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Implicit Learning of Prepositions in Dutch Kindergartners with and without Developmental Language Disorder

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ABSTRACT

It has been proposed that an implicit learning deficit explains the difficulties with grammar commonly observed in children with Developmental Language Disorder (DLD). The present study further investigates this link in two ways. Firstly, we investigate whether kindergartners with DLD have more difficulties with preposition understanding and production as compared to their typically developing peers because they have not (yet) learned to weigh implicit structural information (word order) over more explicit semantic information (noun animacy; Study 1). Secondly, we investigate whether kindergartners with DLD learn to comprehend and produce locative prepositions from an implicit learning context (Study 2). In Study 1 we observed that Dutch kindergartners with DLD ($n = 32$) made more errors in preposition comprehension (picture-matching task) and preposition production (semi-spontaneous production task) as compared to their typically developing peers ($n = 30$). We have no evidence that these differences can be explained by a difference in cue weighing or implicit learning ability (serial reaction time task). In Study 2 we observed that the storytelling context led to an increase in preposition production in children with DLD, but we found no evidence that it also led to a better understanding and more semantically accurate productions of the prepositions. We conclude that Dutch kindergartners with DLD have difficulties with locative prepositions but cannot conclude that differences in cue-weighing or implicit learning play a role herein.

Keywords

Developmental Language Disorder; Implicit learning; Prepositions

While most children seem to acquire language with ease, some children have so many difficulties acquiring language that it negatively impacts their social-emotional development, social interactions and educational progress. If the language problems occur without the presence of any neurological disorders, hearing loss, intellectual impairment or deprivation of linguistic input children commonly receive the diagnosis Developmental Language Disorder (DLD; Bishop et al., 2017). Besides language problems, deficits in other cognitive domains such as attention, working memory (Ebert & Kohnert, 2011; Montgomery et al., 2018), motor skills (Hill, 2001), executive functioning (Aljahlan & Spaulding, 2021; Ebert & Kohnert, 2011; Pauls & Archibald, 2016; Vissers et al., 2015; Vugs et al., 2013) and implicit learning (Obeid et al., 2016; Zwart, Vissers, Kessels, et al., 2018) are also frequently reported in children with DLD. The complex relation between these cognitive deficits and the language problems commonly observed in children with DLD remains a topic of investigation. Insight in this neuropsychological interplay is necessary to come to tailored diagnosis and intervention (Tomas & Vissers,

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2019). It has been proposed that an implicit learning deficit in children with DLD may explain the difficulties with structural aspects of language (grammar) frequently observed in this group of children (Lum et al., 2014; Obeid et al., 2016; Ullman & Pierpont, 2005). There is indeed evidence that children with DLD have more difficulties with implicit learning of sequential structure in a serial reaction time task as compared to their typically developing peers (see meta-analyses by Lum et al., 2014; Obeid et al., 2016). Two recent meta-analyses, however, that explicitly assessed the association between implicit learning ability (measured with the serial reaction time task) and grammatical proficiency in children and adults with DLD provided no evidence for the existence of the association (Lammertink et al., 2020; Oliveira et al., 2022). Lammertink et al. speculated that the association may exist but only if the targeted structure in the implicit learning task is meaningfully related to the targeted structure assessed with the grammatical proficiency task. The latter is not the case in many of the studies included in the meta-analyses, because most of these studies assessed grammatical proficiency using test batteries that include a wide variability of grammatical structures. This could also explain why the study by Kidd (2012) – on the relation between serial reaction time task performance and syntactic priming in typically developing children – is the only study included in the meta-analysis of Lammertink et al. (2020) that provides strong evidence for an association between implicit learning ability and language proficiency. Syntactic priming effects have been explained as a manifestation of implicit learning (e.g., Bock & Griffin, 2000; Chang et al., 2006) and in a study by Garraffa et al. (2018), children with DLD showed syntactic priming effects that are consistent with difficulties in the implicit detection and extraction of abstract structural regularities in linguistic input.

The present study further investigates the link between implicit learning and grammatical proficiency in children with DLD by focusing on their understanding and semi-spontaneous productions of locative prepositional phrases (e.g., the bear hides *under* the table). Correct use and understanding of these phrases require sensitivity to implicit sequential structural knowledge. More specifically – and as explained in more detail below – it requires that children weigh implicit structural information (word order) over more explicit semantic information (noun animacy).

Preposition comprehension and production in DLD

Children with DLD have difficulties understanding and producing prepositional phrases. van der Hoek-Snieders et al. (2021) showed that Dutch children with DLD aged between 4;2 and 5;8 years used fewer prepositions in their spontaneous speech than their typically developing age-matched peers. Also in more controlled production tasks, children with DLD made more errors in their use of prepositional phrases than their typically developing age-matched peers (American-English: Watkins & Rice, 1991; Brazilian-Portugese:; Puglisi et al., 2005) and language-matched peers (American-English: Grela et al., 2004). As for the type of errors that children made, it seems that younger children with DLD made more omission errors than substitution errors (Puglisi et al., 2005; van der Hoek-Snieders et al. (2021) whereas the opposite pattern was observed for older children with DLD (Grela et al., 2004; Puglisi et al., 2005). This developmental change from omission to substitution errors, however, most likely occurs in a continuous rather than dichotomous way and may also depend on features of the child's mother tongue (Armon-Lotem, 2014).

Correct use and understanding of locative prepositional phrases require that children know the lexical meaning (semantic knowledge) of the preposition but also that they understand the relation between the subject and object of the utterance as expressed by the preposition (structural knowledge). That is, *the bear is above the piano* means something different than *the piano is above the bear*. Because prepositional phrases offer a consistent and predictable word order, the structural cue (word order) as opposed to the semantic cue (lexical meaning) is the most reliable cue for correct prepositional phrase understanding. For example, in *the flower is above the cup*, only word order (subject before object) disambiguates the meaning of the utterance. The semantic context is uninformative because *a cup* can be placed above *a flower* as well (example taken from Hsu & Bishop, 2014).

There is evidence that children with DLD are less likely to weigh structural information over semantic information than their typically developing peers when interpreting sentences. In a study by Evans and MacWhinney (1999), 7-year-old children with DLD over-relied on semantic information (noun animacy) when interpreting sentences like *chair chases horse*. Consequently, children with DLD were more likely than typically developing children to select *the horse* (animate) instead of *the chair* (inanimate) as doing the chasing (for similar findings but with other sentence constructions see Marinis & van der Lely, 2007; van der Lely & Harris, 1990). The present study investigated whether differences in cue weighing between children with and without DLD may also explain the difficulties with locative prepositional phrases commonly observed in children with DLD.

Implicit learning of prepositions

Recently two other studies investigated children's implicit learning of prepositions. Nicholas et al. (2019) explored whether children's understanding of prepositional phrases depends on the variability of the subjects and objects used. The authors hypothesized that high variability in the nontarget elements (subjects and objects) implicitly helps children to detect the target element (i.e., the preposition) as the "constant" element. Children received three training sessions and their understanding of the target preposition was measured via elicitation of both nonverbal and verbal responses. No evidence was found for the prediction that high variability in subjects and objects leads to better learning of prepositions than low variability in subjects and objects.

