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Priming the Comprehension of German Object Relative Clauses

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ABSTRACT

Structural priming is a useful laboratory-based technique for investigating how children respond to temporary changes in the distribution of structures in their input. In the current study we investigated whether increasing the number of object relative clauses (RCs) in German-speaking children's input changes their processing preferences for ambiguous RCs. Fifty-one 6-year-olds and 54 9-year-olds participated in a priming task that (i) gauged their baseline interpretations for ambiguous RC structures, (ii) primed an object-RC interpretation of ambiguous RCs, and (iii) determined whether priming persevered beyond immediate prime-target pairs. The 6-year old children showed no priming effect, whereas the 9-year-old group showed robust priming that was long lasting. Unlike in studies of priming in production, priming did not increase in magnitude when there was lexical overlap between prime and target. Overall, the results suggest that increased exposure to object RCs facilitates children's interpretation of this otherwise infrequent structure, but only in older children. The implications for acquisition theory are discussed.



Introduction

Relative-clause processing and acquisition

Relative clauses (RCs) are a commonly studied structure in both adult and child psycholinguistic research. It is a well-known phenomenon that, at least for most European languages (Kirjavainen, Kidd, & Lieven, 2016), subject RCs such as (1) are easier to process for both children and adults than object RCs such as (2) (e.g., Diessel & Tomasello, 2005; Gibson, 1998).

- (1) *The horse that __ chased the cow.*
- (2) *The horse that the cow chased __ .*

Different explanations have been proposed to account for this subject-object asymmetry (for an overview see Kidd, Brandt, Lieven, & Tomasello, 2007). In this article, we focus on the role of canonical word order as one contributing factor to the subject-object asymmetry. Across those languages in which the subject advantage has been observed, subject RCs follow the canonical SO¹/agent-patient word order of most transitive sentences (cf. Diessel & Tomasello, 2005; Wells, Christiansen, Race, Acheson, & MacDonald, 2009). Further support for word order as an important cue comes from studies of acquisition and processing in East-Asian languages, such as Chinese and Japanese, where the subject-object asymmetry is often neutralized or reversed (e.g., Chan, Matthews, & Yip, 2011; Hsiao & Gibson, 2003;

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¹SO = subject-object; OS = object-subject

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Suzuki, 2011). In these languages, object RCs, such as (4), display the canonical SO/agent-patient word order of most transitive sentences, whereas subject RCs, such as (3), display a non-canonical OS/patient-agent word order. The Cantonese examples are taken from Kidd, Chan, and Chiu (2015).

- (3) Sek3 gung1gai1 go2 zek3 lou5syu2.
 ___ kiss chicken **that-CL mouse**
 'The mouse that kissed the chicken'
 (4) Lou5syu2 sek3 go2 zek3 gung1gai1
 mouse kiss ___ **that-CL chicken**
 'The chicken that the mouse kissed'

Brandt, Lieven, and Tomasello (2016) have shown that German-speaking children apply the SO/agent-patient rule to both simple transitives and transitive RCs. In their Experiment 1, German-speaking 3- and 6-year-olds were asked to interpret simple transitives and transitive RCs without case marking (see examples (5) and (6)).

- (5) Das Pferd schubst jetzt die Kuh.
 the-NOM/ACC horse pushes now the-NOM/ACC cow
 'the horse is pushing the cow now/the cow is pushing the horse now'
 (6) Das Pferd, das die Kuh schubst.
 the-NOM/ACC horse who-NOM/ACC the-NOM/ACC cow pushes
 'the horse that is pushing the cow/the horse that the cow is pushing'

In principle, these sentences can be interpreted as SO/agent-first or as OS/patient-first. However, German-speaking adults show a strong preference to interpret these sentences as SO/agent-first (see MacWhinney, Bates, & Kliegl, 1984; Nitschke, Kidd, & Serratrice, 2010). Similarly, German-speaking 6-year-olds almost always applied the agent-first rule to both simple transitives and transitive RCs. That is, they interpreted at least 90% of both simple and complex transitives as SO/agent-first. The 3-year-olds, on the other hand, were more likely to apply the agent-first rule to simple transitives than to transitive RCs. They interpreted about 65% of the simple transitives and only 50% of the transitive RCs as SO/agent-first, suggesting that, for RCs at least, the children were at chance-level responding.

Brandt et al.'s (2016) Experiment 2 confirmed previous findings that German-speaking children struggle with OS/patient-first word orders in both simple transitives and transitive RCs when this interpretation is only signaled by case marking (cf. Dittmar, Abbot-Smith, Lieven, & Tomasello, 2008). Another group of 3- and 6-year-olds were asked to interpret sentences such as (7) and (8):

- (7) Den Vogel schubst jetzt der Hase.
 the-ACC bird pushes now the-NOM rabbit
 'the rabbit is pushing the bird now'
 (8) Der Vogel, den der Hase schubst.
 the-NOM bird who-ACC the-NOM rabbit pushes
 'the bird who the rabbit is pushing'

The younger children performed at chance on both simple transitives and transitive RCs. The older children performed above chance on the simple transitives and at chance on the transitive RCs. Overall, these results suggest that (i) German-speaking children develop a strong tendency to interpret both simple and complex transitives as SO/agent-first when there are no other cues besides word order, and (ii) even 6-year-olds struggle with an OS/patient-first interpretation of transitive RCs when this interpretation is only signaled by case marking.

Priming patient-first structures

One way to alter children's and adults' strong processing preferences for agent-first structures is to increase the number of patient-first structures in their input. As is the case for object RCs in languages like English and German, in (full) passives, the patient is mentioned before the agent. As has been shown for other patient-first structures (e.g., Brandt et al., 2016; Dittmar et al., 2008), children struggle with the non-canonical word order in passives in both production and comprehension (e.g., Gordon & Chafetz, 1990; Harris, 1976).

Although passives are difficult for young children, several structural priming studies have demonstrated that exposure to a high number of passives can significantly increase their production and comprehension of this patient-first structure (e.g., Kidd, 2012; Messenger, Branigan, & McLean, 2011; Vasilyeva, Huttenlocher, & Waterfall, 2006). These priming effects can be long lasting, exerting their effect on production and comprehension beyond their immediate effects on subsequent experimental trials (e.g., Bock & Griffin, 2000; Savage, Lieven, Theakston, & Tomasello, 2006; Vasilyeva et al., 2006). Typically, these results have been interpreted to reflect implicit learning of structure, following theoretical models of priming that argue that priming results in representational change (e.g., Chang, Dell, & Bock, 2006). Such learning-based models of priming therefore predict that prime sentences act directly upon and alter linguistic representations. In acquisition, this leads to the prediction that priming effects will differ depending on representational strength. There is evidence for this assertion, although exactly how priming acts upon linguistic representations of differing strength is unclear. Some studies have found that children and less experienced speakers and adult L2 learners show greater priming effects than adult native speakers (e.g., Hartsuiker & Kolk, 1998; Nitschke, Serratrice, & Kidd, 2014; Rowland, Chang, Ambridge, Pine, & Lieven, 2012), suggesting that weaker representations are more easily primed and strengthened.

