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Abstract Priming and the Lexical Boost Effect across Development in a Structurally Biased Language

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Abstract: The present study investigates the developmental trajectory of abstract representations for syntactic structures in children. In a structural priming experiment on the dative alternation in German, we primed children from three different age groups (3–4 years, 5–6 years, 7–8 years) and adults with double object datives (Dora sent Boots the rabbit) or prepositional object datives (Dora sent the rabbit to Boots). Importantly, the prepositional object structure in German is dispreferred and only rarely encountered by young children. While immediate as well as cumulative structural priming effects occurred across all age groups, these effects were strongest in the 3- to 4-year-old group and gradually decreased with increasing age. These results suggest that representations in young children are less stable than in adults and, therefore, more susceptible to adaptation both immediately and across time, presumably due to stronger surprisal. Lexical boost effects, in contrast, were not present in 3- to 4-year-olds but gradually emerged with increasing age, possibly due to limited working-memory capacity in the younger child groups.

Keywords: structural priming across development; dative alternation; lexical boost; cumulative priming



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1. Introduction

A key question in developmental psycholinguistics is how abstract representations for syntactic structures develop in children and how such representations are integrated into the wider human language processing system. Within this field of research, a substantial number of studies have convincingly shown that children already possess abstract syntactic representations by the age of three or earlier (Bencini and Valian 2008; Branigan and McLean 2016; Gámez and Shimpi 2015; Huttenlocher et al. 2004; Kidd 2012a, 2012b; Messenger et al. 2011; Rowland et al. 2012; Shimpi et al. 2007; Thothathiri and Snedeker 2008a, 2008b). However, only relatively few studies have investigated how these abstract syntactic representations, once established, develop further with increasing age. Also, the potential role of particular linguistic properties of a specific syntactic structure, such as its frequency within the language, is not yet fully understood. It is these issues we focus on in the present study.

An effective methodological approach to studying the nature of syntactic representations in human beings is based on the phenomenon of structural priming, i.e., a speaker's tendency to re-use structures previously encountered (e.g., Bock 1986; Bock and Loebell 1990; Branigan et al. 2000a; Pickering and Branigan 1998). For example, after hearing a prime sentence with a prepositional-object (henceforth, PO) structure (e.g., *The waitress brought a tray of appetizers to the customers*), adult speakers are more likely to produce a PO sentence (e.g., *The woman gave the letter to the lawyer*) than an otherwise identical prime sentence with a double-object (DO) structure (e.g., *The waitress brought the customers a tray*

of appetizers). In experimental psycholinguistic research, structural priming effects can be used as a tool to gain insight into the nature of the syntactic representations involved in language processing and production. If a participant group shows structural priming effects, this can be considered evidence for abstract syntactic representations.

While it is largely uncontroversial that children already show structural priming effects by the age of three, several issues related to key observations from child priming studies remain unresolved. For instance, the results from such studies differ very considerably with respect to the *lexical boost effect*, i.e., the fact that priming effects tend to be stronger when prime and target share the same head verb. Studies investigating structural priming in adults show robust evidence for such lexical boost effects (e.g., Cleland and Pickering 2003; Gries 2005; Hartsuiker et al. 2008; Pickering and Branigan 1998; see Carminati et al. 2019 for a comprehensive review). In the adult literature, these effects are typically interpreted with reference to connections between abstract structural representations and lexical entries for verbs, which can serve as the head of the respective structure (see Pickering and Branigan 1998; van Gompel et al. 2023). For children, lexical boost effects have been subject to considerable debate. While some child priming studies found similar lexical boost effects as in adults (Branigan and McLean 2016; Morris and Scheepers 2015; Messenger and Hardy 2017), other studies did not but showed some numerical indication toward an increase of the lexical boost with growing age (Peter et al. 2015; Rowland et al. 2012; Thothathiri and Snedeker 2008b). Further, in a recent longitudinal study investigating priming for the active/passive alternation in English (Kumarage et al. 2022), children at the age of 36 months already showed significant abstract structural priming but no lexical boost effect. Instead, the lexical boost effect only gradually developed with increasing age, with the same children showing a robust lexical boost at 54 months of age. These results suggest that the lexical boost effect might be attributed to the development of working memory. The existing studies investigating the lexical boost in children differ substantially with regard to a wide range of potentially important properties, such as the experimental task, language, and type of structural alternation investigated, and whether they have looked at priming effects in production or comprehension.

Another key finding is that, in adults, exposure to more than one prime sentence with the same structure causes stronger priming, a finding known as the *cumulative priming effect* (e.g., Bock and Griffin 2000; Bock et al. 2007; Hartsuiker et al. 2008; Huttenlocher et al. 2004; Kaschak et al. 2011). While cumulative priming is discussed with reference to implicit learning and adaptation to external input (e.g., Jaeger and Snider 2008, 2013; Kaan and Chun 2018; Kaschak and Borreggine 2008; Kaschak et al. 2011)¹, cumulative priming effects in children have mainly been found in blocked designs (Gámez and Shimpi 2015; Huttenlocher et al. 2004; Kidd 2012a, 2012b; Savage et al. 2003, 2006; Serratrice et al. 2015) in which children were primed with one structural option throughout one session. To our knowledge, only three studies (Branigan and McLean 2016; Messenger 2021; Messenger et al. 2011) have tried to disentangle immediate and cumulative priming effects in an experimental design based on prime–target pairs within a single test session. However, the results from these studies are mixed and show inconsistent patterns.

Finally, prime sentences with infrequent, rarely encountered structures typically cause stronger priming, a finding referred to as *inverse frequency effect* (see Fine et al. 2013) or *prime surprisal* (see Jaeger and Snider 2008; Scheepers 2003). Peter et al. (2015) report the results from a PO/DO priming study in which they experimentally manipulated verb bias. Children showed stronger priming effects when the prime contained a verb in an unexpected structure. This effect was stronger in children than in adults, suggesting that surprisal effects may generally be enhanced in children.

1.1. Theoretical Accounts of Structural Priming

Several theoretical accounts trying to explain the underlying mechanisms of language processing and production responsible for structural priming effects have been proposed. *Residual Activation Accounts* (e.g., Pickering and Branigan 1998), for example, explain structural priming through the activation of stored, abstract representations for syntactic

structures (called *combinatorial nodes*) situated at the lemma stratum. These structural representations are activated during the processing of a prime sentence. Residual activation of this representation subsequently influences structural choices during the production of a target, causing structural priming. Additionally, Residual Activation Accounts assume connections between structural representations and the lexical representations of verb lemmas, which can be used as the head of the particular structure. When prime and target contain the same verb, activation spreads through these connections. This leads to increased activation of the respective combinatorial node, causing a lexical boost effect.

Given that Residual Activation Accounts explain structural priming through gradually decaying residual activation of a combinatorial node, such accounts predict that priming should be strongest when the target immediately follows the prime and should rapidly become weaker with additional sentences or additional time between prime and target. While the results from some studies (e.g., Branigan et al. 1999; Wheeldon and Smith 2003) indeed suggest that priming effects rapidly decay, other studies (e.g., Bock and Griffin 2000; Branigan et al. 2000b; Hartsuiker and Kolk 1998) have instead reported long-lasting priming, with robust priming effects even when prime and target were separated by a considerable number of intervening sentences and/or an extended time period. Based on this finding, the *Implicit Learning Account* explains priming as a form of implicit learning (Chang et al. 2006). The key assumption of the account is that each exposure to a particular sentence structure causes *long-lasting* changes to the respective structural representation. Specifically, the account assumes that during the processing of a sentence, the processor computes an expectation of its syntactic structure. If this expectation is not met (for instance, because the structure of the sentence is relatively rare in the language), syntactic representations are adapted and weight changes are applied. As a result, the system gradually acquires information about syntactic biases (e.g., the fact that the German dative alternation is strongly biased toward the DO) with each exposure through structural priming.