In another study, Hsu and Bishop (2014) showed that half of their participating children with DLD aged 8 to 9 years old had difficulties understanding locative prepositions in simple reversible sentences (e.g., *the hedgehog is above the boot*). Hsu and Bishop (2014) developed a computerized errorless intervention program that aimed to improve children's understanding of locative prepositions (above/under and before/after). Crucially, because of the reversible sentences, the semantic cue was not informative, and children could only arrive at the correct interpretation using structural information (word order). Twenty-eight children with DLD and 28 language-matched typically developing peers followed the intervention. Hsu and Bishop reported that children implicitly learned to use the structural cue: all children with and without DLD that scored below ceiling in session 1 (before the intervention) were more accurate in session 3 (after the intervention).

The above two training studies used a rather explicit way of teaching prepositions. However, in the literature, a strong claim is made for repeated storybook reading to implicitly expand children's language proficiency. Storytelling creates an optimal situation for children to implicitly learn different aspects of their native language (Damhuis et al., 2013; Dirks & Wauters, 2015). Via stories, children are exposed to words and sentence structures about related events in the world that they are generally not exposed to in daily life. Importantly, during book reading these stories are combined with visualizations of the narration which may support children's implicit learning. Recent advances in technology make it possible to enhance these visualizations with additional multimedia functions and there is evidence that, if contingent with the verbal narration such digital visual features support deeper learning of the story content and may reduce the cognitive load that children face when listening to a story (Bus et al., 2015). This stimulates language development, also in children with DLD (Smeets et al., 2014).

The present study

In sum, children with DLD have difficulties with the comprehension and production of locative prepositional phrases. To better understand why this is the case we ran two studies. In Study 1 we (a) compare differences in preposition comprehension and production in relation to cue weighing between children with and without DLD and (b) investigate whether potential differences in cue weighing are related to differences in implicit learning ability. Study 2 investigates to what extent

children with DLD learn to comprehend and produce locative prepositions from an implicit learning context (storytelling).

For study 1 we hypothesize that children with DLD will score lower on a picture-matching preposition comprehension test as compared to their typically developing age-matched peers and we expect that this difference arises because children with DLD do not (yet) weigh structural information (word order) over semantic information (noun animacy). Cue weighing is something that we expect children to learn implicitly. Therefore, we also hypothesize that children with better implicit learning ability (i.e., better serial reaction time task performance) will score higher on the preposition comprehension test than children with lower implicit learning ability. As for preposition production we expect typically developing children to use more and more correct prepositional phrases in their semi-spontaneous descriptions of visual scenes as compared to the children with DLD.

For study 2, we developed a digital storytelling application – in which children with DLD watch and listen to a story where bear and mouse play hide and seek – to answer our second research question. This way we create a controlled, but realistic learning environment to learn prepositional phrases. The prepositional phrases used in the story contain many examples of the Dutch locative prepositions *above, below, before*, and *behind*. We hypothesize that children with DLD will score higher on the preposition comprehension test and use more prepositions in their semi-spontaneous speech after they listened to and watched the digital story than before. We expect this increase in children's understanding and use of prepositional phrases because children implicitly learn to weigh structural information over semantic information from the storytelling context. Furthermore, we explore whether additional multimedia visual support enhances children's learning of locative prepositions even more. Therefore, we developed two versions of the digital story: a visually-enhanced version with extra focus on the prepositions using a zoom function and (2) a non-enhanced version without this zoom function. We decided to work with a zoom function, because this type of multimedia feature, rather than interactive elements, was found most beneficial for story comprehension and expressive vocabulary in children (see meta-analysis by Takacs et al., 2015). Note that this question is exploratory and therefore no part of the research questions as outlined above.

Study 1

Method

Participants

We recruited 35 children with DLD and 34 typically developing (TD) children. After data collection, but before data analyses we excluded three participants with DLD and four TD children. The children with DLD were excluded because of missing data on the preposition tests ($n = 2$) or because they had a centile score below 2 (which corresponds to a standard score < 70) on the Raven Coloured Progressive Matrices ($n = 1$; Raven, 1984). The four TD children were excluded because they were older than 6 years and 3 months (see inclusion criteria). The final sample included 32 children with DLD (9 females, 23 males; 18 monolinguals, 14 multilinguals) and 30 TD children (12 females, 18 males; 26 monolinguals, 4 multilinguals) aged between 58 months (4;10) and 75 months (6;3) of age.

We recruited children with DLD through special education schools for children with DLD of Royal Kentalis and Viertaal. The schools were located in different areas of The Netherlands (4 schools in the Western part of the country; 2 schools in the southeastern part of the country and 3 schools in the northeastern part of the country). All children had been diagnosed with DLD by licensed clinicians and met the following criteria: (a) they had scored 1.5 standard deviations below the norm on two out of four subscales (speech production, auditory processing, grammatical knowledge, lexical semantic knowledge) of a standardized language assessment test battery; (b) none had been diagnosed with autism spectrum disorder, attention deficit hyperactivity disorder or with other (neuro)physiological problems as their primary deficit; (c) they had scored at least 70 on a nonverbal reasoning test of a standardized

test battery administered by a licensed clinician and a centile score above 2 on the Raven Coloured Progressive Matrices test (Raven, 1984) that was part of our test battery (see procedure); (d) they were between 5 and 6 years old (±3 months).

We recruited the TD children from four different primary schools in southeast and eastern part of the Netherlands. Based on parental and teacher reports, all TD children were unfamiliar with any language, hearing or (neuro)physiological problems. Furthermore, TD children had to obtain a centile score of at least 2 on the Raven Coloured Progressive Matrices (Raven, 1984) that was part of our test battery.

We obtained ethical approval from the ethical review committee of the Radboud University, Faculty of Social Sciences (ESCW-2020-095). All parents and caregivers of the participating children gave informed consent prior to their children's participation in the study and all speech therapists gave informed consent prior to their own participation with the digital storytelling application as well. All children received a small gift (sticker, pencil, or coloring book) to thank for their participation.

Note that data collection was interrupted several times because of the COVID-19 pandemic. This is also why we ended up testing four TD children that were too old and that we eventually had to exclude for data analyses.