However, results from other studies suggest that priming effects are stronger in older children, adults, and advanced L2 learners than in younger children and less advanced learners (e.g., Arai & Mazuka, 2014; Kim & McDonough, 2008; Peter, Chang, Pine, Blything, & Rowland, 2015; Savage, Lieven, Theakston, & Tomasello, 2003). In fact, priming effects are usually interpreted as evidence for abstract representations of specific syntactic structures (e.g., Bock, 1989), which can take time to emerge, especially when they are infrequent in the learners' input (e.g., Tomasello, 2003). For example, Savage et al. (2003) have found that 3- and 4-year-olds only increased their production of passive structures when they could use the same pronouns in the target as in the prime sentences. Six-year-olds, on the other hand, also showed priming in the absence of any lexical overlap between primes and targets. Savage et al. suggested that this interaction between lexical overlap and age indicates that 6-year-olds have an abstract representation of passives, whereas the younger children's representation of the passive is still lexically specific (for similar findings in L2 learners see Kim & McDonough, 2008).

Priming the comprehension of object relative clauses in English and German

Recent studies with adults have also shown training and priming effects for more complex structures such as object RCs. These studies suggest that the processing of object RCs disproportionately benefits from increased exposure to RCs. For example, Wells et al. (2009) used a self-paced reading paradigm to test the effect of increased exposure to subject and object RCs with English-speaking adults. Before the exposure phase, participants showed longer reading times for object RCs. In the exposure phase, the training group was exposed to the same number of subject and object RCs and some unrelated structures while the control group was exposed to other complex structures. Both groups were again tested on their online processing of subject and object RCs post-training. Crucially, the training group no longer showed a significant subject-RC advantage post-test.

Other studies have reported similar findings. Hutton and Kidd (2011) reported on a structural priming study that primed English subject and object RCs using self-paced reading. Subject-and

object-RC primes were fully crossed with subject and object RC targets. The results revealed that object RC-object RC pairs resulted in a larger priming effect than subject RC-subject RC pairs, suggesting that the non-canonical object RCs profit greater from increased exposure via priming. Furthermore, Scheepers and Crocker (2004) showed that German-speaking adults were more likely to interpret temporarily ambiguous transitives as patient-first after hearing other patient-first transitive clauses. An exposure to agent-first transitives, however, did not significantly increase the likelihood to interpret a temporarily ambiguous transitive as agent-first. The general finding that patient-first structures are more strongly affected by training and priming than agent-first structures has been taken as evidence that the processing of simple and complex patient-first structures is less well entrenched and thus more sensitive to an increased exposure of patient-first structures (e.g., Wells et al., 2009).

Finally, Nitschke et al. (2010, 2014) investigated how adults' experience with ambiguous RCs can change their interpretation of these RC types. Since the current study made use of the same design, we provide a more detailed description here. They tested native speakers and English L2 learners of German and Italian. We will focus on the German data here and just note that the Italian speakers and L2 learners showed similar patterns. The experiments consisted of three phases: baseline, priming, and post-test. Ambiguous RCs, such as (9), were presented as primes and targets.

- (9) Hier ist die Frau, die das Mädchen umarmt.
 here is the-NOM/ACC woman that-NOM/ACC the-NOM/ACC girl hugs
 'here is the woman that is hugging the girl'
 'here is the woman that the girl is hugging'

These sentences can, in principle, be interpreted as agent-first subject RCs or as patient-first object RCs. For the target items, both interpretations were available. That is, participants saw two pictures, one showing the agent-first subject-RC interpretation and the other showing the patient-first object-RC interpretation (see bottom panel of Figure 1).

During the baseline and post-test phase participants were asked to interpret ambiguous target items only. During the prime phase each ambiguous target item was preceded by a prime forcing a patient-first object-RC interpretation, achieved by only making the object-RC reading available to participants. In the first study (Nitschke et al., 2010), each target sentence contained the same RC verb as the preceding prime sentence (see top panel of Figure 1). During the baseline phase, native speakers of German interpreted almost all target items as agent-first subject RCs. During the prime phase and in the post-test, their agent-first interpretation significantly decreased to about 85%. The L2 learners interpreted only about 65% of the target items as agent-first in the baseline, but this tendency also decreased to only 25% in the prime phase and in the post-test.

These results were replicated without any lexical overlap between prime and target items and with case-disambiguated primes, such as (10) (see Experiments 1 and 2 in Nitschke et al., 2014; for cross-linguistic English-German priming see Kidd, Tennant, & Nitschke, 2015).

- (10) Hier ist die Frau, die **der** Mann küsst.
 here is the-NOM/ACC woman that-NOM/ACC **the-NOM** man kisses
 'here is the woman that the man is kissing'

The disambiguated primes were used to rule out the possibility that the ambiguous primes used in the first study caused a conscious change in participants' processing strategy. Native speakers and learners of German have a strong tendency to interpret ambiguous RCs as agent-first subject RCs (Nitschke et al., 2010). The pictures accompanying the prime items, however, only showed a patient-first interpretation. The mismatch between the preferred agent-first interpretation and the patient-first interpretation shown in the pictures could have drawn the participants' attention to the manipulation. In contrast, case-disambiguated primes, such as (10), must be interpreted as patient-first. That these unambiguous primes led to the same priming effect in the interpretation of the ambiguous target items suggests that the priming effect observed with ambiguous prime items was not driven by any conscious