The Implicit Learning Account establishes a connection between sentence processing, structural priming, and language acquisition and is, thus, particularly well-suited to derive predictions for structural priming in children from it. For instance, children who, across their lifetime, have previously encountered a particular structure on only very few occasions (and whose respective structural representation is less stable in the sense that it is based on very few prior observations) should, when being primed by the respective structure, show particularly strong priming effects, due to surprisal. As a result, immediate priming effects should be enhanced in young children and should gradually decrease with higher age due to increased exposure to the structure.

As the account assumes that the effect of a prime should be long-lasting, priming effects should also emerge when the prime and target are separated by intervening linguistic input. Also, as each exposure to a prime sentence causes weight changes, exposure to several primes with the same structure should result in stronger priming, i.e., cumulative priming effects. Just like immediate priming effects, cumulative priming should initially be boosted by surprisal and should gradually decrease with increasing exposure to the structure.

Finally, with regard to the lexical boost effect, the account assumes that, during the formulation of the target, an additional lexical overlap between prime and target serves as a memory cue, which makes it easier to retrieve the prime's structure from memory and repeat it, causing a lexical boost effect (Bock and Griffin 2000; Chang et al. 2006, 2012). For adults, there is at least some experimental support for the claim that the lexical boost is connected to memory: Zhang et al. (2020), in a priming study manipulating the amount of working memory load during the experiment, found weaker priming effects when participants experienced high cognitive load. With regard to the lexical boost in children, the account suggests that lexical boost effects can only emerge when the individual possesses sufficient working-memory capacity. Thus, individuals with limited working memory capacity, such as young children, may show no lexical boost effect. Given that working memory capacity improves with increasing age due to maturation (Naito 1990; Sprondel et al. 2011), the model predicts that the lexical boost effect should gradually emerge with increasing age.

Newer accounts try to integrate residual activation and implicit learning (Ferreira and Bock 2006; Hartsuiker et al. 2008; Reitter et al. 2011) to account for immediate and cumulative priming effects. For instance, Reitter et al. (2011) suggested a hybrid account based on the ACT-R framework. The account is based on the assumption that structural priming effects consist of a short-term and a long-term component, in the sense that immediate priming effects are based partly on residual activation (as assumed by Residual Activation Accounts) and partly on long-term adaptation (as assumed by the Implicit Learning Account). Just like Residual Activation Accounts, this account explains lexical boost effects through associations between structural representations and lexical entries for words, which can occur as part of the respective structure, with spreading activation from the lexical entries causing additional activation of the structural representation. However, unlike in Residual Activation Accounts, such associations are not only assumed for verbs but also for other lexical material, which can occur as part of the respective structure. Thus, lexical boost effects should not only emerge when prime and target share the same verb but also for the repetition of other lexical material. Also, given that the lexical boost is assumed to be based entirely on spreading activation, the account predicts that, unlike the priming effect as such, the lexical boost should rapidly decay.

Unlike the Implicit Learning Account, Reitter's account makes no specific claims about how the assumed processing architecture develops during language acquisition in children. That said, both immediate and cumulative priming effects caused by residual activation should occur as soon as the individual possesses abstract representations for syntactic structures. The fact that priming effects are partly based on long-term adaptation should also lead to surprisal effects in children. Whether or not lexical boost effects emerge in children of a particular age depends on how quickly the assumed associations between structural representations and lexical entries can be established through associative learning.

1.2. The Present Study

Most previous studies investigating structural priming in children have only tested a single age group, and only a few studies have tested two age groups. As a result, fairly little is known about how the above-mentioned effects develop with increasing age. Although structural priming in children as such has been extensively investigated in languages other than English–Spanish (Gómez et al. 2009; Gómez and Shimpi 2015—transitive structures), Chinese (Hsu 2014—SVO-ba alternation with 5-year-olds), Italian (Contemori and Belletti 2023; Manetti and Contemori 2019—relative clauses), Japanese (Arai and Mazuka 2014—transitive structures), Dutch (van Beijsterveldt and van Hell 2009—adjective noun structures), French (Havron et al. 2020—syntactic ambiguities in PP-attachments), Russian (Vasilyeva 2012—transitive structures), and German (Brandt et al. 2017—ambiguous relative clauses; Lehmden 2013—transitive structures), priming effects for the dative alternation in languages other than English have received relatively little attention in child research. To our knowledge, only one such study has been conducted—a study by Wolleb et al. (2018) that investigated cross-linguistic structural priming between Norwegian and English and included a within-Norwegian control experiment with a small sample of Norwegian-speaking children aged 4;5 to 8;5. The results showed similar, significant priming effects within and across languages. Hence, it is not entirely clear to what extent the findings for English on the dative alternation can be generalized across languages.

The key goal of the present study was to gain insight into how syntactic representations in children develop with increasing age. In a German structural priming experiment for the dative alternation, we investigated abstract structural priming, the lexical boost, surprisal effects, and cumulative priming in children from three different age groups (3–4, 5–6, and 7–8) as well as adult controls. The case of the German dative alternation is interesting because, unlike English, German is biased toward the DO structure, even though the PO structure is possible with a wide range of different ditransitive verbs (Adler 2011; Callies and Szczesniak 2008; De Vaere et al. 2018; Drenhaus 2004; Proost 2014, 2015). Our examination of German child and child-directed speech in the CHILDES database revealed that children

between the ages of 1;5 and 7;5 only rarely hear or produce POs. Looking at a biased structure of this kind allows us to test one of the key predictions of the Implicit Learning Account (Bock and Griffin 2000), according to which language input is processed via an error-based learning mechanism (Chang et al. 2000). As a result, less frequent structures (such as the German PO structure) should yield stronger priming due to surprisal.

The task and design of our study are similar to Rowland et al. (2012) and Peter et al. (2015). As part of a bingo game, participants were exposed to a PO or otherwise identical DO prime sentence. Immediately after each prime, they described a video displaying an event that involved an agent, a recipient, and a theme. In addition, we experimentally manipulated whether the verb in the prime sentence and the verb required to describe the action displayed in the target video were the same or not. This design allows us to determine both abstract structural priming and lexical boost effects. We also tested a final exploratory hypothesis (which we did not specify a priori before data collection but which emerged from our preliminary analysis): Is it possible to distinguish between immediate priming (i.e., the influence of the specific prime preceding a target) and cumulative priming (i.e., a gradual increase of PO structures after encountering a number of PO prime sentences while the experiment proceeds)?

Our study addresses four main research questions. First, we assess the general structural bias in German and the strength of the initial representations of POs and DOs across age when not influenced by priming with ditransitive structures (baseline). We hypothesized that the PO structure, the dispreferred option, would be rarely produced by the youngest children but would be increasingly prevalent in older groups. We assumed, however, that the structural bias toward the DO would still be strong across all age groups.

Second, we investigate the developmental trajectory of abstract structural priming effects to gain insight into the stability of syntactic representations in children. If structural priming is indeed a form of implicit learning, the weights of syntactic representations should initially be less stable and, therefore, easier to prime. As a result, abstract structural priming (i.e., priming for prime–target pairs that do not share the same head) should be strongest in younger children, reflecting surprisal, and should subsequently decrease with age.

Third, we examine the lexical boost effect across age groups. Suppose we find abstract priming effects across all age groups but only a developmental trajectory for the lexical boost effect (i.e., lexical boost only in older age groups), that would support Chang et al.'s (2006) assumption that the lexical boost is strongly associated with working memory and emerges across time. Based on Rowland et al.'s (2012) and Peter et al.'s (2015) results, which only observed a numerical trend toward a lexical boost effect in 5- to 6-year-olds, we hypothesize that a significant effect might be present in the 7- to 8-year-olds.

Finally, we investigate cumulative priming during the experiment. According to the Implicit Learning Account, cumulative priming effects should occur as a function of adaptation to the syntactic form with increasing input, irrespective of whether the particular prime immediately preceding a target was a PO or a DO. In our experiment, the dispreferred PO structure is encountered considerably more often than in natural language (given that 50% of all experimental primes are POs). This increased exposure to PO structures should lead to cumulative priming, with a gradual increase of PO targets while the experiment proceeds. Just as for immediate priming, if it is indeed the case that syntactic representations in young children are less stable, 3- to 4-year-olds should show stronger cumulative priming effects than the older groups.