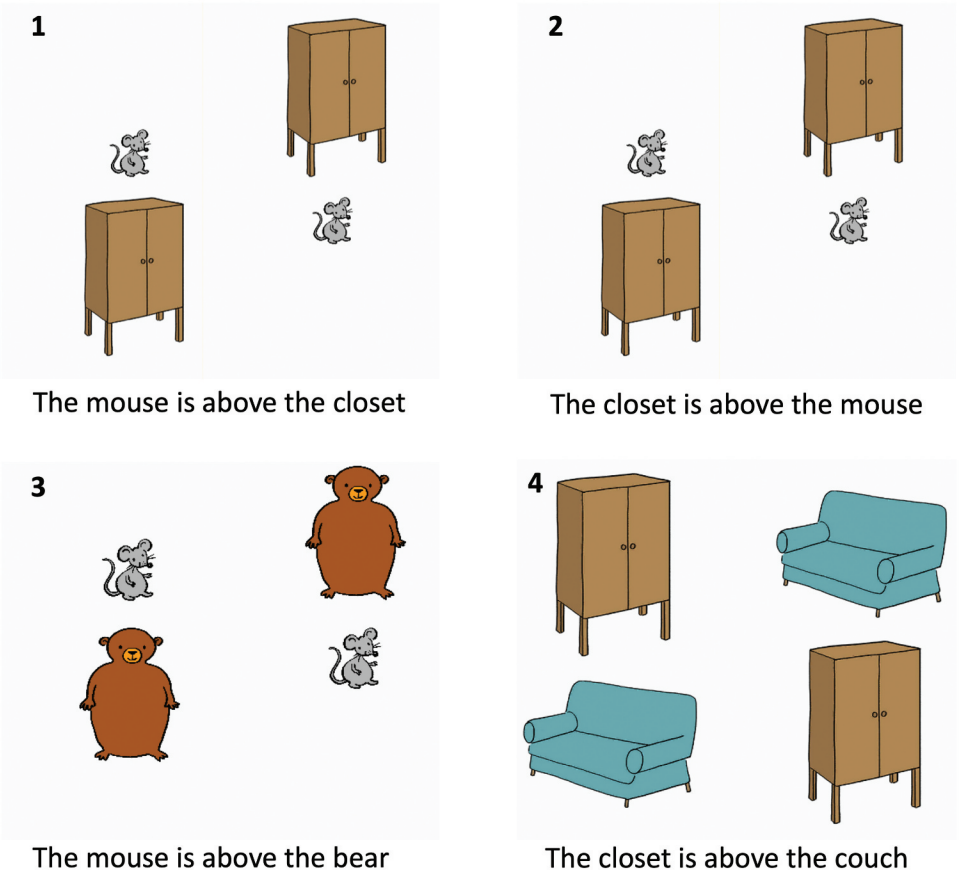

Figure 1. Picture-matching task: example of a trial in each of the four conditions. 1: Example condition 1 with an animate subject (mouse) and inanimate prepositional object (closet). 2: Example condition 2 with an inanimate subject (closet) and animate prepositional object (mouse). 3: Example condition 3 with an animate subject (mouse) and an animate prepositional object (bear). 4: Example condition 4 with an inanimate subject (closet) and inanimate prepositional object (couch).

Instruments

Preposition comprehension in relation to cue weighing

To measure preposition comprehension, we used a picture-matching task. The comprehension test measured children's understanding of four Dutch locative prepositions: *boven* (above), *onder* (under), *voor* (in front of) and *achter* (behind). The test consisted of 32 target utterances, divided over four conditions (see Figure 1) and the utterances were presented to the children in random order. Four conditions were included to test children's weighing of structural (word order) and semantic information (noun animacy). During the test, children heard an utterance and saw two pictures on a tablet screen. The two pictures differed in how the prepositional subject was placed relative to the prepositional object, representing either the preposition placement combination above/under or the combination in front of/behind. Only one of the two pictures corresponded to the target utterance and the child was asked to pick the picture that matches the target utterance (see Figure 1 for examples). In all four conditions, the target utterances followed the canonical Dutch word order (SVO):

$$[\text{Noun}(N_1)]\ [\text{Verb}]\ [\text{Preposition}]\ [\text{Noun}(N_2)].$$

The structural cue (word order: subject before object) could be used for correct interpretation of the prepositional phrases in all four conditions. The semantic cue (animate subject; inanimate object) was only informative in condition 1. In condition 2 use of animacy (semantic cue) led to selecting the incorrect picture (e.g., see example for condition 2 in Figure 1). In conditions 3 and 4 the semantic cue was uninformative for utterance interpretation: items in condition 3 had both animate subjects (N_1) and animate prepositional objects (N_2) and items in condition 4 had both inanimate subjects (N_1) and inanimate prepositional objects (N_2).

The split-half reliability of the task (Spearman-Brown corrected Pearson correlation between children's accuracy scores for the odd versus even items) is .69 with the 95% confidence interval ranging from .54 to .80.

The preposition comprehension test is part of a digital application that was developed for this study in Unity (Unity Technologies, 2019) and made available to our participants via the Testflight app (Apple inc., 2022) for iPads or as a Microsoft Windows application for Windows desktops and laptops. A preview of the application can be found here: https://www.socsci.ru.nl/gameon/voorzetsel/. A short video of the test can also be found at our Data Repository Project Page (Lammertink et al., 2023).

Preposition production

To assess preposition production, we elicited semi-spontaneous productions of locative prepositions in children with and without DLD. We asked children to describe nine different visual scenes: in four of these scenes Bear was in front of, behind, below or above an object, in another four scenes Mouse was in front of, behind, below or above an object and in one of the scenes both Bear and Mouse were present. Children received no further instructions; they were simply asked to describe what they saw on the scenes. For the first scene the children's speech therapists were allowed to help the children and to provide examples of utterances with the prepositions (with maximal one utterance per preposition). During scenes 2–9 the speech therapists were no longer allowed to provide examples or to correct the children's utterances.

A preview of the preposition production task can be found in the digital storytelling application (https://www.socsci.ru.nl/gameon/voorzetsel/) and on our Data Repository Project page (Lammertink et al., 2023).

Implicit learning ability

We used a serial reaction time task (SRT) to assess children's implicit learning ability. We modeled the task after Zwart, Vissers, and Maes (2018) and used Psychopy Software (Peirce, 2019) to program and run the task. During the task, children sat in front of a laptop screen, with a gamepad controller attached to it. A visual stimulus (a cartoon picture of a smiley from Lum & Kidd, 2012) appeared

repeatedly in one of four marked locations on the screen. These locations and the color of the smiley cartoons (red, green, blue or yellow) corresponded to the location and color of four buttons on the gamepad controller. Children were instructed to press the button on their gamepad controller that matched with the color and location of the smiley that appeared on the screen, as fast and accurately as possible. A smiley remained visible until a child pressed a button. The task started with a practice block. This practice block had a minimum of 25 trials and continued until the child pressed the correct button for 80% of the trials. During test, the screen locations in which the smiley appeared followed two different second-order sequence types: a probabilistic sequence (first half of the experiment) and a deterministic sequence (second half of the experiment). In total, the experiment consisted of five blocks with short breaks in between. The experiment started with 23 repetitions of the probabilistic sequence (block 1 and 2: 9 repetitions of the sequence each, first half of block 3: 5 repetitions of the sequence; Zwart, Vissers, & Maes, 2018) and was then followed by 23 repetitions of the deterministic sequence (second half block 3, block 4 and block 5; Gabriel et al., 2015; Zwart, Vissers, & Maes, 2018). In between each block there was a pause during which children received a sticker for their certificate. The base probabilistic sequence was [2, 1, 3, 4, 3, 2, 4, 1] – where each number represents a screen position. Each of the 23 repetitions of this probabilistic base sequence included one deviant trial/position. For example, in the first repetition of the sequence the screen positions were: [2, 4*, 3, 4, 3, 2, 4, 1] with a deviant trial in second position (4 instead of 1), in the second repetition of the sequence, the screen position was [2, 1, 3, 4, 3, 2, 3*, 1] with a deviant trial in seventh position (3 instead of 4). The deviant positions were depicted by two different randomization sequences and a child received either randomization sequence 1 or randomization sequence 2. We also had two different deterministic sequences and children either received 23 repetitions of sequence 1: [4, 2, 4, 1, 3, 2, 1, 2] (Zwart, Vissers, Kessels, et al., 2018) or sequence 2: [1, 3, 4, 2, 3, 1, 2, 4] (Gabriel et al., 2015).

We computed split-half reliabilities (Spearman-Brown corrected Pearson correlation between children's response times to odd and even trials) for both the probabilistic and deterministic sequences. The split-half reliability for the probabilistic sequences is 0.52, with the 95% confidence interval ranging from −0.30 to 0.69. The split-half reliability for the deterministic sequences is 0.54, with the 95% confidence interval ranging from 0.32 to 0.70. For more details, see the README document and Rmarkdown analyses script at our Radboud Data Repository Collection (Lammertink et al., 2023).