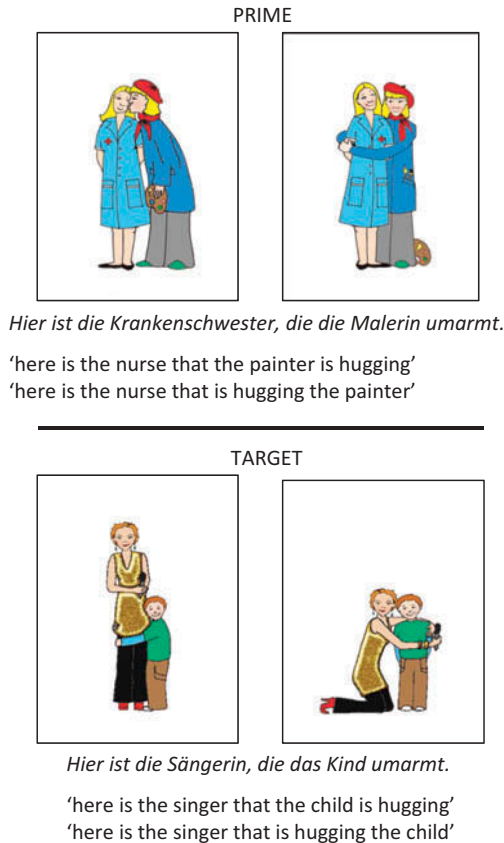


Figure 1. Primes and targets with lexical overlap (Nitschke et al., 2010).

processing strategy. That is, it is unlikely that participants strategically changed their interpretation of ambiguous RCs to patient-first after detecting the mismatch between their preferred agent-first interpretation and the patient-first interpretation displayed in the pictures. In addition, that the same priming effect could also be found without any lexical overlap between primes and targets suggests that the prime items strengthened the representation and facilitated the processing of patient-first object RCs on an abstract level.

To summarize, native adult speakers of German have a very strong tendency to interpret ambiguous RCs as agent-first subject RCs. L2 learners of German exhibit the same tendency, but it is less pronounced. Both native speakers’ and learners’ tendency to interpret ambiguous RCs as agent-first can be decreased by exposing them to ambiguous and disambiguated prime items that require a patient-first object-RC interpretation.

Priming the comprehension of object relative clauses in German-speaking children

Between the ages of 3 and 6, German-speaking children also develop a strong tendency to interpret ambiguous RCs as agent-first subject RCs (Brandt et al., 2016). Based on the adult studies summarized above, we should expect that an increased exposure to object RCs will prime and strengthen German-speaking children’s tendency to interpret ambiguous RCs as patient-first object RCs. This would show how structural representations are affected by the input and support the view that priming effects indicate implicit learning (cf. Chang et al., 2006).

On the other hand, priming should only occur once children have acquired an abstract representation of the primed structure (cf. Savage et al., 2003). Previous studies on children's acquisition of RCs suggest that it takes them a long time to develop fully abstract representations of object RCs, and that even German-speaking 6-year-olds struggle to correctly interpret object RCs when the patient-first order is only signaled by case marking (see Brandt et al., 2016). Therefore, we might expect to see stronger priming effects in the 9-year-olds than in the 6-year-olds that were tested in the current study.

In addition, we explored the issue of lexical overlap in structural priming. For adults, but not for children, it has been found that priming effects can be significantly increased when the prime and the target sentence contain the same verb (Peter et al., 2015; Pickering & Branigan, 1998; Rowland et al., 2012). On the other hand, Savage et al. (2003) found that 3- and 4-year-olds only show priming effects when the prime and the target sentence contain the same pronoun. Finally, Cleland and Pickering (2003) and Branigan, McLean, and Jones (2005) found that both adults and children between the age of 3 and 5 show greater priming effects when the prime and the target sentence contain the same noun. More specifically, children and adults were more likely to use the same ADJ-NP (e.g., *the red ball*) or NP-RC (e.g., *the ball that's red*) structure when prime and target contained the same noun (e.g., *ball*). These previous studies all investigated priming in production. In the current study we investigated whether lexical overlap between the head noun of the RCs in prime-target pairs influences priming in comprehension.

Finally, in order to exclude the possibility that the mismatch between the patient-first reading displayed by the prime pictures and the preferred agent-first interpretation of ambiguous RCs leads to any conscious and strategic changes in children's processing strategies (cf. Nitschke et al., 2014), we also included a condition that tested case-disambiguated primes.

Method

Participants

We ran a pilot study with 19 3- and 4-year-old German-speaking children and used the same three-phase design as Nitschke et al. (2010). However, as has also been shown by Brandt et al. (2016), these younger children did not show any clear processing preferences for ambiguous RCs in the baseline. We return to the pilot data in the Discussion. For the final sample, we tested 6- and 9-year-olds, who have a clear preference to interpret ambiguous RCs as subject-first (cf. Brandt et al., 2016). A total of 105 German-speaking children participated. Fifty-one children were between 6;0 and 6;11 (mean 6;5) and 54 were between 9;0 and 9;11 (mean 9;6). The 6-year-olds were recruited and tested in kindergartens and the 9-year-olds were recruited and tested in schools in a midsize German city. All were growing up monolingual; none had any known language impairments.

Materials

The experiment contained 78 sentences. Thirty-six of these sentences served as targets. These target sentences were ambiguous transitive RCs, such as (9) above, which can be interpreted as agent-first or patient-first. Another 12 sentences served as primes, which had to be interpreted as patient-first. The remaining 30 sentences served as fillers to distract the children from the RC structure. The filler sentences consisted of simple sentences with transitive (e.g., *wo kitzelt das Mädchen den Jungen?* 'where is the girl tickling the boy') or intransitive actions (e.g., *wo tanzt der Großvater?* 'where is the grandfather dancing'), and sentences with prepositional phrases (e.g., *wo fährt das Mädchen mit dem Fahrrad?* 'where is the girl riding on her bicycle').

All 78 sentences were pre-recorded by a male native speaker of German. Each of these 78 sentences was accompanied by two pictures (see Figures 2–4 below). The unit of one sentence and its corresponding pair of pictures will be called an *item*. The material was prepared for three between-subjects conditions: (i) an "ambiguous primes" condition in which the prime sentences were ambiguous, but only one picture matched the sentence (see Figure 2), (ii) a "case disambiguated primes" condition in which the prime



Figure 2. Ambiguous primes.

sentences were disambiguated by case marking but also matched only one of the pictures (see Figure 3), and (iii) an “NP1 overlap” condition in which the ambiguous prime sentences and the target sentences contained the same head NP (e.g., *die Krankenschwester* “the nurse” in Figure 4).