2. Materials and Methods

2.1. Participants

A total of 193 native German-speaking children and adults participated in the study. Specifically, the sample consisted of sixty 3- to 4-year-olds (mean age 3;9, range 3;1–4;11), fifty 5- to 6-year-olds (mean age 5;8, range 5;0–6;10), forty-five 7- to 8-year-olds (mean age 7;9, range 7;0–8;11), and thirty-seven adults (mean age 25;0, range 20–35). No participants were reported as being diagnosed with any cognitive impairment. Fifteen additional children were recruited but excluded from analysis because they did not complete the experimental session.

The children were tested in a separate room in their nurseries and schools in south-western Germany. The adult group consisted of students and employees of the University who participated in payment. They were tested in a quiet laboratory room. After the experiment, each child received a ‘thank you’ snack box with the logo of the study on it.

2.1.1. Design

The study is based on a 4 (*age group*) × 2 (*prime type*) × 2 (*verb condition*) mixed design, with ‘*age group*’ (3–4 years, 5–6 years, 7–8 years, adults) as a between-subjects variable and ‘*prime type*’ (double object (DO)/prepositional object (PO))² and ‘*verb condition*’ (different verb (DV)/same verb (SV)) as within-subjects variables. Both ‘*prime type*’ and ‘*verb condition*’ were manipulated within-items. In addition to the experimental session, we included a baseline pretest session in which target pictures were preceded by intransitive (IN) primes to assess participants’ initial structural preferences when not primed by either a PO or DO. Each item from the baseline pretest was matched to a particular item with the same target picture in the experiment.

2.1.2. Sentence Stimuli

Our sentence stimuli used four German dative-alternating verbs: *bringen* ‘bring’, *geben* ‘give’, *schicken* ‘send’, and *verkaufen* ‘sell’. A prior analysis of CHILDES data showed that these verbs were used frequently in the DO form and occasionally in the PO form in the child and child-directed speech of five German-speaking children aged 1;6–7;5 (MacWhinney 2000; Leo: Behrens 2006; Cosima, Pauline, Sebastian: Lieven and Stoll 2013; Caroline: Von Stutterheim 2014). Further, most of the verbs are documented in the literature on the acquisition of the dative alternation in German (Eisenbeiss et al. 2006; Woods 2015).

As German POs can contain two different prepositions (*zu* and *an*), we conducted a pilot study to check whether the four verbs used in the experimental materials are acceptable when used in combination with a particular preposition. Based on the results from this pilot study, PO materials with the verbs *schicken* and *verkaufen* contained the preposition *an*, while materials with the verbs *bringen* and *geben* contained the preposition *zu*.

As agents and recipients for these verbs, we chose four pairs of cartoon characters: Dora and Boots (from *Dora the Explorer*), Wendy and Bob (from *Bob the Builder*), Jake and Izzy (from *Jake and the Never Land Pirates*), and Mickey and Minnie (from Disney cartoons). As themes, we selected six small animals that could easily be transferred from the agent to the recipient: *der Hase* ‘the rabbit’, *der Hund* ‘the dog’, *der Papagei* ‘the parrot’, *der Schmetterling* ‘the butterfly’, *der Frosch* ‘the frog’, and *der Fisch* ‘the fish’. We purposefully chose agents and recipients with proper names, as well as themes with masculine gender, in order to avoid complexity with gender and case agreement as has been previously shown for the dative marking (Eisenbeiss et al. 2006; Scherger et al. 2022). Further, all arguments were animate in order to ensure that priming effects would not be affected by animacy contrasts (Bock et al. 1992).

To create the prime sentences (see Appendix A), we first combined the agent–recipient pairs and themes to create 16 character groupings (e.g., *Dora-Boots-Hasen*), with each agent–recipient represented four times, and each theme represented either three or four times. We also created 16 target combinations, respectively. Each verb appeared four times across the 16 prime–target pairs (items), once with each agent–recipient pair. Each target (e.g., *Micky-geben-Minnie-Papagei*) was paired with a prime sentence from a different character set containing four versions: a DO and PO structure in the different verb (DV) condition (e.g., *Dora bringt Boots den Hasen/Dora bringt den Hasen zu Boots*) and a DO and PO structure in the same verb (SV) condition (e.g., *Dora gibt Boots den Hasen/Dora gibt den Hasen an Boots*). This ensured no lexical overlap between primes and targets other than the verb in the SV condition. Correspondingly, each verb appeared once in each prime condition (PO-DV, DO-DV, PO-SV, DO-SV). Thus, there were 64 prime sentences in total. The items were equally distributed across four presentation lists, with each participant tested on one presentation list only. As a result, each participant encountered 16 experimental prime–target pairs (i.e., four items from each of the four conditions) during testing. Each verb was presented eight times per list, four times in the prime and four times in the target.

Immediately before the actual experiment, participants went through a baseline pretest consisting of prime–target pairs with intransitive primes (henceforth IN) in order to assess participants' initial PO/DO production preferences when not primed with ditransitives. The intransitive prime sentences used in this pretest described non-causal actions (e.g., *Dora schwimmt* 'Dora is swimming'). In the baseline pretest, each child encountered four items with intransitive primes. To allow for a direct comparison between the results from the baseline pretest and those from the PO and DO prime conditions in the DV condition in the actual experiment, each target sentence used in the pretest was matched to a particular target sentence in the experimental session. As the experimental session contained more targets than the pretest, two matched versions of the pretest were created, with each of the 2×4 pretest items matched to a particular item in the experimental session.

2.1.3. Visual Stimuli

We designed a total of 82 animated video clips using *Anime Studio Pro 10* to depict each of the sentence stimuli. This included 36 clips depicting transfer actions (*give, bring, send, sell*), which were used as prime and target stimuli for the experimental items, and 46 clips depicted non-causal intransitive actions. We controlled for directional effects by displaying the action either from right to left ($R > L$) or from left to right ($L > R$) and counterbalanced the order across lists. The action in the corresponding prime and target clip always traveled in opposite directions. The video clips were presented in E-Prime 2.0 on a laptop computer. The experiment took place as a modified Bingo game³ in which picture cards (still images of corresponding video clips) were collected to fill up a Bingo grid with blank spaces.

2.2. Procedure

Prior to playing the game, the experimenter introduced all of the characters appearing during the game on individual cards to ensure that children would not fail on descriptions due to character recognition difficulty. The main experimenter and the child sat next to each other in front of a laptop screen and described videos in turns. A second experimenter held up a puppy hand puppet named Mobi, who had a set of bingo cards depicting some of the video actions. The main experimenter modeled the prime sentence while the video actions unfolded (e.g., *Dora gibt den Hasen an Boots* 'Dora gives the rabbit to Boots'). The participant was then asked to repeat the sentence, with the explanation that Mobi could only comprehend child speech. The main experimenter then modeled the agent and verb of the target sentence corresponding to the participant's video clip (e.g., *Jake schickt . . .* 'Jake sends. . .'). The participant repeated the agent and verb, and then completed the sentence on their own. This stem completion technique ensured that participants would use the target verb, even if the action could be described with a different verb (Pickering and Branigan 1998). If the child produced an incomplete target structure, the main experimenter prompted them using phrases designed not to bias any particular structural option (e.g., *Please name all characters/objects on the screen; Please describe the whole action in one sentence; Can you include him/her in the sentence?*). After every time either the participant or the main experimenter produced a sentence, Mobi handed over a card to fill the bingo grid of each player if the sentence produced matched one of his cards. For the 7- to 8-year-olds, there was no second experimenter; instead, the experimenter or child put a stamp on their Bingo grid when a happy face was displayed on the laptop screen. The system of filling up the grids was the same across all groups, with the participant always being the winner.

In total, the test session consisted of three Bingo games: Game 1 (practice), Game 2 (baseline pretest; 4 intransitive primes), and Game 3 (priming experiment; 8 PO and 8 DO primes). For the groups of children aged 3–4 years and 5–6 years, the experiment was split into two test sessions, with Games 1 and 2 taking place in the first and Game 3 in the second session. The second test session took place 1–4 weeks after the first. Children aged 7–8 years and adults completed all three games in a single session.