Other cognitive measures

To control for potential differences in cognitive abilities between children with and without DLD that are important for language and implicit learning, we also assessed children's nonverbal reasoning, their verbal short-term memory and their visual sustained attention (Bishop et al., 2017; Ebert & Kohnert, 2011; Montgomery et al., 2018). Children's nonverbal reasoning was also assessed because it was part of our inclusionary criteria.

Nonverbal reasoning. To assess children's nonverbal reasoning, we used the Raven Coloured Progressive Matrices test (Raven, 1984). During the task children were asked to complete 36 visual patterns by selecting the correct missing pattern from six possible options. The maximum score to obtain on this task was 36. Split-half reliability of the Raven Coloured Progressive Matrices for 5-year-old children is $r = .68$ (Raven, 1984).

Verbal short-term memory. We assessed children's verbal short-term memory using the digit span forward task of the Clinical Evaluation of Language Fundamentals – Dutch version (Semel et al., 2010). During the task children were asked to immediately repeat several sequences of increasing length. The task terminated when a child incorrectly repeated two sequences in a row. The maximum score for the task was 16. Test-retest reliability of the digit span task for our age groups (5;0, 5;6 and 6;0) is: $r = .75$ (Semel et al., 2010).

Visual sustained attention. We assessed children's visual sustained attention using a visual continuous performance task (VCPT). We built and ran the experiment in Psychopy (Peirce, 2019) and modeled it after the fast event rate condition of the VCPT as described in Finneran et al. (2009). Children were presented with 200 trials without a break. These trials were either a red square figure (60% of the trials) or a red circle figure (40% of the trials). The squares and circles appeared in the center of a laptop screen. Children were instructed to press the spacebar every time a circle appeared. When the square appeared, they should inhibit their responses. The circles and squares were visible for 400 ms and children had 1100 ms to respond if needed. Children received 1 point each time they correctly pressed the button (circle figure) suppressed their response (square figure). The split-half reliability (Spearman-Brown corrected Pearson correlation between even and odd items) of the VCPT is .83 (95% CI [.73, .90]). Please see the R markdown analysis script at our Radboud Data Repository Collection (Lammertink et al., 2023) for more details.

Procedure

All children with DLD completed the preposition comprehension and production test with their speech therapist. The implicit learning task, nonverbal reasoning task, verbal short-term memory task and visual sustained attention task were administered by research assistants during two other testing sessions. For the TD children all tasks (preposition comprehension, preposition production, implicit learning, nonverbal reasoning, verbal short-term memory and visual sustained attention) were administered by research assistants during two separate testing sessions (usually one morning session and one afternoon session). For both groups of children, data were collected in quiet rooms at their schools.

Data analyses

All data, scripts and full model outcomes (including details on contrast-coding of our model predictors and the random-effects structures of the [generalized] linear mixed effects models) that we used for data analyses are publicly accessible on our Radboud Data Repository Collection (Lammertink et al., 2023)

To compare preposition comprehension in relation to cue weighing between children with and without DLD we ran a generalized linear mixed effects model on children's accuracy on the preposition comprehension test. The model fits children's accuracy as a function of the orthogonal sum-to-zero coded predictors Group (DLD vs TD); Condition (condition 1, condition 2, condition 3, condition 4); Language Status (Monolingual vs Multilingual) and the centered and scaled (using the *scale* function in R; R Core Team, 2022) continuous predictors Nonverbal reasoning (raw score) and Verbal Short-term memory (raw score). The predictors Condition and Group answer our research questions and therefore these two predictors are added in interaction with each the other. The other predictors (Language, Nonverbal reasoning, and Verbal Short-term memory) are included as control variables. The random-effects structure of the model contains by-subject and by-item random intercepts, by-subject random slopes for the main effect of Condition and by-item random slopes for the main effect of Group.

To compare preposition production between children with and without DLD, we transcribed all utterances that children had produced to describe the scenes. The utterances were coded for locative preposition use (i.e., does the utterance contain one of the four locative prepositions) and for semantic accuracy. Utterances were coded as semantically incorrect if a child made a prepositional substitution error (e.g., used "before" instead of "behind"). We did not code accuracy of children's preposition use at the grammatical/syntactic level. For analyses we ran independent *t*-tests with 97.50% WALD confidence intervals to assess whether children with and without DLD differ in the relative frequency with which they use locative prepositions and in the semantic accuracy of their spontaneously produced locative prepositional phrases. We Bonferroni corrected these comparisons with 0.05/2

because we assessed preposition production with two measures: frequency of use and accuracy of use. For each child, we calculated the relative frequency of locative preposition use as the number of locative prepositions divided by the total of words used to describe the different scenes. Please note that we had missing production data of one child with DLD because of unintelligible speech during the production test and for three TD children because their parents gave no consent to make audio recordings.

We could not answer our research question concerning the relationship between children's individual implicit learning ability and their preposition understanding because of the low reliability of our SRT task (see Methods) and because we had no conclusive evidence for implicit learning at the group level. For transparency, however, the analysis script and outcomes of children's serial reaction time task performance can be found in our Radboud Data Repository Collection (Lammertink et al., 2023).

Results

We only report the descriptive and confirmatory outcomes relevant to our research questions. The full model outcomes can be found in the analysis scripts at our Radboud Data Repository Project Page (Lammertink et al., 2023).

Participant demographics and cognitive measures

Table 1 summarizes the demographic variables and group-level comparisons for our measures of nonverbal reasoning, verbal short-short memory and sustained visual attention in children with and without DLD. Between-group *t*-tests showed that children with DLD have lower raw scores on the nonverbal reasoning task and lower raw scores on the verbal short-term memory task than their age-matched TD peers. We found no evidence that the groups of children differ in age or visual sustained attention (d-prime scores, see Finneran et al., 2009).

Preposition comprehension and preposition production in children with and without DLD

Preposition comprehension by cue weighing

To compare preposition comprehension as a function cue weighing in children with and without DLD we fitted a generalized linear mixed effects model on the accuracy data for both groups of children (for a descriptive visualization of these comparisons, see Figure 2). The model estimated that children score, on average, 75% correct on the preposition comprehension test. This estimate

Table 1. Summary of demographic and cognitive measures (control variables) for children with DLD and TD children.

	DLD ($N = 32$) F = 9 Monolingual = 18	TD ($N = 30$) F = 12 Monolingual = 26		Difference DLD – TD		Effect size
	Mean (SD)	Mean (SD)	*t*	*p*	95% CI	Cohen's *d*
Age (Years; months)	5;6 (6 months)	5;9 (5 months)	−1.8	.07	[−5, 0]	−0.47
Nonverbal reasoning[a]						
Raw score	17 (5)	22 (5)	−3.4	.001	[−7, −2]	−0.88
Verbal short-term memory[b]						
Raw score	4 (1)	6 (2)	−5.5	$1.5 \cdot 10^{-6}$	[−3, −1]	1.4
Visual sustained attention[b]						
d' score[c]	1.5 (0.9)	1.9 (0.8)	−1.7	.097	[−0.86, +0.074]	−0.45

Note. [a]Missing data for 1 child with DLD; [b]Missing data for 8 children with DLD (6 children did not understood the task and 2 children were absent at days that we collected data from these tasks) and 1 typically developing child (absent on day of testing); [c]d' score close to 3 is perfect performance and a d' score close to 0 means guessing. DLD = Developmental Language Disorder; TD = Typically Developing.