In German case is marked on adjectives, determiners, and pronouns (including relative pronouns). For masculine nouns nominative and accusative case have distinct surface forms and therefore unambiguously signal thematic role assignment. This is not the case for feminine and neuter nouns, where nominative and accusative case are marked by the same forms. Therefore, in the “ambiguous primes” and in the “NP1 overlap” conditions all human characters were female or neuter, making the sentence ambiguous. In these conditions, the 48 RCs were assembled out of 12 different nouns of either feminine or neuter gender. Six different verbs were used (see test sentences in the Appendix). In the “case disambiguated primes” condition, the 36 target RCs were assembled out of the same 12 feminine or neuter nouns and the same six verbs from the “ambiguous primes” condition. Additionally, 12 different masculine nouns were used in the prime sentences (see test sentences in the Appendix).

Procedure

Each child was assigned to one of two groups by age and randomly to one of the three prime conditions, see Table 1.

The structural priming task was presented using E-Prime 2 (MacWhinney, James, Schunn, Li, & Schneider, 2001) on a laptop computer. The children were told that they were going to play a game where they had to find pictures. Each child was tested individually in a quiet room in their kindergarten or school.



Figure 3. Case disambiguated primes.

Prior to participating in the experiment the children were tested on 24 warm-up items that required them to identify all characters that were used later in the experimental items. The children were shown two pictures (e.g., of a nurse and a grandmother) and heard an audio (e.g., *Wo ist die Krankenschwester?* 'Where is the nurse'). The overwhelming majority of children knew all characters. When a child could not name a character the experimenter named it for them.

The children then moved on to the experimental items. For each item the pictures were displayed first. Following a delay of 1,000 ms a pre-recorded description was played. The children's task was to point to the appropriate picture. The picture display did not time out and the children were given the option to hear the sentence again if required.

Following Nitschke et al. (2010, 2014), the picture selection task was divided into three continuous phases: (i) a baseline phase, (ii) a prime phase, and (iii) a post-test phase. All three phases contained pairs of transitive RCs separated by one or two fillers. In the prime phase, each pair was made up of the prime and the target item. In the baseline and post-test phases ambiguous RCs were presented throughout.

In the baseline phase all ambiguous RCs were presented together with pictures providing both the patient-first object RC reading and the agent-first subject RC reading of each sentence (see target items in Figures 2–4). This phase served to determine whether the children had a (strong) tendency to interpret the ambiguous RCs as agent-first.

During the prime phase, the first RC of each RC pair was disambiguated to a patient-first object-RC reading and served as a prime (see primes in Figures 2–4). Only one picture, which displayed the patient-first object-RC reading, matched the prime sentence. Another picture in which the role assignment also corresponded to the patient-first mapping, but which showed an action that did not



Figure 4. NP1 overlap.

Table 1. The six participant groups.

	Ambiguous primes condition	Case disambiguated primes condition	NP1 overlap condition
Age 6	<i>Age 6, ambig</i> (n = 15)	<i>Age 6, case</i> (n = 18)	<i>Age 6, NP1 overlap</i> (n = 18)
Age 9	<i>Age 9, ambig</i> (n = 18)	<i>Age 9, case</i> (n = 18)	<i>Age 9, NP1 overlap</i> (n = 18)

match the verb of the description (see top panel of Figures 2–4), acted as a distracter. In the “case disambiguated primes” condition, the prime was also disambiguated by case marking on the first and second NP. In all conditions, the second RC of each prime-target pair, the target, was fully ambiguous and provided both interpretations (agent-first subject RC and patient-first object RC) (see bottom panel of Figures 2–4).

The post-test phase was constructed like the baseline phase. Each phase contained 12 ambiguous RC target items; the prime phase contained an additional 12 RC prime items. The logic behind the design was that, by restricting the choice to a patient-first object-RC mapping in the prime items, the children would be primed to select the patient-first scene in the target items despite also having the agent-first scene available.

Six fully balanced lists were created so that each target item occurred in each of the three phases across the participants. Additionally, the location of the picture with the patient-first scene (left picture vs. right picture) was fully balanced throughout the experiment. In each picture paired with the RCs the first NP (i.e., the head NP) was on the left and the second NP (i.e., the embedded NP) was on the right, allowing a left-to-right analysis of each picture (see Figures 2–4).

Results

Figure 5 shows the proportions of patient-first object-RC interpretations of the ambiguous target items for the two age groups in each condition and phase.

To investigate the patterns in Figure 5, the data were analyzed using Generalized Linear Mixed Models (GLMM) (Baayen, Davidson, & Bates, 2008) with the lme4 package (version 1.17) for Linear Mixed Effects (Bates, Maechler, Bolker, & Walker, 2014) in R, version 3.12. Following Jaeger (2008) we fitted a logistic generalized linear mixed model using forward selection. Random slopes and random intercepts were included. One after another we added Phase (baseline, prime-phase, post-test), Age (6, 9), and Prime Type (ambiguous primes, case disambiguated primes, NP1 overlap) to the null model. The predictors Phase (baseline = -0.5, prime-phase = 0, post-test-phase = + 0.5), Age (age 6 = -0.5; age 9 = + 0.5) and Prime Type (ambiguous primes = -0.5; case disambiguated primes = 0; NP1 overlap = 0.5) were coded as numbers and centered in order to reduce collinearity. Model improvement was tested using likelihood-ratio tests.

The model improved with adding Phase ($\chi^2(1) = 10.22, p = .001$), Age ($\chi^2(1) = 13.46, p < .001$), and Phase*Age ($\chi^2(1) = 14.86, p < .001$). Adding Prime Type, however, showed no further improvement ($\chi^2(1) = 0.20, p = .65$) and no improvement at any other stage of model selection (all $p > .50$). The final model is shown in Table 2. The final model was unaffected by any collinearity ($K = 1.0$).²

The interaction between Age and Phase is plotted in Figure 6. As Figure 6 shows, the source of the interaction between Age and Phase is rooted in the increase of patient-first choices from the baseline phase to the prime phase in the 9-year olds while the 6-year olds made slightly less patient-first choices from the baseline to the prime phase.

We next analyzed the data for each of the six participant groups separately leaving Phase as the only predictor. Table 3 shows the likelihood ratio test of each condition and the results of the models if the likelihood ratio test was significant.