Coding of Priming Data

The audiotaped target responses were transcribed and coded as either 'PO', 'DO', or 'other' by two coders. The agreement rate between coders was 98% for both transcription and coding.

In total, the data set consisted of 3860 target utterances. These were coded as 'PO' when the verb was followed by an object NP specifying the theme and then by a prepositional object specifying the recipient (NP_PP; e.g., *den Hasen an Bob* 'the rabbit to Bob'). Sentences in which the two objects were scrambled (PP_NP; e.g., *an Bob den Hasen* 'to Bob the rabbit'; 3.0% of all utterances) and sentences in which participants used a different preposition with the recipient (7.4% of all utterances) were also coded as 'PO'. Targets were coded as 'DO' when the verb was followed by an object NP specifying the recipient and then by a second object NP specifying the theme without any prepositions (NP_NP; e.g., *Bob den Hasen* 'Bob the rabbit'). Targets in which the order of the two objects was scrambled (NP_NP; e.g., *den Hasen Bob* 'the rabbit Bob'; 7.2% of all utterances) also counted as 'DO' targets.

Note that target responses were coded even if the participant used a different name for a character (1.9% of all utterances), used incorrect case marking on the theme (2.3% of all utterances), omitted the determiner (1.7% of all utterances), failed to produce the modeled target subject and/or verb themselves (11.7% of all utterances), or used a different verb than modeled (1.5% of all utterances). Responses were also coded if the direct or indirect object was realized by a pronoun or demonstrative, given that the relevant ditransitive structure was still evident (0.3% of all utterances). If the response for a target consisted of more than one sentence (e.g., a monotransitive structure followed by a ditransitive structure or a PO followed by DO), only the first structure resembling a ditransitive was coded. Any target responses not conforming to the above designation as 'PO' or 'DO' (i.e., grammatically incorrect responses, incomplete responses, and grammatically correct responses that were neither a PO nor a DO, such as monotransitive responses) were coded as 'other' (6.4%) and were excluded from the analysis.

As is typical in studies with children, the younger child groups (age 3–6) often omitted sentence constituents or used an alternative structure (see [Bencini and Valian 2008](#) for similar observations). Thus, we followed [Peter et al.'s \(2015\)](#) approach of categorizing the data according to three coding schemes: *strict*, *intermediate*, and *lax*. The criteria for the strict coding included the following: (1) no more than one prompt to repeat the prime sentence, (2) only the prepositions *an* and *zu* in prime repetitions and target responses, and (3) only the correct verb. The criteria for the intermediate coding included the following: (1) any number of prompts to repeat the prime sentence, (2) any preposition for prime repetition and target responses except *von* 'of/from' since it takes the structure of a PO (*Wendy bringt den Frosch von Bob* 'Wendy brings the frog of/from Bob') but does not imply the meaning of transfer, and (3) any verb in the DV condition as long as it was one of the experimental verbs and the prime and target verbs were different. The criteria for the lax coding included the same criteria as for intermediate coding except that all prepositions were allowed and that ditransitive verbs not included in the design were accepted in the target. As the analyses on all three coding schemes revealed very similar patterns of results, only the results for the strict coding scheme are reported below.

3. Results

3.1. General Bias for the German DO Structure

The results from the baseline pretest showed a bias in favor of the DO structure for all four age groups, with an average use of 78% DOs vs. 22% POs across all participants. This bias was strongest in the 3- to 4-year-olds (90% DOs produced in the baseline relative to 10% POs) and gradually decreased in the older child groups (75% DOs vs. 25% POs in the 5- to 6-year-olds; 68% DOs vs. 32% POs in the 7- to 8-year-olds). The adult group also showed a bias toward the DO structure (79% DOs vs. 21% POs).

3.2. Immediate Priming and the Lexical Boost Effect

We analyzed the data using logit mixed effects models, which are well suited to analyze binary dependent measures like structural choice ([Baayen et al. 2008](#); [Barr et al.](#)

2013; Jaeger 2008). Analyses were carried out in “R version 4.2.1 (2022-06-23)” (R Core Team 2021) using *glmer* in the *lme* package (e.g., *lme4* version 1.1-30). All models included by-subject and by-item (where “item” is each prime–target pair of all conditional combinations) random intercepts and random slopes, known as the *maximal model* following Barr et al. (2013). If a model did not reach convergence, we applied the optimizer *bobyqa* (bound optimization by quadratic approximation) taken from the *nloptr* package, which helped to achieve a stable maximal model for all our analyses.⁴

Figure 1 shows the mean proportion of PO responses (relative to the sum of all PO and DO responses, excluding ‘other’ responses) by condition and age group. Across all age groups, we observed numerical trends toward structural priming, with a higher proportion of PO targets following PO primes than following DO primes in both the SV and DV conditions.

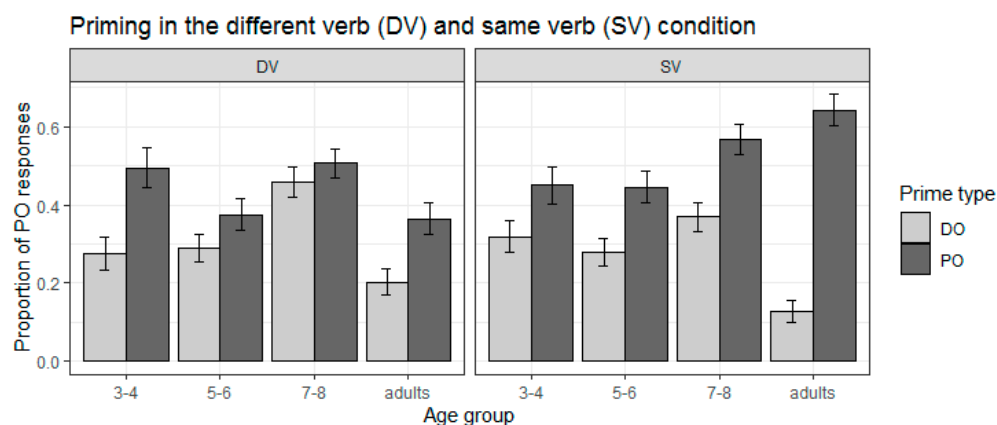


Figure 1. Mean proportion of PO responses after double object (DO) and prepositional object (PO) primes in the different verb (DV) and same verb (SV) conditions (Error bars are based on SE).

We fitted a logit mixed-effects model to the data. The model contained ‘prime type’ (DO vs. PO), ‘verb condition’ (SV vs. DV), ‘age group’, and their interactions as fixed effects. ‘Prime type’ and ‘verb condition’ were centered prior to analysis. For ‘age group’, a sum contrast was applied⁵. The results from the model are shown in Table 1 below.

Table 1. Results from the logistic mixed-effects model on the PO productions as a function of prime type, verb condition, and age group.