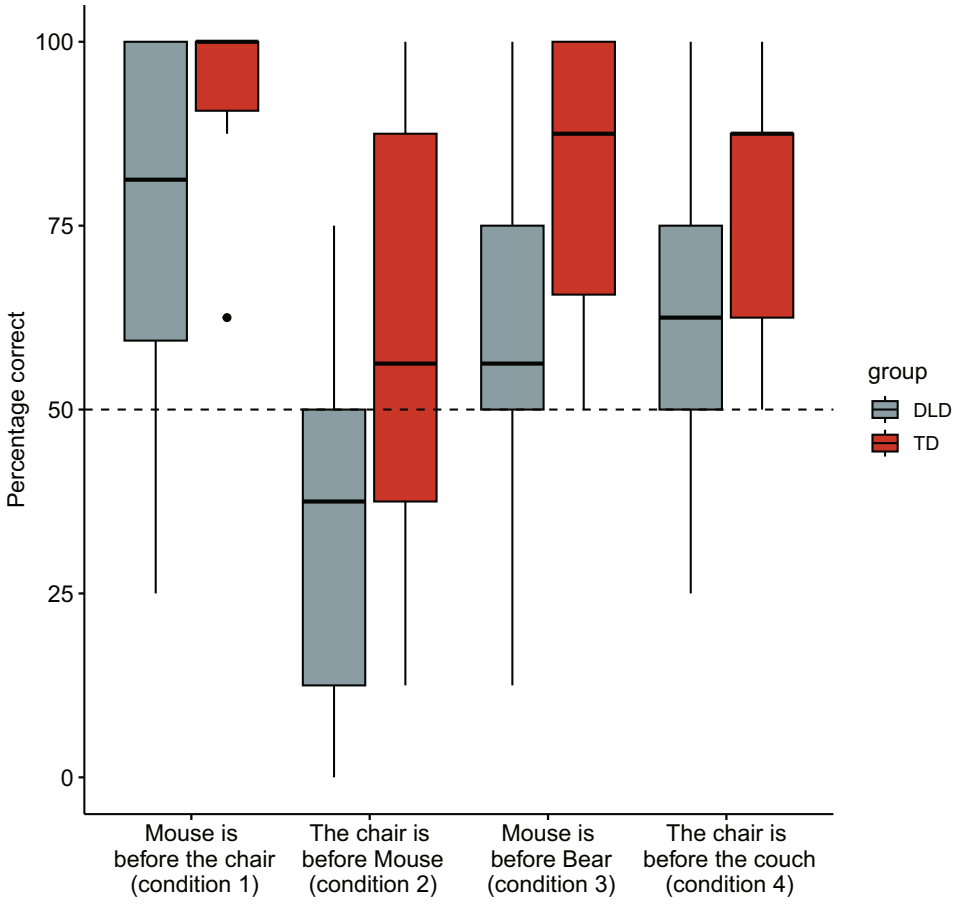

Figure 2. Children's medium raw percentages correct across the four conditions of the preposition comprehension test. DLD (grey) = Developmental Language Disorder; TD (red) = Typically Developing.

exceeded chance performance of 50% (Intercept log odds = 1.1; probability = .75; $z = 6.8$; $p = 7.3{\cdot}10^{-12}$; 95% CI probability correct = [.69, .80]. The model also estimated that averaged over the four conditions, the likelihood (odds ratio) that TD children score higher than children with DLD is 3 (log-odds estimate Group = 1.1; odds ratio = 3.0; $z = 4.1$; $p = 3.3{\cdot}10^{-5}$; 95% CI odds ratio [1.8, 5.1]). As for cue weighing, the model estimated (1) that children with and without DLD scored on average 9.9 times more accurately in condition 1 than in the other three conditions (log-odds estimate Condition contrast 1 = 2.3; odds ratio = 9.9; $z = 6.0$; $p = 2.5{\cdot}10^{-9}$; 95% CI odds ratio [4.7, 21]) and (2) that the ratio with which they make an error is 2.7 times higher (1/0.31) in condition 2 as compared to conditions 3 and 4 (log-odds estimate Condition contrast 2: −1.2; odds ratio = 0.31; $z = -3.7$; $p = .00025$; 95% CI odds ratio [0.2, 0.6]). We have no evidence that children's accuracy rates differed between conditions 3 and 4. Importantly, we observed no statistically significant interactions between the different contrasts of the predictor Condition and the predictor Group, meaning that we have no evidence that children with DLD weigh the structural and semantic cues differently in their comprehension of locative prepositional phrases than their TD peers do.

Preposition production

To compare the semi-spontaneous productions of locative prepositions in children with and without DLD we first compared the relative frequency (proportion of total words that they used to describe the scenes) with which children with and without DLD used one of the four target locative prepositions (in front of, behind, above and below) in their semi-spontaneous productions. In their semi-spontaneous productions, 3.4% of TD children's total words were locative target prepositions (Median [*Mdn*] = 2.2%, *SD* = 3.0%). For children with DLD, 3.6% of their total words were locative prepositions (*Mdn* = 2.6%, *SD* = 3.3%). An independent *t*-test provided no evidence for differences between TD children and children with DLD in the frequency with which they produced locative prepositional phrases ($t(53.688) = 0.14$; $p = .81$; 97.50% CI = [−1.7%, + 2.1%]). Secondly, we compared the semantic accuracy with which children used locative prepositions in their semi-spontaneous productions. We observed that TD children make fewer semantic errors ($M_{\%\ correct} = 86\%$, *Mdn* = 95%, *SD* = 20%) than children with DLD ($M_{\%\ correct} = 60\%$, *Mdn* = 64%, *SD* = 30%, $t[49.645] = -3.5$; $p = .0010$; 97.50% CI = [−39%, −8.0%]).

Implicit learning in relation to preposition comprehension

Since we have no conclusive evidence of implicit learning at the group level for neither the probabilistic nor deterministic sequence (see analysis scripts at our Radboud Data Repository Collection, Lammertink et al., 2023) and since the split-half reliabilities of children's performance on both sequence types did not reach the psychometric standards of $r = .80$ (e.g., Nunnally & Bernstein, 1994; Streiner, 2003, see Methods) we question the reliability and validity of our serial reaction time task as a measure of implicit learning in children this young. Therefore, we no longer present the originally planned analysis on the relation between serial reaction time task performance and children's preposition comprehension.

Discussion study 1

In this first study we investigated preposition comprehension and production in children with and without DLD and aimed to assess the role of implicit learning herein. We find that Dutch kindergartners with DLD have difficulties understanding and producing locative prepositions. On average, the ratio by which children with DLD pick a correct answer on the preposition test is 3 times lower than their typically developing age-matched peers. Also, in their semi-spontaneous productions Dutch kindergartners with DLD make relatively more semantic substitution errors than their typically developing age-matched peers. We found no evidence however, that these differences in preposition comprehension and production between children with and without DLD can be explained by a difference in cue weighing. Also, it remains unclear whether there is a link between children's implicit learning ability and their preposition understanding because we failed to assess children's implicit ability with the serial reaction time task. The serial reaction task that we used may have been too difficult for the young children that participated in the study. Furthermore, there is an ongoing debate on reliability of the serial reaction time task to detect and assess individual differences in implicit learning ability (see Arnon, 2019; Lammertink et al., 2020; Oliveira et al., 2022; West et al., 2017). Indeed, in the present study split-reliability measures for both the probabilistic and deterministic sequence do not reach the psychometric standard of $r = 0.80$ (e.g., Nunnally & Bernstein, 1994; Streiner, 2003). At the start of the project, we decided to use the serial reaction time task, however, because to the best of our knowledge there is (yet) no alternative child-friendly measure of implicit learning ability available. In future research, it is recommended to use a serial reaction time task with either probabilistic sequences or deterministic sequences rather than our mixed design. Our decision to include both probabilistic and deterministic sequences may have hampered the reliability of the task even more because it reduces the number of trials and could potentially cause interference between both types.