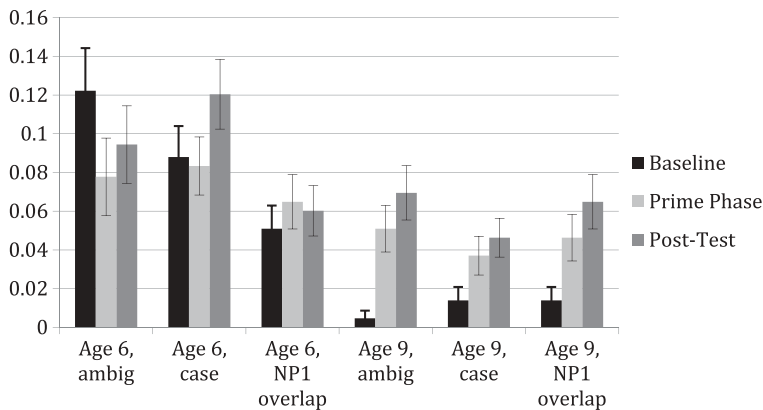


Figure 5. Proportions of patient-first interpretations for both age groups in each condition (error bars represent +/-1SE).

Table 2. Final model for the combined data of all four conditions.

Predictor	Estimate	SE	z	p
(Intercept)	-3.51	0.17	-20.37	<.001
Phase	0.86	0.21	4.20	<.001
Age	-1.28	0.32	-4.09	<.001
Phase*Age	1.58	0.41	3.74	<.001

²Function kappa.mer() on <https://github.com/aufrank/Rhacks/blob/master/mer-utils.R>; no collinearity: $K < 6$; medium collinearity: $K \geq 15$; severe collinearity: $K \geq 30$.

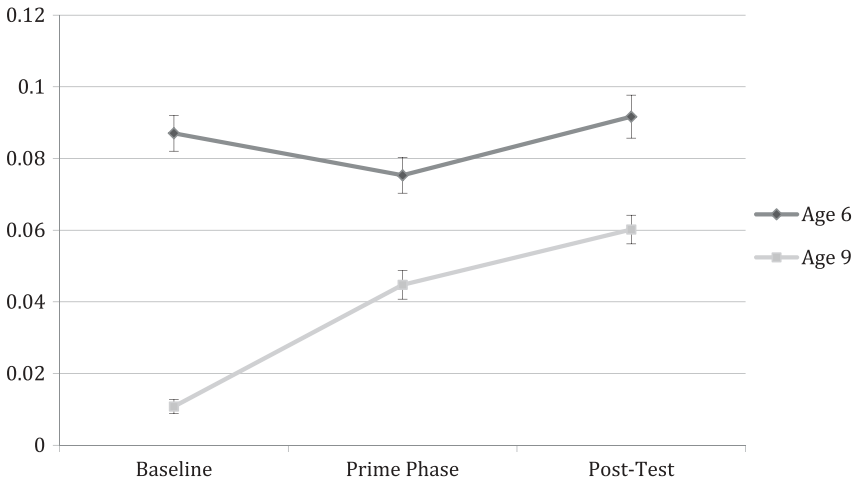


Figure 6. Proportions of patient-first interpretations for both age groups across conditions (error bars represent +/-1SE).

Table 3. GLMMs for each condition.

Condition	Likelihood ratio test $\chi^2(1) =$	Predictor	Estimate	SE	z	p
Age 6, ambig	0.87, $p = .35$					
Age 6, case	1.48, $p = .22$					
Age 6, NP1overlap	0.17, $p = .68$					
Age 9, ambig	14.60, $p < .001$	(Intercept)	-5.43	1.00	-5.42	<.001
		Phase	2.24	0.65	3.46	<.001
Age 9, case	3.77, $p = .052$	(Intercept)	-3.75	0.43	-8.83	<.001
		Phase	1.1	0.59	1.88	.061
Age 9, NP1 overlap	8.95, $p < .01$	(Intercept)	-4.48	0.61	-7.33	<.001
		Phase	1.70	0.61	2.80	.005

Significant effects of Phase were only found with the 9-year olds. As evident from Figure 6, this is due to the increase of patient-first choices across the experiments. In contrast, the decreases and increases of patient-first choices in the 6-year olds across the experiment were not significant.

We followed up the data of the 9-year olds groups by comparing children’s performance across the phases. The results are shown in Table 4.

As Table 4 shows, the 9-year olds that were primed using ambiguous prime sentences or pairs of ambiguous primes and targets with NP1 overlap showed an immediate effect of priming (i.e., from the Baseline to the Prime-Phase) as well as a longer term effect of priming over the Post-Test phase (i.e., from the Baseline to the Post-Test). The 9-year olds who were primed using transitive RCs with

Table 4. Post-hoc analyses for 9-year old children.

Condition	Phases	Likelihood ratio test $\chi^2(1) =$	Predictor	Estimate	SE	Z	p
Age 9, ambig	base vs. prime	10.93, $p < .001$	(Intercept)	-4.08	0.84	-4.85	<.001
			Phase	5.32	2.16	2.46	.01
	base vs. post	18.06, $p < .001$	(Intercept)	-7.29	2.41	-3.02	<.005
			Phase	3.29	1.13	2.91	<.005
Age 9, case	base vs. prime	2.46, $p = .12$	(Intercept)	-3.90	0.47	-8.23	<.001
			Phase	1.26	0.67	1.88	.061
	base vs. post	4.15, $p < .05$	(Intercept)	-3.85	0.67	-5.76	<.001
Age 9, NP1 overlap	base vs. prime	4.42, $p = .04$	(Intercept)	2.67	1.38	1.94	.05
			Phase	1.96	0.72	2.72	<.01
	base vs. post	9.78, $p < .01$	(Intercept)	-4.75	0.73	-6.54	<.001
			Phase	1.96	0.72	2.72	<.01

number of object RCs. In other words, we were able to decrease the proportion of preferred agent-first interpretations and increase the proportion of dispreferred patient-first interpretations in 9-year-olds' processing of ambiguous RCs. The increase of dispreferred patient-first interpretations was evident in both the priming and the post-test phase. Taken together, these findings suggest that it may take children a long time to develop a fully abstract representation of object RCs (cf. Brandt et al., 2016) that can be further supported by an increased exposure to object RCs (cf. Nitschke et al., 2010; Wells et al., 2009). In the remainder of this article, we discuss the issue of long-term priming effects, developmental differences, task effects, and the issue of lexical overlap between primes and targets.

Long-term priming effects and cumulative learning

The 9-year-olds showed priming effects in both the priming and the post-test phase. This indicates that exposure to an increased number of syntactic patterns that deviate from the canonical agent-first word order can lead to small but significant and long-lasting changes in processing preferences and the use of word order as a cue to thematic roles.³ Since the time gap between the priming and the post-test phase was minimal in the current study, future research will have to investigate whether the changes in processing preferences would still be evident after a couple of hours, days or weeks. Previous studies with both children and adults suggest that they can be (e.g., Bock & Griffin, 2000; Savage et al., 2006; Vasilyeva et al., 2006; although see Kidd, 2012), and these long-term effects indicate that priming can be seen as a form of implicit learning, whereby linguistic representations are altered (Chang et al., 2006).