Fixed Effect	β	SE	z	p	
(intercept)	−0.89	0.29	−3.10	<0.01	**
prime type (DO vs. PO)	1.20	0.18	6.55	<0.001	**
verb condition (DV vs. SV)	0.31	0.18	1.67	0.10	
3- to 4-year-olds (vs. grand mean)	−0.12	0.26	−0.45	0.66	
5- to 6-year-olds (vs. grand mean)	−0.25	0.26	−0.96	0.34	
7- to 8-year-olds (vs. grand mean)	0.66	0.27	2.42	0.02	*
prime type * verb condition	0.76	0.30	2.50	0.01	*
prime type * 3- to 4-year-olds	−0.29	0.28	−1.05	0.29	
prime type * 5- to 6-year-olds	−0.47	0.21	−2.29	0.02	*
prime type * 7- to 8-year-olds	−0.34	0.26	−1.33	0.18	
3- to 4-year-olds * verb condition	−0.04	0.29	−0.15	0.88	
5- to 6-year-olds * verb condition	−0.01	0.24	−0.02	0.98	
7- to 8-year-olds * verb condition	−0.35	0.30	−1.18	0.24	
prime type * 3- to 4-year-olds * verb condition	−1.22	0.48	−2.55	0.01	*
prime type * 5- to 6-year-olds * verb condition	−0.31	0.49	−0.63	0.53	
prime type * 7- to 8-year-olds * verb condition	0.18	0.43	0.41	0.68	

Based on 2388 observations. Strict coding; LogLik = −1195.6. Random effects include by-subject and by-item intercepts; by-subject random slopes for ‘prime type’ and ‘verb condition’; and by-item random slopes for ‘prime type’, ‘verb condition’, and ‘age group’. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

The model revealed a main effect of ‘prime type’, indicating a priming effect across all age groups irrespective of ‘verb condition’ and ‘age group’. The model also showed a significant main effect for the group of 7- to 8-year-olds, indicating that, irrespective of the prime, this age group produced significantly more POs than the sample overall. We also found a significant two-way interaction between ‘prime type’ and ‘verb condition’, with significantly stronger priming in the SV condition than in the DV condition, i.e., a lexical boost effect, and a significant two-way interaction between ‘prime type’ and the age group of 5- to 6-year-olds, with weaker priming for this age group than for the sample as a whole. Finally, the results revealed a significant three-way interaction between ‘prime type’, ‘verb condition’, and the age group of 3- to 4-year-olds, suggesting that the group of 3- to 4-year-olds differed from the other groups with regard to the lexical boost effect.

Priming Effects and the Lexical Boost within Each Age Group

To explore the observed interactions in the above omnibus model in more detail, we fitted additional, separate logit mixed-effects models to the data from each age group. Each model contained ‘prime type (DO vs. PO)’, ‘verb condition (SV vs. DV)’, and the interaction between the two as centered fixed predictors. The results from these analyses are shown in Table 2. For all four age groups, these model analyses revealed significant main effects of ‘prime type’, with more PO targets following PO primes than following DO primes. As indicated by the β coefficients for the main effect of ‘prime type’ in each group, priming was numerically more robust in the adult group than in the three child groups. With respect to lexical boost effects, only the adults showed a significant two-way interaction between ‘prime type’ and ‘verb condition’. While the 5- to 6-year-olds and 7- to 8-year-olds also showed numerical trends toward a lexical boost, this trend was only marginally significant for the 7- to 8-year-olds and non-significant for the 5- to 6-year-olds.

Table 2. Priming effects and lexical boost by age group.

	β	SE	z	p	
age group					
3–4					
(intercept)	−1.04	0.36	−2.94	<0.01	**
prime type	0.88	0.29	3.08	0.002	**
verb condition	0.12	0.30	0.40	0.69	
prime type * verb condition	−0.22	0.58	−0.35	0.73	
5–6					
(intercept)	−1.16	0.42	−2.77	<0.01	**
prime type	0.80	0.24	3.39	<0.001	***
verb condition	0.24	0.26	0.92	0.36	
prime type * verb condition	0.73	0.55	1.32	0.18	
7–8					
(intercept)	−0.21	0.45	−0.46	0.65	
prime type	0.80	0.31	2.62	<0.01	**
verb condition	−0.01	0.41	−0.04	0.97	
prime type * verb condition	0.79	0.41	2.00	0.051	
adults					
(intercept)	−1.01	0.26	−3.84	<0.001	***
prime type	2.22	0.34	6.50	<0.001	***
verb condition	0.46	0.26	1.80	0.071	
prime type * verb condition	2.46	0.64	3.83	<0.001	***

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

To obtain effect sizes for the priming effects in each age group, we conducted additional model analyses with only ‘prime type’ as a fixed effect, separately for the DV and SV conditions. Table 3 reports the β coefficients for the priming effects in the SV and DV conditions for each age group, which contain information about the size of the priming effect.

Table 3. Effects sizes for priming effects in the different verb (DV) versus same verb (SV) conditions by age group.

Age Group	Different Verb (DV)			Same Verb (SV)		
	β	SE	p	β	SE	p
3–4	1.48	0.42	0.000 ***	0.79	0.37	0.01 *
5–6	0.39	0.34	0.25	1.23	0.37	0.000 ***
7–8	0.43	0.32	0.18	1.17	0.35	0.000 ***
adults	0.93	0.41	0.02 *	3.26	0.46	0.000 ***

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Both the significant three-way interaction in the omnibus model and the results from the separate analyses for each age group suggest group differences with regard to the lexical boost effect. Figure 2 shows the size of the lexical boost (i.e., the difference between the amount of priming in the SV versus the DV condition) and its distribution by age group.

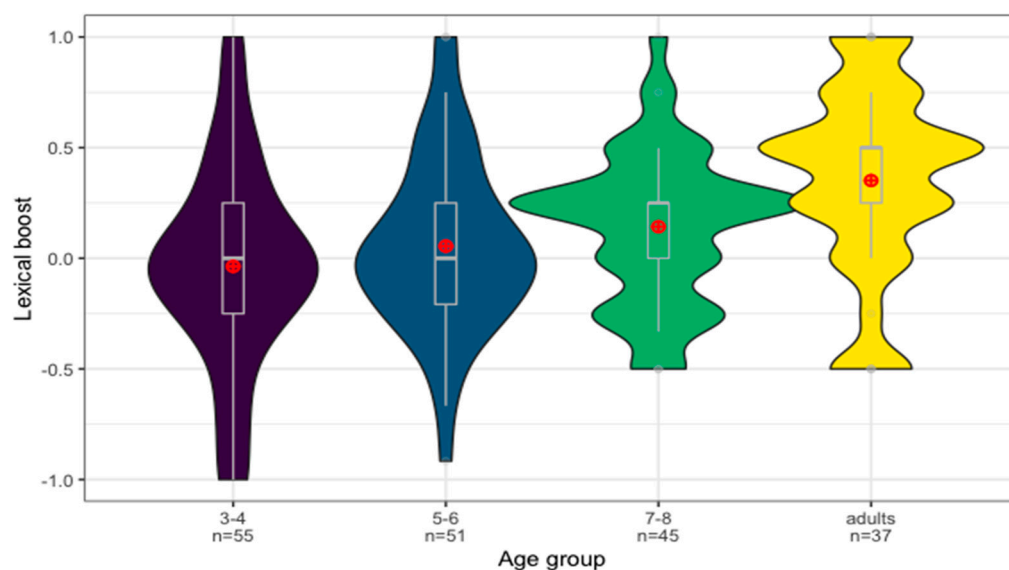


Figure 2. Lexical boost effects (i.e., the difference between the amount of priming in the SV versus the DV condition) by age group. Mean lexical boost effects are represented by red dots (i.e., the difference between the amount of priming in the SV versus the DV condition).

While the other three age groups showed numerical trends toward a lexical boost effect, with stronger priming in the SV than in the DV condition, the 3- to 4-year-olds instead showed no signs of a lexical boost effect but instead stronger abstract priming in the DV condition than in the SV condition. We will further comment on this in the discussion.

To explore the developmental trajectory for the lexical boost effect in more detail, we also ran a supplementary model analysis in which ‘age in months’ was included as a centered continuous predictor. We did not include the adult group in this analysis because age differences within the adult group do not contain the same developmental information as in children. ‘Prime type’ and ‘verb condition’ were again sum-coded. In addition to the main effect of prime type ($\beta = 0.82$ (SE = 0.20), $z = 4.06$, $p < 0.001$), the results also showed a significant three-way interaction between ‘prime type’, ‘verb condition’, and ‘age in months’ ($\beta = 0.03$ (SE = 0.01), $z = 2.26$, $p = 0.02$). This confirms that the age groups differ with regard to the lexical boost.