Before we turn to the General discussion where we will discuss the outcomes of children's preposition understanding and production in terms of cue weighing, we first present the outcomes of Study 2 in which we investigated to what extent preposition understanding and production in children with DLD increases from an implicit learning context (storytelling).

Study 2

In this second study we investigated to what extent children with DLD learn to comprehend and produce locative prepositions from and implicit learning context. We developed a digital storytelling application to create a controlled but realistic learning environment to learn prepositional phrases. To assess whether children implicitly learned the prepositions in a storytelling context we compared their preposition comprehension and production scores before and after they listened and watched to the digital story. Furthermore, and as explained in more detail below, we developed two versions of the digital story: a visually-enhanced version with extra focus on the prepositions using a zoom function and (2) a non-enhanced version without this zoom function. This way we explore whether additional multimedia visual support enhances children's learning of locative prepositions even more (see meta-analysis by Takacs et al., 2015).

Participants

The final dataset for study 1 includes the same 32 children with DLD that were included for Study 1. For more details we thus refer to Study 1.

Instruments

For study 2 we re-used children's scores on the preposition comprehension task and preposition production task as baseline measure. After the children listened and watched to the digital storytelling application (see below), they again did the exact same preposition comprehension task and preposition production task. For more details on the preposition comprehension and preposition production task we refer to Study 1.

Digital storytelling

To assess whether children with DLD learn to understand and use locative prepositional phrases in an implicit learning context, we designed a digital story in which a prerecorded female voice told a story about a bear and a mouse playing hide and seek. The story consisted of different parts: a short introduction, four training episodes, three breaks and a closing section. During all parts children saw visual scenes of Bear and Mouse on a tablet screen. Each of the four training episodes consisted of four little hide-and-seek passages, one passage for each preposition. Within every passage, the target preposition was repeated three times (e.g., passage 1: "Mouse is going to sit *under* the blanket;" "He sits *under* the blanket;" "Mouse! I found you, you were sitting *under* the blanket"). Across the four training episodes, children heard each target preposition twelve times.

We controlled the context in which the four prepositions occurred at the subject, verb, and object level. We had two subjects: Mouse and Bear; four different verbs: to stand, to hang, to lie and to sit and seven different objects: a blanket, a cupboard, a staircase, a chair, a table, curtains and a sofa. Within each of the four training episodes, every preposition and every verb occurred once, objects were not repeated and Bear and Mouse alternated as subject. Across the four training episodes, we ensured that each preposition occurred twice with Bear as subject and twice with Mouse as subject, each preposition occurred once with each verb and each preposition occurred only once in the context of a specific object.

Although we prerecorded the story, we aimed to achieve interactive reading between the child and the speech therapist. Therefore, stories included questions like "Where do you think Mouse/Bear is

going to hide?" and "Can you find Mouse/Bear?." Also, we included small breaks in between the four training episodes during which children could hide bear and mouse themselves. Using their fingers, children could move Bear or Mouse over the tablet screen and hide them behind one of the objects presented on the screen. Children (or the speech therapist) could swipe to go to the next story. It was not possible to swipe backwards to avoid repetition of the target sentences/prepositions.

To explore whether additional focus on the preposition (using the multi-media zoom function) further enhanced children's learning of the prepositions, we created two different versions of the story: a basic version and a visually-enhanced version. The visually-enhanced version contained an additional zoom feature as compared to the basic version, meaning that in this version, the picture zoomed in on the part of the visual scene where Bear or Mouse was *above, below, before* or *behind* the object, each second time a preposition is named. This zoom-function was absent in the basic version of the story.

The preposition comprehension test, preposition production test and digital story are all part of a digital application that was developed for this study in Unity (Unity Technologies, 2019) and made available to our participants via the Testflight app (Apple inc., 2022) for iPads or as a Microsoft Windows application for Windows desktops and laptops. A preview of the application can be found here: https://www.socsci.ru.nl/gameon/voorzetsel/ and videos of the different parts of the application can be viewed in our Radboud Data Repository Collection (Lammertink et al., 2023).

Procedure

All children with DLD completed the preposition comprehension test and preposition production test twice: once before they listened to and watched the digital story (these scores are used in Study 1) and once after they listened to and watched the digital story. In total, both tests and listening/watching to the digital story took 3 consecutive weeks to complete, with two sessions of approximately 15–20 minutes per week. During the first session, the speech therapist administered the preposition comprehension and production tests; during the second, third and fourth session the speech therapist and child listened to and watched the digital story (every session the same story) and during the fifth session the speech therapist administered the preposition comprehension and production tests again. Children were randomly allocated to either the visually enhanced version or the basic version of the digital story. We instructed the speech therapists not to repeat the prepositions and not to provide any feedback on children's preposition use while listening to the story. This way we controlled for differences in the number of prepositions that children were exposed to while listening and watching the digital story.

Data analysis

To assess whether children with DLD learn to understand locative prepositions from an implicit learning context (storytelling), we ran (1) a generalized linear mixed model on the accuracy rates for children with DLD on the preposition comprehension test before and after they listened to and watched the digital story. This model fitted children's accuracy rates as a function of the orthogonal sum-to-zero coded predictors Session (pretest vs posttest); Condition (condition 1, condition 2, condition 3, condition 4), Story Type (basic vs visually-enhanced) and Language Status (Monolingual vs Multilingual). The model included the main effects of all these predictors as well as interactions between Session and Condition and between Session and Story Type. The random-effects structure included by-subject and by-items random intercepts as well as by-subject random slopes for the interaction between Session and Condition and by-item random slopes for Story Type.