Further support for the idea of implicit learning comes from the cumulative learning effects partly observed within the prime phase in the older age group. Depending on the condition, the proportion of patient-first interpretations of the ambiguous RCs increased from 2–3% during the first half of the prime phase to 6–8% during the second half of the prime phase (see Table 5 above). This gradual increase indicates that the more patient-first primes the children experienced, the more likely they were to interpret the ambiguous target items as patient-first. If priming merely reflected an activation of abstract syntactic structures, rather than implicit learning, we would not expect to see a gradual increase but a clear priming effect after the first prime item (Pickering & Branigan, 1998; Thothathiri & Snedeker, 2008).

Developmental differences and task effects

Before we tested 6- and 9-year-old German-speaking children, we ran a pilot study with 19 children between the ages of 3 and 4. However, as has also been shown by Brandt et al. (2016), these younger children did not show any strong processing preferences for ambiguous RCs. In the baseline phase, they interpreted 38% of the ambiguous RCs as patient-first object RCs. In the prime phase, when the ambiguous RCs were preceded by primes forcing a patient-first object-RC interpretation, the proportion of patient-first interpretations of the ambiguous targets decreased to 28%. In the post-test phase, where children's unprimed interpretation of ambiguous RCs was again measured, the proportion of patient-first interpretations was at 31%. So, if anything, we found a reverse priming effect in these younger children. We suggest that the 3- and 4-year-old children did not show priming because of their current immature structural knowledge and explain this with reference to error-based learning (Chang et al., 2006).

According to error-based learning (Chang et al., 2006), priming occurs in contexts where one structure (e.g., active) is predicted, but another structure (e.g., passive) is encountered. That is, the processor errs in predicting a specific, frequent, structure. If this mismatch between predicted and encountered structure occurs multiple times, the processor will readjust and slowly become more likely to expect the otherwise unpredicted structure (e.g., passive). Furthermore, in order for this priming mechanism to work, the

³By long-lasting we mean persistence beyond adjacent prime-target pairs (e.g., Bock & Griffin, 2000).

processor must be able to predict both structural alternatives. For example, children must be able to predict both actives and passives. In other words, priming will only occur after children have learned passives and, since passives are relatively rare in children's input, might only be evident in older children (cf. Savage et al., 2003). In addition, priming effects will be strongest in contexts where one structure is strongly predicted and the alternative structure is encountered (cf. Arai & Mazuka, 2014).

For ambiguous RCs it has been shown that 3- and 4-year-olds do not have any strong processing preferences. It would thus be difficult to alter their processing of these ambiguous structures and show priming effects. Six-year-olds, however, have a strong tendency to interpret ambiguous RCs as agent-first subject RCs. In the current study and in (Brandt et al., 2016), they interpreted about 90% of the ambiguous RCs as agent-first subject RCs.⁴ In the current study, this expectation of an agent-first interpretation was not met during the prime phase, where children only saw pictures displaying patient-first interpretations. Therefore, we could have expected the 6- and the 9-year-olds to show priming effects, but we only found priming effects in the older age group. As mentioned before, this could mean that the children in the younger age group have not yet developed a fully abstract representation of object RCs. In other words, they were not able to predict the patient-first interpretation of the ambiguous RCs. Similar findings have been reported in studies that attempted to prime children's production of passives (e.g., Savage et al., 2003). However, we must also note that our task differed from most previous priming tasks and that the developmental differences might also partly be driven by these task effects. First of all, we used structurally ambiguous RCs, whereas in previous studies, children were primed with unambiguous structures. Secondly, we were attempting to prime the dispreferred interpretation of these ambiguous RCs by showing only patient-first interpretations for the prime items. Children's performance on the prime items suggests that this attempt to prime was not always successful. That is, not all children accepted the patient-first reading of the primes (see Table 7).

The children who did not accept the patient-first interpretation of the ambiguous RCs would say that neither of the two pictures matched the sentence. That is, they did not understand that you could interpret structurally ambiguous RCs as patient-first. However, excluding these children from the analyses does not greatly affect the magnitude of the priming effect. The numbers only change for the 9-year-olds in the ambiguous primes condition. In this condition, only nine out of 18 9-year-olds accepted the patient-first interpretation of the ambiguous primes. If we only look at these children's patient-first interpretations across the experiment, they show an increase from 0% in the baseline to 10% in the prime phase and an additional increase to 14% in the post-test phase. These findings support Kidd's (2012) suggestion that priming effects do not just vary across development, but that they can also vary greatly between individuals. Kidd also found that the magnitude of priming effects correlates with children's general linguistic abilities and their non-linguistic pattern-finding skills. In our case, the 9-year-olds who were ready to interpret ambiguous RCs as patient-first showed greater priming effects than the children who rejected this patient-first interpretation.

Future research will have to show whether this readiness can also be predicted by more general linguistic and non-linguistic measures. Future research will also have to show whether alternative tasks, such as picture description, might yield priming effects for children's use of subject and object RCs in younger age groups. As discussed in the Introduction, we can only speculate about the various mechanisms that drive priming effects observed in experimental studies with children and adults and whether and under what circumstances we should expect developmental differences in priming effects (see also Rowland et al., 2012). In other words, future research is needed to determine the extent to which priming *depends on* the representational strength of abstract syntactic structures and the extent to which priming can *affect* the representational strength of abstract syntactic structures.

⁴That the 6-year-olds still showed a lower proportion of agent-first interpretations than the 9-year-olds is probably due to the fact that the task was demanding for the younger age group—as it contained complex, ambiguous test sentences with two lexical NP's—and that we can, thus, expect to see some noise in the data.

Table 7. Mean proportions and range of patient-first interpretation of the prime items across children

	Ambiguous primes	Case disambiguated primes	NP1 overlap
Age 6	71% (0–100%)	97% (83–100%)	78% (17–100%)
Age 9	58% (0–100%)	99% (92–100%)	87% (0–100%)

Does the priming effect reflect a conscious strategy?