3.3. Priming Relative to the Baseline Pretest and Cumulative Priming

In an additional analysis, we compared the results from the PO and DO prime conditions with those from the intransitive baseline pretest. This comparison is potentially informative with regard to surprisal effects: If it is indeed the case that structures that are only rarely encountered (such as the German PO structure) cause stronger priming due to surprisal, we should observe stronger priming for PO primes than for DO primes relative to the intransitive baseline. This effect should be stronger for younger children due to less prior exposure to PO structures. The items used in the baseline pretest did not contain the same verb in prime and target and were, thus, not comparable with the SV condition. To allow for a direct comparison between the results from the baseline pretest and the experiment, each item from the pretest was matched to a particular experimental item from the DV condition. This ensured that each baseline trial could be compared to a corresponding PO and DO trial with the same target stimulus. Figure 3 shows the proportion of PO target responses for IN primes from the baseline pretest and their corresponding PO and DO counterparts from the experimental session, separately for each age group. (Note that, due to the fact that the DV condition in the experiment contained twice as many items as the pretest, the PO and DO bars in Table 3 are not based on all PO and DO items but only on those matched to a particular item in the pretest).

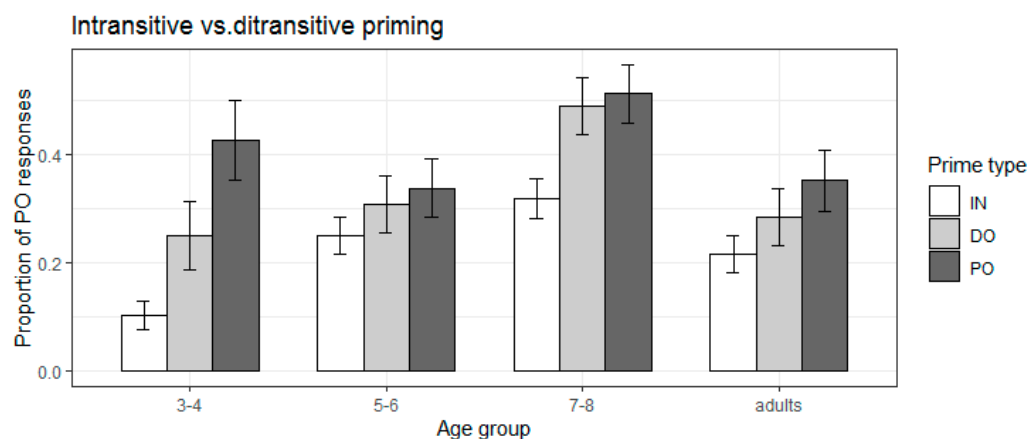


Figure 3. Mean proportion of responses that are POs after intransitive (IN) primes (baseline) compared to double object (DO) and prepositional object (PO) primes in the different verb conditions (error bars represent standard errors).

We fitted a logit mixed effects model with two contrasts for ‘prime type’ (‘DO vs. IN’ and ‘PO vs. IN’), ‘age group’, and their interactions as fixed effects. We used treatment coding for ‘prime type’ with IN primes serving as the reference level and applied a sum contrast for ‘age group’ as in the previous model. The model revealed a main effect of PO prime vs. IN prime ($\beta = 1.58$ (SE = 0.42), $z = 3.79$, $p < 0.001$), indicating that participants were significantly more likely to produce PO structures after a PO prime than after an IN prime. Further, there was also a main effect of DO prime vs. IN prime ($\beta = 1.12$ (SE = 0.39), $z = 2.89$, $p < 0.001$), indicating more PO targets (and, therefore, fewer DO targets) after a DO prime than after an IN prime for all participant groups. As indicated by the main effect of the 3- to 4-year-olds ($\beta = -1.59$ (SE = 0.54), $z = -2.95$, $p < 0.001$), the youngest child group generally produced more POs in the experimental session than the older groups. The results also showed a two-way interaction of PO vs. IN prime and the group of 3- to 4-year-olds ($\beta = 1.54$ (SE = 0.65), $z = 2.36$, $p < 0.05$), suggesting that the priming effect for PO primes relative to the baseline was stronger in 3- to 4-year-olds than in the other groups.

Note, however, that for all participant groups, the intransitive baseline pretest showed a highly unexpected result: We expected PO primes to raise the PO/DO ratio relative to the baseline (i.e., with relatively more PO and fewer DO targets produced), and DO primes to lower it, with the ratio for the baseline pretest situated between the two prime conditions.

However, all participant groups produced more DO target sentences following IN primes than following DO primes. As a result, it was obviously not possible to utilize the baseline pretest as a control condition to determine priming effects separately for POs and DOs, as originally intended. However, the fact that this observation was consistent across all four participant groups suggests that the unexpectedly low PO/DO ratio in the baseline pretest was not a fluke and, therefore, demands an explanation. One possibility is that during the experimental session, structural choices made by the participants were not only affected by immediate priming (i.e., the influence of the prime sentence immediately preceding the respective target) but also by cumulative priming (i.e., the influence of the overall ratio of PO vs. DO sentences encountered during the test session). While PO sentences are only rarely encountered in natural language, 50% of all experimental prime sentences encountered during the experimental session were PO primes. This high proportion of PO sentences during the experimental session might have increased participants' tendency to produce PO targets, in addition to the influence of the preceding prime. We investigated this possibility in an additional post-hoc analysis of the data from the experimental session, in which we included 'trial number' as an additional predictor in the model. If the results are affected by cumulative priming, this should lead to a main effect of 'trial number', with more POs produced toward the end of the experiment. As illustrated in Figure 4, the proportion of PO targets indeed increased with increasing trial numbers in all four age groups, irrespective of whether the immediately preceding prime was a PO or DO. This effect decreased with growing age.

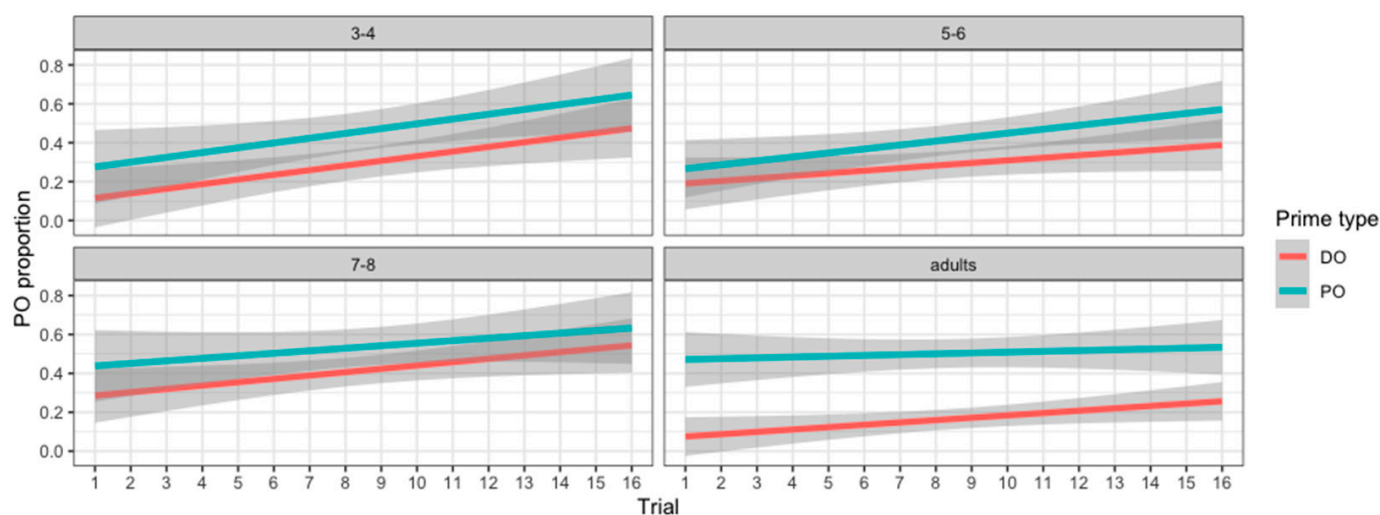


Figure 4. Cumulative priming effects as a function of trial number (16 trials) and prime type (PO/DO) in four age groups (shadowed area represents SE).