To assess whether children with DLD learn to use locative prepositions in an implicit learning context we compared the relative frequency with which they use the four locative prepositions and semantic accuracy rate of the four target locative prepositions (above, below, in front of, behind) before and after they listened/watched the digital story using independent *t*-tests with 97.50% WALD

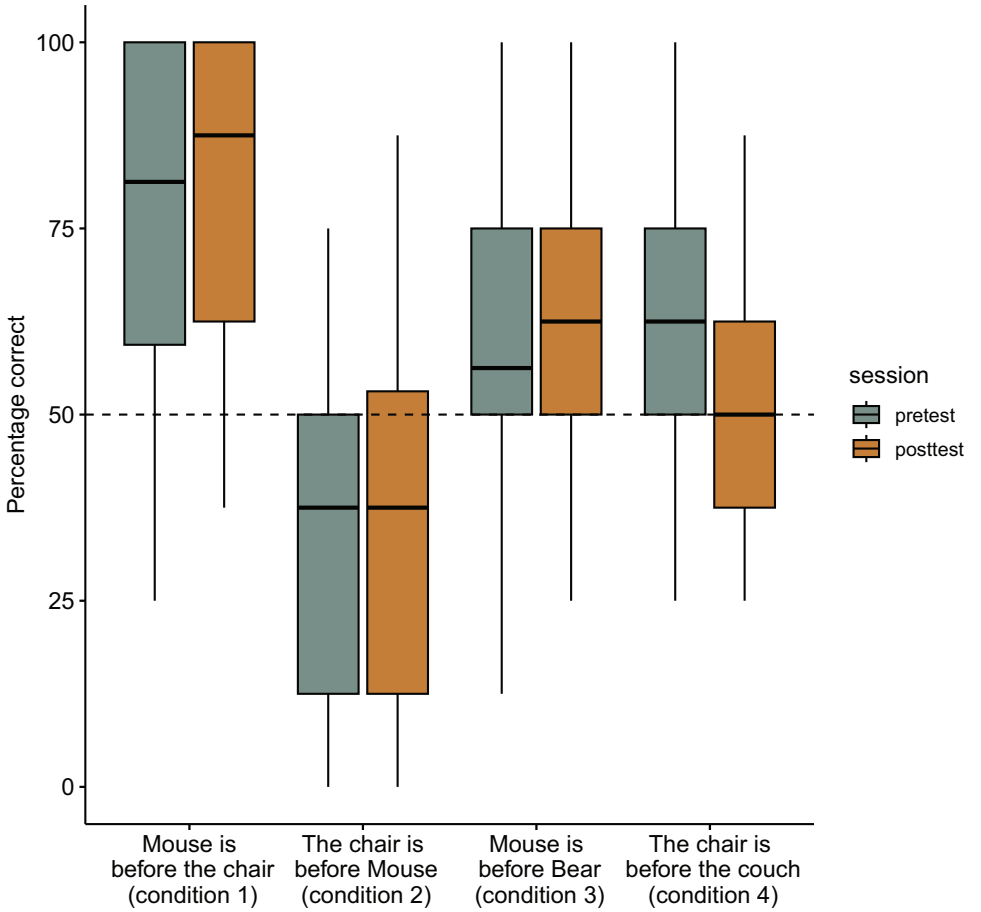

Figure 3. Medium raw percentages correct across the four conditions of the preposition comprehension test for children with DLD before they listened and watched the digital story (pretest; grey) and after they listened and watched the story (posttest; brown).

confidence intervals. Note that these intervals are Bonferroni corrected because we assessed preposition production of the children with two measures: relative frequency of use and semantic accuracy.

Results

Implicit learning of prepositions in children with DLD: comprehension

The model outcome of our generalized linear mixed-effects model that assessed whether children scored higher on the comprehension test after listening and watching to the digital story than before estimated that children with DLD were as accurate in the posttest preposition comprehension as in the pretest preposition comprehension (estimate log-odds PrePost = −0.0036; odds ratio = 1.0; $z = -0.034$; $p = .97$; 95% CI odds ratio [0.8, 1.2], see Figure 3). None of the estimates for the interactions between the PrePost predictor and the different contrasts of the predictor Condition were statistically significantly different from zero. Also, we had no evidence that the extra visual zoom function in the visually-enhanced version ($n = 17$ children) led to different outcomes compared to basic version without zoom-function ($n = 15$ children; exploratory research question). The estimate for the two-way interaction between Story Type and PrePost was statistically not significantly different from zero (estimate Story Type × PrePost = −0.095; odds ratio = 0.9; $z = -0.46$; $p = .65$; 95% CI odds ratio [0.6, 1.4]).

Implicit learning of prepositions in children with DLD from a storytelling context: production

In children's semi-spontaneous productions of the target locative preposition we did find a positive effect of the storytelling context: after watching and listening to the digital story, children with DLD used relatively more locative prepositions ($M = 6.5\%$; $Mdn = 5.8\%$; $SD = 5.4\%$) in their semi-spontaneous descriptions of visual scenes than before ($M = 3.6\%$; $Mdn = 2.6\%$; $SD = 3.3\%$; $t(29) = 3.3$, $p = .0029$; 97.50% CI = [+0.79%, +4.9%]). We had no evidence, however, that the children made fewer errors in their semi-spontaneous use of locative prepositions after listening and watching the digital story ($M_{\%\ correct} = 61\%$; $Mdn = 64\%$, $SD = 26\%$) than before ($M_{\%\ correct} = 63\%$, $Mdn = 67\%$, $SD = 24\%$; $t[26] = 0.33$; $p = .74$; 97.50% CI = [−14%, +18%]).

Discussion study 2

In Study 2 we investigated whether children with DLD implicitly learn to comprehend and produce locative prepositions (above, below, in front of, behind) from a digital story that included many examples of these prepositions (i.e., an implicit learning context). We did find that watching and listening to the story increases the semi-spontaneous use of these prepositions in children with DLD when they describe visual scenes. At the same time, however, we have no evidence that watching and listening to the story also leads to better understanding and fewer semantic errors in children's semi-spontaneous productions nor that the implicit learning context changes children's weighing of structural and semantic information when interpretating locative prepositional phrases. We discuss these outcomes in the context of study 1 and 2 in our General discussion.

General discussion

This paper investigated preposition comprehension and production in children with and without DLD and the role of implicit learning herein. We find that Dutch kindergartners with DLD have difficulties understanding and producing locative prepositions (Study 1). We found no evidence however, that these differences in preposition comprehension and production between children with and without DLD can be explained by a difference in weighing of linguistic cue information (Study 1). In Study 2 we did find that watching and listening to a digital story increases the semi-spontaneous use of prepositions in children with DLD when they describe visual scenes. At the same time, however, we have no evidence that watching and listening to the story also leads to better understanding and fewer semantic errors in children's semi-spontaneous productions. Finally, due to limitations in our measure of implicit learning ability, neither study 1 nor study 2 provides insight concerning the role of implicit learning in children's cue weighing for their understanding and use of locative prepositional phrases.

We hypothesized that children with DLD would score lower on the preposition comprehension test as compared to their typically developing children because children with DLD may have not (yet) learn to weigh structural information (word order) over semantic information (noun animacy). The outcomes of our preposition comprehension test reveal, however, that both groups of children weigh semantic information over structural information in their interpretation of the locative prepositional phrases. This suggests that cue weighing is difficult for typically developing children as well. Other studies have shown that before 2 years of age typically developing children rely preliminary on animacy cues when interpreting sentences. From 4 years of age English speaking children begin to rely more on word order in utterances with canonical word order and that between 7 to 12 years of age children use word order in sentences with non-canonical word order as well (Bates et al., 1984; Bever, 1970; Nelson, 1974; Von Berger et al., 1996). It could thus well be the case that the participating typically developing children in our study were still developing their cue weighing system as well. This might explain why we do not have evidence for a difference in cue weighing between children with and without DLD. Despite, even though both groups of children in our study weigh noun animacy over

word order – visual inspection of Figure 2 suggests that the effect may be more prolonged for the children with DLD. In condition 2 – where use of noun animacy leads to an incorrect interpretation – we see that children with DLD score below chance performance, meaning that they rely on noun animacy even when it leads to an incorrect sentence interpretation whereas typically developing children show guessing behavior in this condition (i.e., we have no evidence that their answers differ from chance in this condition).