In order to exclude the possibility that the mismatch between the patient-first reading displayed in the prime pictures and the preferred agent-first interpretation of ambiguous RCs leads to any conscious changes in children's processing strategies (cf. Nitschke et al., 2014), we also tested one group with case disambiguated primes (see Figure 3). For these disambiguated primes, children were more likely to accept the patient-first interpretation (see Table 7). The priming effect, however, was not greater than in the other conditions. In fact, in the case disambiguated condition, the 9-year-olds only showed a marginal priming effect in the post-test phase (see Table 4). That case disambiguated primes led to relatively smaller priming effects might indicate that the priming effects that we observed with ambiguous primes in the other two conditions were due to conscious changes in children's processing strategy. That is, participants might have strategically changed their interpretation of ambiguous RCs to patient-first after detecting the mismatch between their preferred agent-first interpretation and the patient-first interpretation displayed in the prime pictures. However, the fact that the priming effects were rather small in all conditions speaks against this explanation. If children had been aware that, in the context of the experiment, the RCs should all be interpreted as patient-first, we should have seen a greater increase in patient-first interpretations. However, the vast majority of ambiguous RCs were still interpreted as agent-first subject RCs. Moreover, the full model showed no significant interaction between prime type and phase (see Table 2).

Similarities across primes and targets

The current study suggests that lexical overlap between prime and target does not necessarily increase priming effects. That is, prime items that contained the same head NP as the target items did not lead to greater priming effects than prime items that contained different head NPs than the target items. Both prime types showed significant effects in the prime and post-test phase and the full model did not show an interaction between prime type and phase. In other words, unlike other priming studies, we did not find a lexical boost. However, the results from previous priming studies with children (and adults) are also mixed.

Looking at other priming studies that tested the effect of lexical overlap in noun slots, Savage et al. (2003) found that 3- and 4-year-olds only showed priming effects when the prime and the target sentence contained the same pronouns. Other studies, however, also found priming effects for young children's comprehension and/or production of passives without any lexical overlap (e.g., Bencini & Valian, 2008; Messenger et al., 2011). Cleland and Pickering (2003) and Branigan et al. (2005) found that both adults and children between the age of 3 and 5 showed greater priming effects in their production of ADJ-NP (e.g., *the red ball*) and NP-RC structures (e.g., *the ball that's red*) when the prime and the target sentence contained the same noun (e.g., *ball*). The studies that have found a greater priming effect when prime and target items contained the same nouns were primed production studies. As mentioned above, future research will have to investigate whether we can also prime children's production of subject and object RCs and whether there is a lexical boost in children's and adults' primed production of RCs.

Turning to priming studies that tested the effect of lexical overlap in verb slots, Rowland et al. (2012) did not find a lexical boost in 3- and 4-year-olds' primed production of dative structures (see also Peter et al., 2015). However, the 5–6-year-olds and adults did show a lexical boost. Furthermore, Thothathiri and Snedeker (2008) found a lexical boost in 3- and 4-year-olds' comprehension of

native structures. Interestingly, both production and comprehension studies found a greater lexical boost in the older children and in adults.

One interesting explanation suggested by Rowland et al. (2012) is that the lexical boost observed in older children and adults and the general priming effect that can also be observed in younger children are driven by two separate mechanisms. Rowland et al. propose that the lexical boost is associated with the activation of syntactic structures for which children and adults have already developed abstract representations (cf. Pickering & Branigan, 1998; Thothathiri & Snedeker, 2008). The general priming effect, on the other hand, is associated with implicit learning and the strengthening of abstract syntactic representations (cf. Chang et al., 2006). This could also explain why we were not able to find a lexical boost in the current study. Thothathiri and Snedeker (2008) suggested that we should only expect to see a lexical boost if children have experienced and learned the connection between specific verbs and syntactic constructions. Similarly, we could suggest that we should only see a lexical boost if children have experienced and learned the connection between the semantic properties of nouns and specific syntactic constructions. This would mean that we were unable to find a lexical boost in the current study because German-speaking children have very little experience with object RCs with animate head NPs like the ones we used in the current study (e.g., *where is **the nurse** that the painter is hugging*). They usually experience object RCs with inanimate head NPs (e.g., *where's **the pen** that the painter bought*) (cf. Kidd et al., 2007). The priming effect found for the older children suggests that increasing the exposure to these infrequent kinds of object RCs has small, but significant effects on children's interpretation of RCs.

Conclusions

Priming studies with children are still quite rare and the implications of priming effects for language acquisition theories are not entirely clear. In the current study, we were attempting to prime the dispreferred interpretation of a low-frequency structure, namely ambiguous RCs. The results indicate that it takes German-speaking children a long time to understand that these ambiguous structures can be interpreted as patient-first object RCs. At the same time, increased exposure to object RCs had a small, but significant and lasting effect on the older children's interpretation of these ambiguous structures, suggesting that priming also reflects implicit learning (cf. Chang et al., 2006). Future studies will have to show whether we would find the same priming and learning effects in children's production of subject and object RCs.

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Appendix

Ambiguous primes

- Wo ist das Kind, das die Krankenschwester bespritzt?
 'where is the child who the nurse is splashing'
 'where is the child who is splashing the nurse'
- Wo ist die Ballerina, die die Frau bespritzt?
 'where is the ballerina who the woman is splashing'
 'where is the ballerina who is splashing the woman'
- Wo ist die Malerin, die das Mädchen kämmt?
 'where is the painter who the girl is combing'
 'where is the painter who is combing the girl'
- Wo ist die Sängerin, die die Großmutter kämmt?
 'where is the singer who the grandma is combing'
 'where is the singer who is combing the grandma'
- Wo ist die Ärztin, die die Ballerina küsst?
 'where is the doctor who the ballerina is kissing'
 'where is the doctor who is kissing the ballerina'
- Wo ist das Mädchen, das das Kind küsst?
 'where is the girl who the child is kissing'
 'where is the girl who is kissing the child'
- Wo ist die Hexe, die die Sängerin schubst?
 'where is the witch who the singer is pushing'
 'where is the witch who is pushing the singer'
- Wo ist die Königin, die die Ärztin schubst?
 'where is the queen who the doctor is pushing'
 'where is the queen who is pushing the doctor'
- Wo ist die Großmutter, die die Fotografin umarmt?
 'where is the grandma who the photographer is hugging'
 'where is the grandma who is hugging the photographer'
- Wo ist die Krankenschwester, die die Malerin umarmt?
 'where is the nurse who the painter is hugging'
 'where is the nurse who is hugging the painter'

Wo ist die Frau, die die Königin weckt?
 'where is the woman who the queen is waking'
 'where is the woman who is waking the queen'
 Wo ist die Fotografin, die die Hexe weckt?
 'where is the photographer who the witch is waking'
 'where is the photographer who is waking the witch'