To test these numerical trends for statistical significance, we conducted an additional model analysis which included 'prime type', 'age group', 'trial number', and their interactions as fixed effects. In addition to the significant effects reported in the main model above, the analysis revealed a significant main effect of 'trial number' ($\beta = 0.09$ (SE = 0.02), $z = 5.54$, $p < 0.001$), with a linear increase of PO responses during the experiment, as well as a two-way interaction between 'trial number' and the 3- to 4-year-olds ($\beta = 0.06$ (SE = 0.03), $z = 2.43$, $p < 0.02$), indicating that the effect of 'trial number' was significantly stronger in 3- to 4-year-olds than in the sample as a whole. In addition, just as in the main analysis, the model showed a main effect of 'prime type' ($\beta = 1.16$ (SE = 0.18), $z = 6.22$, $p < 0.001$), with more POs produced following PO primes than following DO primes irrespective of 'age group' and 'trial number'. This suggests that structural choices for target sentences were influenced by both immediate and cumulative priming.

4. Discussion

The key research questions investigated in the present study were designed to gain insight into how syntactic representations in children develop with increasing age: (1) what kind of structural representations German-speaking children of various age ranges possess at baseline; (2) whether structural representations in children are less stable than in older individuals and, therefore, easier to prime (surprisal effects) by comparing priming effects sizes across age; (3) whether children already show a lexical boost effect from the start or whether this effect only gradually emerges with age; and (4) whether structural representations in children are subject to implicit learning by exploring cumulative priming effects. In the following, we discuss our experimental results with reference to these four questions.

4.1. Initial Structural Representations in Children

In the baseline data in the present study, we found the hypothesized pattern of structural bias, with an average use of 78% DOs and 22% POs across the four age groups (in line with [Kholodova and Allen 2023](#)). Our prediction that the youngest children would show the strongest DO bias (90%), which would decrease with increasing age, was confirmed both descriptively and by the model. This suggests initially weaker structural representations for the PO structure, which become somewhat stronger across age. Note, however, that the adult group actually showed a stronger bias toward the DO structure than the 7- to 8-year-olds.

4.2. Abstract Immediate Structural Priming Effects

During the priming session, all age groups in our study showed immediate structural priming effects, suggesting that children as young as 3–4 years of age already possess abstract representations for syntactic structures. In this respect, our results are consistent with a considerable number of previous studies that have also shown significant structural priming effects for this age group.

As shown by both the interactions in the omnibus model and the effect sizes shown in [Table 3](#), abstract structural priming (i.e., the priming effect in the DV condition) in the 3- to 4-year-olds was stronger than in the older groups. This finding is consistent with the results from several previous studies, which observed at least a numerical trend for stronger priming in young children than in adults ([Messenger et al. 2011](#); [Peter et al. 2015](#); [Rowland et al. 2012](#); [Thothathiri and Snedeker 2008b](#); [Wolleb et al. 2018](#)). A possible explanation for enhanced priming effects in young children is offered by the Implicit Learning Account ([Chang et al. 2000, 2006](#)), which predicts that, due to surprisal, less prior exposure to the respective syntactic structure should lead to stronger priming effects. With regard to this issue, note that stronger priming effects have also been reported for other speaker groups who have experienced less prior exposure to a particular structure, such as L2 speakers ([Flett 2006](#)). In our case, 3- to 4-year-olds have come across ditransitive structures substantially less often than older speakers, which may have caused surprisal. For the German dative alternation, such surprisal effects may be additionally boosted by the fact that German is heavily biased in favor of the DO structure. Thus, in addition to little prior exposure to ditransitive structures in general, prior exposure to PO structures was particularly low for 3- to 4-year-olds, potentially leading to particularly strong priming effects enhanced by surprisal. In sum, our findings are consistent with the claim that syntactic representations in children are less stable and, therefore, more susceptible to the influence of a prime.

The Lexical Boost Effect and Its Development across Age

While the 3- to 4-year-olds in our study showed structural priming, no lexical boost effect emerged for this age group. Instead, the significant interactions in both the omnibus model and in the additional analysis, which included age as a continuous predictor, suggest that, unlike the priming effect, the lexical boost gradually develops with increasing age. This finding is consistent with [Kumarage et al.'s \(2022\)](#) longitudinal study on active/passive

priming in English, where the lexical boost also showed a developmental trajectory, and with the results from a number of previous studies in which the lexical boost did not occur in children but only in adult control groups (Foltz et al. 2015; Peter et al. 2015; Rowland et al. 2012; Thothathiri and Snedeker 2008a).

In studies investigating structural priming in children, a lack of a lexical boost effect has typically been attributed to limited working memory capacity in children. Indeed, if a verb that is encountered during the processing of the prime cannot be kept in working memory for long enough, the processor may not be aware that the prime and target share the same verb. As a result, lexical boost effects should only emerge when working memory capacity is sufficiently developed through maturation, leading to the developmental trajectory observed in our study. The developmental trajectory for the lexical boost observed in our study is consistent with this account. Note, however, that the slope of this developmental trajectory differs considerably between studies. For instance, in Kumarage et al.'s (2022) longitudinal study on English, lexical boost effects emerged at a substantially earlier age than in our study, with a robust lexical boost at 4;6 years of age. Similar results were also reported by Rowland et al. (2012), with evidence for a marginal lexical boost in 5- to 6-year-olds. Our results, in contrast, showed a considerably slower developmental trajectory, with no lexical boost at all in 5- to 6-year-olds, and even 7- to 8-year-olds showing a substantially weaker lexical boost than adults. Also, recall again that at least some previous structural priming studies that have investigated the lexical boost in only a single age group (Branigan and McLean 2016; Branigan et al. 2004; Gerard and Keller 2010; Messenger and Hardy 2017; Morris and Scheepers 2015; Savage et al. 2003) report significant lexical boost effects in children at age 5–6 or younger. This suggests that working memory capacity at this age is, in principle, sufficient for lexical boost effects to emerge and that whether and at which age the effect emerges also depends on other properties of the specific language and structural alternation investigated. Finally, priming studies on children aside, a working-memory-based explanation for the lexical boost effect is potentially inconsistent with recent findings on the lexical boost in adult speakers. In particular, if it is the case that (as claimed by the Implicit Learning Account) the lexical boost emerges because a content word that occurs in both the prime and target serves as a memory cue for the prime, lexical boost effects should occur irrespective of the syntactic function of the shared content word. Indeed, Scheepers et al. (2017) found lexical-boost effects not only for prime–target pairs that shared the head verb but also for shared non-head constituents. In several recent studies investigating the lexical boost in adults, however, robust lexical boost effects only emerged when the head verb was repeated in the target, with either no or considerably reduced effects for the repetition of other lexical material, such as the subject or one of the objects (e.g., Carminati et al. 2019; van Gompel et al. 2023). If correct, these findings point toward residual activation as the locus of lexical boost effects, at least in adults. In sum, given that only very few studies have investigated the developmental trajectory of the lexical boost effect by comparing groups of children of different ages, it is too early to draw any strong conclusions about this issue. Future research on this issue should investigate the possible role of task demands and properties of the specific structural alternation investigated.

4.3. Surprisal Effects and Implicit Learning

In our baseline pretest, we clearly found a relatively strong DO bias in German that was most strongly reflected in the youngest children. When primed with ditransitives, all age groups showed an increase in PO production after a PO prime compared to an IN prime, but this effect was twice as high in the 3- to 4-year-olds, suggesting strong surprisal effects. In fact, we find that the youngest children are most susceptible to priming and thus most likely to change their structural representations (Chang et al. 2006; Jaeger and Snider 2008). However, for all four age groups, the results from the baseline pretest with intransitive prime sentences revealed an unusual and unexpected pattern, with participants producing an even higher proportion of DO targets in the baseline pretest than after being primed by a DO in the actual experiment. A possible explanation for this

unusual observation is that structural choices for target sentences during the experimental session may be affected not only by immediate priming (i.e., by the structure of the prime sentence encountered immediately before the respective target) but also by cumulative priming (i.e., the overall proportion of PO vs. DO sentences encountered during the entire experimental session). Indeed, the results from our post-hoc analysis, which included the trial number as an additional predictor, showed a cumulative priming effect in addition to immediate priming: Irrespective of whether the preceding prime was a PO or DO, the probability of producing a PO target increased while the experimental session proceeded. As predicted by the Implicit Learning Account, these cumulative priming effects, just as the immediate priming effects discussed above, turned out to be strongest in 3- to 4-year-olds and declined with increasing age. This finding constitutes another indication that syntactic representations in young children may be less stable (in the sense that children have only experienced a small number of previous encounters with the respective structure) and, therefore, more susceptible to cumulative priming. Older children, in contrast, have already encountered the respective structure considerably more often, leading to relatively more stable representations and, thus, weaker priming effects.