An alternative but related explanation for our findings comes from studies that investigate the developmental trajectory of the neurobiological networks that underly sentence comprehension. In adults, semantic and syntactic domains are dissociable both in terms of their neuroanatomical localization and in terms of the time windows in which processing in both domains occur. In children this functional selectivity for sentence-level semantic processing versus sentence-level syntactic processing become neuro-anatomically separable from each other between the ages of 7 and 9. Before that, neuroanatomical and behavioral evidence shows that children mainly use their conceptual semantic world knowledge to master syntactic complexity (Skeide & Friederici, 2016). If we translate this to the outcomes of our study, it could be that both children with and without DLD do not weigh structural information over semantic information because they interpret sentences using language processing networks that are not (yet) sensitive to structural sequential syntactic information. Plausibly, these language processing networks develop gradually and in parallel with the development of other cognitive domains such as short-term memory, working memory and attention. We therefore recommend follow-up research with a dimensional approach zooming in on the interplay between language networks and other cognitive domains across childhood.

While we could not assess the role of implicit learning ability as a predictor of children's use of structural cues (word order) for sentence interpretation (see Discussion Study 1 and Limitations and future directions), our test battery also included a measure of verbal short-term memory. Earlier work by Hsu and Bishop (2014) reported on a correlation between verbal short-term memory and preposition understanding in children with and without DLD. From this Hsu and Bishop conclude that children may acquire prepositions via rote learning strategies rather than implicit learning strategies because rote learning – as compared to implicit learning – puts larger demands on verbal short-term memory. Though it was not part of our confirmatory research question, we did include verbal short-term memory as a control variable in our model for preposition understanding (Study 1). In line with Hsu and Bishop, we also observe that children with better verbal short-memory scores, score higher on the preposition comprehension task (see statistically significant outcome of the predictor verbal short-term memory in the model outcome as presented in our analysis script at our Radboud Data Repository Collection), suggesting that verbal short-term memory plays a role in locative preposition understanding.

Several studies have also reported that children with stronger receptive language skills rely more on word order cues for sentence interpretation than children with weaker receptive language skills (Evans & MacWhinney, 1999, van der Lely & Dewart, 1986; van der Lely & Harris, 1990). The outcomes of our production data together with the outcomes of production data from another – but similarly aged – group of Dutch children with DLD (van der Hoek-Snieders et al., 2021) also suggest that receptive language skills may play a role in children's semi-spontaneous productions of locative prepositions. In the present study we observe that children with DLD make more substitution errors in their semi-spontaneous productions of locative prepositions than their typically developing peers. This suggests that children with DLD have difficulties with the lexical meanings of the locative prepositions *above, under, in front of* and *behind*. Although van der Hoek-Snieders et al. (2021) found no evidence for such difference in the number of prepositions errors in the spontaneous productions of children with and without DLD, they did observe large individual differences in the number of errors made between the children with DLD and speculate that these individual differences may correlate with individual differences in children's receptive language abilities.

Limitations and future directions

A limitation of the present study is that we could not assess children's implicit learning ability with the administered serial reaction time task. Neither for the probabilistic sequence nor for the deterministic sequence did we observe a learning effect at the group level. Furthermore, split-half reliabilities of the task did not reach the psychometric standard of 0.8 (Nunnally & Bernstein, 1994; Streiner, 2003, see Methods). As we are not the first to report low reliability and validity of the task (see Arnon, 2019; Lammertink et al., 2020; Oliveira et al., 2022; West et al., 2017) but at the same time are not aware of alternative child-friendly measures of implicit learning ability, we hope that future studies will develop more reliable measures of (nonverbal) implicit learning ability.

Study 2 provides no evidence that the digital storytelling application leads to better understanding of locative prepositional phrases in children with DLD. Null results, however, can never be used to prove that an effect is absent. We can only conclude that if a difference would exist at all, children with DLD would either perform maximally 1.2 better (upper bound CI) or 1.2 times worse (lower bound CI) on the preposition test after listening to and watching the digital storytelling application than before. As there is no general consensus on how to interpret the magnitude of odds ratio effect sizes, we refrain from calling these effect sizes small, medium or large (but see Chen et al., 2010). Future studies could, however, use these values to specify whether this effect size is large enough to be of interest and define it as the smallest effect size of interest (SESOI) to a-priori determine the needed sample size to detect this effect size (Kumle et al., 2021; Lakens et al., 2018).

An alternative explanation for the null result could be that the design of our digital storytelling application may not have been appropriate to enhances children's understanding of locative prepositional phrases. In our digital story we decided to expose children to utterances that all had animate subjects and inanimate objects, because this is the most natural and most frequent semantic-syntactic condition. These utterances, however, can all be interpreted by weighing semantic information over structural information and from Study 1 we learned that this is how children with and without DLD interpret the utterances. For future studies, it would therefore be interesting to investigate whether training children on utterances that force them to use structural information rather than semantic information (e.g., prepositional phrases with animate subjects and objects only or with inanimate subjects and objects only; for examples see Hsu & Bishop, 2014 or utterances from conditions 3 and 4 of our preposition comprehension test) is more effective. Vasilyeva et al. (2006) show that storytelling interventions can be successful for training children on less frequent constructions. In their study, 4-year-old typically developing children produced more passives and understood passive constructions better after hearing 10 stories with a high proportion of passive sentences. In line with these outcomes, work on syntactic priming and implicit learning of passives in children with and without DLD also suggests that children with DLD and without DLD can benefit from exposure to input that contains complex syntactic structure (Garraffa et al., 2018). Simultaneously Garraffa and colleagues observed that the learning effect of each syntactic priming experience is smaller in children with DLD as compared to their typically developing age matched peers which implies that children with DLD require more input to derive the same learning outcome.

Another question that remains unanswered with our current set of results is whether use of the structural cue (word order) for preposition understanding in children with DLD is impaired or delayed only. Therefore, for future studies it would be interesting to run our preposition comprehension test in older children (<7 years) or to compare the outcomes to younger, language-matched typically developing peers to fully understand if (and when) children with and without DLD start to weigh structural information over semantic information in their interpretation of locative prepositional phrases.

Clinical implications

Clinically, the findings indicate that Dutch kindergartners with DLD find it more difficult to understand and produce prepositions than their typically developing age-matched peers. In therapy,

grammatical proficiency in DLD can be increased by offering these children variable contexts of different lexical verbs with a prepositional phrase (e.g., Bear *lies under* the sofa or Mouse *sits in front of* the closet). In this way children might better learn the semantic and structural properties of prepositions to become better language users.

Further, the results might indicate that the exposure time to the digital story was too short (i.e., 3 weeks) for children with DLD. Provision of therapy in learning complex language should ideally last 8 weeks or more in DLD (Law et al., 2004). Another clinical implication might be that the learning effect in these children increases if they actively produce prepositional phrases. In the current study they only had to watch and listen to the digital story of Mouse and Bear and were not asked to produce the target constructions actively. Grammatical treatment of children with DLD should take these aspects into account.

Conclusion

The outcomes of our study show that locative preposition comprehension and preposition use are difficult for Dutch children with DLD and that children with DLD may not implicitly learn to use and understand these constructions from watching and listening to a digital story. We cannot conclude that implicit learning ability does (or does not) play a role in children's understanding of locative prepositional phrases nor that children with and without DLD differ in their weighing of structural and semantic information for the interpretation of locative prepositional phrases. Rather it seems that, in comparison to their typically developing peers, children with DLD have more difficulties with the lexical meaning of locative prepositions.

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