Case disambiguated primes

Wo ist der Clown, den der Junge bespritzt?
 'where is the clown who the boy is splashing'
 Wo ist der Fotograf, den der Koch bespritzt?
 'where is the photographer who the cook is splashing'
 Wo ist der Mann, den der Clown kämmt?
 'where is the man who the clown is combing'
 Wo ist der Polizist, den der Maler kämmt?
 'where is the police man who the painter is combing'
 Wo ist der Großvater, den der Polizist küsst?
 'where is the grandpa who the police man is kissing'
 Wo ist der Zauberer, den der König küsst?
 'where is the magician who the king is kissing'
 Wo ist der Koch, den der Doktor schubst?
 'where is the chef who the doctor is pushing'
 Wo ist der Seeman, den der Großvater schubst?
 'where is the sailor who the grandpa is pushing'
 Wo ist der Doktor, den der Mann umarmt?
 'where is the doctor who the man is hugging'
 Wo ist der König, den der Seemann umarmt?
 'where is the king who the sailor is hugging'
 Wo ist der Junge, den der Fotograf weckt?
 'where is the boy who the photographer is waking'
 Wo ist der Maler, den der Zauberer weckt?
 'where is the painter who the magician is waking'

Target items

Wo ist die Ballerina die die Fotografin bespritzt?
 'where is the ballerina who the photographer is splashing'
 'where is the ballerina who is splashing the photographer'
 Wo ist die Fotografin die die Sängerin bespritzt?
 'where is the photographer who the singer is splashing'
 'where is the photographer who is splashing the singer'
 Wo ist die Hexe die die Frau bespritzt?
 'where is the witch who the woman is splashing'
 'where is the witch who is splashing the woman'
 Wo ist die Königin die die Großmutter bespritzt?
 'where is the queen who the grandma is splashing'
 'where is the queen who is splashing the grandma'
 Wo ist die Malerin die die Ärztin bespritzt?
 'where is the painter who the doctor is splashing'
 'where is the painter who is splashing the doctor'

Wo ist die Sängerin die das Mädchen bespritzt?
 'where is the singer who the girl is splashing'
 'where is the singer who is splashing the girl'
 Wo ist das Kind das die Malerin kämmt?
 'where is the child who the painter is combing'
 'where is the child who is combing the painter'
 Wo ist die Ärztin die die Hexe kämmt?
 'where is the doctor who the witch is combing'
 'where is the doctor who is combing the witch'
 Wo ist die Frau die die Großmutter kämmt?
 'where is the woman who the grandma is combing'
 'where is the woman who is combing the grandma'
 Wo ist die Königin die das Kind kämmt?
 'where is the queen who the child is combing'
 'where is the queen who is combing the child'
 Wo ist die Krankenschwester die die Fotografin kämmt?
 'where is the nurse who the photographer is combing'
 'where is the nurse who is combing the photographer'
 Wo ist die Sängerin die die Ballerina kämmt?
 'where is the singer who the ballerina is combing'
 'where is the singer who is combing the ballerina'
 Wo ist das Kind das die Krankenschwester küsst?
 'where is the child who the nurse is kissing'
 'where is the child who is kissing the nurse'
 Wo ist das Mädchen das die Sängerin küsst?
 'where is the girl who the singer is kissing'
 'where is the girl who is kissing the singer'
 Wo ist die Fotografin die die Hexe küsst?
 'where is the photographer who the witch is kissing'
 'where is the photographer who is kissing the witch'
 Wo ist die Großmutter die die Königin küsst?
 'where is the grandma who the queen is kissing'
 'where is the grandma who is kissing the queen'
 Wo ist die Krankenschwester die die Frau küsst?
 'where is the nurse who the woman is kissing'
 'where is the nurse who is kissing the woman'
 Wo ist die Krankenschwester die die Malerin küsst?
 'where is the nurse who the painter is kissing'
 'where is the nurse who is kissing the painter'
 Wo ist das Kind das die Königin schubst?
 'where is the child who the queen is pushing'
 'where is the child who is pushing the queen'
 Wo ist die Ballerina die die Malerin schubst?
 'where is the ballerina who the painter is pushing'
 'where is the ballerina who is pushing the painter'
 Wo ist die Fotografin die die Ärztin schubst?
 'where is the photographer who the doctor is pushing'
 'where is the photographer who is pushing the doctor'
 Wo ist die Frau die das Mädchen schubst?
 'where is the woman who the girl is pushing'
 'where is the woman who is pushing the girl'

Wo ist die Frau die die Großmutter schubst?
 'where is the woman who the grandma is pushing'
 'where is the woman who is pushing the grandma'
 Wo ist die Großmutter die das Mädchen schubst?
 'where is the grandma who the girl pushing'
 'where is the grandma who is pushing the girl'
 Wo ist die Ärztin die die Hexe umarmt?
 'where is the doctor who the witch is hugging'
 'where is the doctor who is hugging the witch'
 Wo ist die Frau die das Mädchen umarmt?
 'where is the woman who the girl is hugging'
 'where is the woman who is hugging the girl'
 Wo ist die Königin die die Ärztin umarmt?
 'where is the queen who the doctor is hugging'
 'where is the queen who is hugging the doctor'
 Wo ist die Königin die die Malerin umarmt?
 'where is the queen who the painter is hugging'
 'where is the queen who is hugging the painter'
 Wo ist die Krankenschwester die die Ballerina umarmt?
 'where is the nurse who the ballerina is hugging'
 'where is the nurse who is hugging the ballerina'
 Wo ist die Sängerin die das Kind umarmt?
 'where is the singer who the child is hugging'
 'where is the singer who is hugging the child'
 Wo ist das Mädchen das die Ballerina weckt?
 'where is the girl who the ballerina is waking'
 'where is the girl who is waking the ballerina'
 Wo ist die Ärztin die die Ballerina weckt?
 'where is the doctor who the ballerina is waking'
 'where is the doctor who is waking the ballerina'
 Wo ist die Hexe die das Kind weckt?
 'where is the witch who the child is waking'
 'where is the witch who is waking the child'
 Wo ist die Hexe die die Krankenschwester weckt?
 'where is the witch who the nurse is waking'
 'where is the witch who is waking the nurse'
 Wo ist die Malerin die die Großmutter weckt?
 'where is the painter who the grandma is waking'
 'where is the painter who is waking the grandma'
 Wo ist die Sängerin die die Fotografin weckt?
 'where is the singer who the photographer is waking'
 'where is the singer who is waking the photographer'