Cumulative effects in children have been mainly found in blocked designs (Gámez and Shimpi 2015; Huttenlocher et al. 2004; Kidd 2012a, 2012b; Savage et al. 2006; Serratrice et al. 2015), which makes it difficult to disentangle immediate and cumulative priming. A few studies used alternating structures in their experiments by comparing earlier and later sessions (Branigan and Messenger 2016; Messenger 2021). Both found cumulative priming effects, but there was no indication of greater effects in children. In the few studies that investigated cumulative effects on a trial by trial basis, the results for cumulative priming were not entirely clear. Messenger et al. (2011) did not find any cumulative effects in either children or adults, while in Branigan and McLean (2016), cumulative effects in children only reached significance in the analysis for lenient coding. One possible reason why the effect came out so clearly in the present study may be that in German, the dative alternation is strongly biased toward the DO. As a result, cumulative priming for the generally rare PO structure during the experimental session may have been substantially boosted by surprisal.

5. Conclusions

In summation, the following key findings from the present study strike us as particularly relevant. First, German-speaking children at the age of 3–4 years showed enhanced immediate and cumulative priming effects for prepositional object structures relative to older children and adults due to surprisal, suggesting that abstract syntactic representations in this age group are less stable and stabilize with increasing exposure.

Second, while 3- to 4-year-olds already showed robust abstract priming, this effect was not enhanced when prime and target shared the same verb. Instead, the lexical boost only gradually emerged with increasing age, starting no earlier than 7- to 8 years of age. While our results for the presence of abstract structural representations across all child groups are largely consistent with previous child studies, the results for the lexical boost effect and its developmental trajectory differ from the results obtained by at least some previous child research on English, in which lexical boost effects were present from early on. Future studies should determine to what extent our findings generalize across different languages, age ranges, and structural alternations.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics committee of the University of Kaiserslautern-Landau (protocol code 5/2014, 8 May 2014).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study, as well as their parents.

Data Availability Statement: Data and all analyses (R script) are available on OSF: https://osf.io/gknb4/?view_only=73611a184ba146c2b33a0a9d9f3806d5 (accessed on 30 October 2023).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Experimental Items

Prime sentences before the slash are presented in the DO structure; those after the slash are in the PO structure. Each character pair occurred four times as a prime and was combined once with each verb (*geben* ‘give’; *bringen* ‘bring’; *verkaufen* ‘sell’ and *schicken* ‘send’). Target stems used the same combination of agent, verb, recipient, and theme as prime sentences (e.g., *Micky gibt Minnie den Papagei* (‘Micky is giving Minnie the parrot’) or *Micky gibt den Papagei an Minnie* (‘Micky is giving the parrot to Minnie’) for the target set A. Target set B was designed to be the same except for the theme *Frosch* (e.g., ‘frog’). The eight intransitive primes used in the baseline contained each agent of a character pair twice combined with eight intransitive verbs (presented under prime sentences in italics).

German

Dora gibt Boots den (Hasen/Frosch)/den
(Hasen/Frosch) an Boots

Dora schwimmt.

Dora bringt Boots den (Hasen/Frosch)/den
(Hasen/Frosch) zu Boots

Dora verkauft Boots den (Papagei/Hund)/den
(den Papagei/Hund) an Boots

Dora springt.

Dora schickt Boots den (Papagei/Hund)/den
(den Papagei/Hund) zu Boots

Jake gibt Izzy den
(Schmetterling/Papagei)/den
(Schmetterling/Papagei) an Izzy

Jake bringt Izzy den
(Schmetterling/Papagei)/den
(Schmetterling/Papagei) zu Izzy

Jake tanzt.

Jake verkauft Izzy den (Fisch/Frosch)/den
(Fisch/Frosch) an Izzy

Jake fliegt.

English

Dora is giving Boots the (rabbit/frog)/the
(rabbit/frog) to Boots

Dora is swimming.

Dora is bringing Boots the (rabbit/frog)/the
(rabbit/frog) to Boots

Dora is selling Boots the (parrot/dog)/the
(parrot/dog) to Boots

Dora is jumping.

Dora is sending Boots the (parrot/dog)/the
(parrot/dog) to Boots

Jake is giving Izzy the (butterfly/parrot)/the
(butterfly/parrot) to Izzy

Jake is bringing Izzy the
(butterfly/parrot)/the (butterfly/parrot)
to Izzy

Jake is dancing.

Jake is selling Izzy the (fish/frog)/the
(fish/frog) to Izzy

Jake is flying.

Jake schickt Izzy den (Fisch/Frosch)/den (Fisch/Frosch) zu Izzy	Jake is sending Izzy the (fish/frog)/the (fish/frog) to Izzy
Wendy gibt Bob den (Hund/Hasen)/den (Hund/Hasen) an Bob	Wendy is giving Bob the (dog/rabbit)/the (dog/rabbit) to Bob
<i>Wendy saugt.</i>	<i>Wendy is (vacuum) cleaning.</i>
Wendy bringt Bob den (Schmetterling/Hasen)/den (Schmetterling/Hasen) zu Bob	Wendy is bringing Bob the (butterfly/rabbit)/the (butterfly/rabbit) to Bob
Wendy verkauft Bob den (Hund/Hasen)/den (Hund/Hasen) an Bob	Wendy is selling Bob the (dog/rabbit)/the (dog/rabbit) to Bob
Wendy schickt Bob den (Schmetterling/Hasen)/den (Schmetterling/Hasen) zu Bob	Wendy is sending Bob the (butterfly/rabbit)/the (butterfly/rabbit) to Bob
<i>Wendy schaukelt.</i>	<i>Wendy is swinging.</i>
Micky gibt Minnie den (Fisch/Schmetterling)/den (Fisch/Schmetterling) an Minnie	Micky is giving Minnie the (fish/butterfly)/the (fish/butterfly) to Minnie
<i>Micky läuft.</i>	<i>Micky is walking.</i>
Micky bringt Minnie den (Fisch/Hund)/den (Fisch/Hund) zu Minnie	Micky is bringing Minnie the (fish/dog)/the (fish/dog) to Minnie
Micky verkauft Minnie den (Fisch/Schmetterling)/den (Fisch/Schmetterling) an Minnie	Micky is selling Minnie the (fish/butterfly)/the (fish/butterfly) to Minnie
Micky schickt Minnie den (Fisch/Hund)/den (Fisch/Hund) zu Minnie	Micky is sending Minnie the (fish/dog)/the (fish/dog) to Minnie
<i>Micky winkt.</i>	<i>Micky is waving.</i>

Notes

- ¹ Initially, we did not intend to investigate cumulative priming effects. However, an unusual effect in the results led us to running an analysis which pointed towards cumulative effects. Because this analysis may considerably contribute to child priming research, we decided to include cumulative effects as an additional research question in this paper but because this hypothesis was not determined a priori it should be considered exploratory.
- ² In contrast to our design, Rowland et al. (2012) included ‘Verb Condition’ as a between-subjects variable, in order to reduce the number of items presented to each child. We opted to follow Peter et al. (2015), who adapted the typical design used in adult priming studies, using as many within-participant variables as possible such that each participant would be exposed to all experimental conditions.
- ³ The Bingo game was adapted from Rowland et al. (2012) and Peter et al. (2015).
- ⁴ For a justification for the use of optimizers in such analyses, see Darmasetiyawan et al. (2022) and Linck and Cummings (2015).
- ⁵ Effects of ‘age group’ are based on a sum contrast, with each age group getting compared to the grand mean of all four groups (based on Schad et al. 2020).

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