Case – Number : Accuracy	-0.132	0.079	-1.671	.095
RoI5-4 : Case – Number : Accuracy	-0.119	0.081	-1.476	.140
RoI6-5 : Case – Number : Accuracy	0.088	0.091	0.965	.334
RoI7-6 : Case – Number : Accuracy	0.108	0.093	1.166	.244
RoI8-7 : Case – Number : Accuracy	-0.024	0.092	-0.265	.791
RoI9-8 : Case – Number : Accuracy	-0.017	0.094	-0.180	.857
RoI10-9 : Case – Number : Accuracy	-0.081	0.096	-0.839	.402
RoI11-10 : Case – Number : Accuracy	0.044	0.098	0.452	.651

Note. RoI = Region of Interest, SE = standard error

EIGENSTÄNDIGKEITSERKLÄRUNG

Hiermit bestätige ich, Anne Adelt, dass ich die vorliegende Arbeit selbstständig verfasst und über die Beiträge meiner Koautor*innen hinaus, welche in der beiliegenden *Erklärung zum eigenen Anteil an den vorgelegten wissenschaftlichen Abhandlungen* spezifiziert sind, keine Hilfe Dritter in Anspruch genommen habe. Die Stellen der Arbeit, die dem Wortlaut oder dem Sinn nach anderen Werken (dazu zählen auch Internetquellen) entnommen sind, wurden unter Angabe der Quelle kenntlich gemacht. In der Abfassung der Arbeit wurden stets alle Regelungen guter wissenschaftlicher Standards eingehalten.

Wörth a.d. Donau, den 25. Mai 2023

Anne Adelt