The role of age and instruction in children's learning of vocabulary and grammar

Abstract

It is generally assumed that children and adults learn language through fundamentally different mechanisms: children predominantly rely on implicit learning, while adults utilize more explicit strategies (Lichtman, 2016). However, little is known about when and how learners begin to benefit from explicit instruction in the course of language development. Addressing this gap, the present study responds to DeKeyser's (2012, 2013) call to investigate age-treatment interactions (ATIs) under highly controlled experimental conditions. Using a cross-situational learning (CSL) paradigm, we trained 150 learners aged 8 to 13 to acquire both vocabulary and grammar in a complex artificial language under two instructional conditions: implicit and explicit. Results indicated that, in this task, 12-13-year-old children showed clearer benefits from explicit instruction than younger children, particularly for grammatical information related to word order. These findings shed light on the developmental stage at which explicit instruction may become beneficial for children's non-native language (L2) learning.

Keywords: Age-treatment interaction, implicit instruction, explicit instruction, statistical learning, cross-situational learning, child second language acquisition

Introduction

Children acquire their first language(s) without substantial explicit instruction (Lichtman, 2016). Through extended exposure to language and interaction with caregivers and other speakers, children gradually learn which words map onto which features of the environment (e.g., Smith & Yu, 2008), and how words relate to one another within syntactic structures (e.g., Gleitman, 1990). It is widely assumed that much of this process relies largely on implicit learning (Williams & Rebuschat, 2023). In contrast, classroom-based foreign language learning typically involves a significant degree of explicit instruction (R. Ellis, 2009). This raises a critical question: How does the shift from immersive, implicit exposure to explicit instruction about language affect children’s L2 learning?

In this study, we investigated how explicit instruction interacts with children’s implicit statistical learning of language under conditions designed to approximate immersive learning. We examined both how instruction influences the learning of vocabulary and grammar in a novel language, and how age affects children’s ability to integrate metalinguistic knowledge provided through explicit instruction with the structural properties of the language. The findings clarify when children are most responsive to explicit instruction and which aspects of L2 learning (vocabulary or grammar) are more amenable to instructional support.

Native language learning

In acquiring their native language(s), children respond to the statistical properties of the linguistic environment to learn multiple levels of language structure (Ambridge et al., 2015). This sensitivity to statistical regularities, which emerges through exposure, supports the learning of various linguistic components: the sound structure of words (e.g., Ge et al., 2025), the mappings between words and potential referents in the environment (e.g., Monaghan et al., 2019; Smith & Yu, 2008), grammatical word categories (Aslin & Newport, 2014), and syntactic structure (Walker et al., 2020).

Learning word-referent mappings can be supported by accumulating distributed statistics across multiple learning experiences (e.g., Monaghan et al., 2021; Roembke et al., 2023; Yu & Smith, 2007), referred to as cross-situational learning (CSL). CSL supports word learning across developmental stages (Akhtar & Montague, 2007; Bunce & Scott, 2017; Crespo & Kaushanskaya, 2021; Ge et al., 2024; Hu, 2017; Scott & Fisher, 2012; Smith & Yu, 2008; Vlach & DeBrock, 2017; Yu & Smith, 2007), and can also promote grammar learning, if children are first trained on vocabulary (Spit et al., 2022). Though adults can learn both vocabulary and syntax simultaneously from cross-situational statistics in immersive artificial language contexts (Monaghan et al., 2015; Rebuschat et al., 2021), much less is known about the extent to which children can simultaneously learn different language features through CSL. One exception is Savarino et al. (2025), who tested 7- to 11-year-old children’s simultaneous learning of vocabulary and morphophonological rules indicating animacy. Children learned noun-object mappings through CSL, but found it difficult to detect the morphophonological rules.

The role of explicit and implicit instruction in cross-situational learning

The CSL paradigm reflects the immersive language experience of learners, in that no explicit information about the language is provided, and learning occurs through exposure.

However, two theoretical accounts have been proposed to explain the mechanisms underlying cross-situational statistical learning: “Hypothesis Testing” (e.g., Markman, 1992) proposes that learners form a hypothesis about a specific word-object mapping, which is then either confirmed or rejected based on subsequent co-occurrences. This framework assumes an inference-based learning process and thus awareness and strategic attention may play a functional role in guiding which hypotheses are considered and how evidence is interpreted. Within this account, explicit information (e.g., instruction about structure or task goals) may therefore facilitate learning by constraining the hypothesis space, guiding attention toward relevant dimensions, and supporting deliberate evaluation of hypothesized mappings. In contrast, “Associative Learning” (e.g., McMurray et al., 2012) posits that learning emerges gradually through accumulated associative strength with less reliance on explicit knowledge and conscious hypothesis generation; instead, statistical regularities are aggregated through largely implicit mechanisms (Roembke et al., 2023). Thus, these two accounts diverge in their assumptions about the role of awareness and explicit information (Kachergis et al., 2014). The present study does not provide a direct adjudication between these accounts; rather, it uses this distinction to motivate the question of whether explicit instructional information can modulate learning in a CSL context, and whether such modulation varies with age. That is, if CSL primarily proceeds associatively, we would expect limited sensitivity to explicit instruction. In contrast, if CSL recruits hypothesis-testing processes, we should observe instructional sensitivity.

This theoretical distinction therefore leads to a question: what is the interface between CSL and explicit information from sources such as instruction[1]? Kachergis et al. (2014) found that adult learners showed enhanced word-referent learning when task instructions explicitly directed them to track word-object co-occurrences, as opposed to performing an incidental task. Similarly, Monaghan et al. (2019) found that explicit instruction about syntactic structure improved CSL for intransitive sentences, but Monaghan et al. (2021) found no instruction effect when more complex transitive sentences were employed. These mixed findings indicate that the existing evidence regarding the effectiveness of explicit instruction is context-dependent, and, there is thus a need to investigate when and how CSL incorporates external cues (e.g., explicit instruction; feedback) to support language learning under more ecologically valid conditions.

Explicit instruction in children’s language learning

As children transition from acquiring their first language(s) to learning additional languages, there is a marked shift from implicit learning through natural exposure to more explicit, formal instruction (e.g., in classroom settings) (Pfenninger & Singleton, 2019). This shift raises important practical and theoretical questions about the role of explicit instruction in language learning. Practically, it concerns how best to support children’s learning in educational contexts; theoretically, it speaks to the fundamental issue of how explicit instruction interacts with implicit statistical learning processes.

Children are often assumed to be primarily implicit language learners (DeKeyser, 2000; Ellis, 2005, 2009; Hamrick & Rebuschat, 2014; Lichtman, 2016), meaning that their learning typically occurs without conscious awareness (Hulstijn, 2015). Explicit instruction, which provides metalinguistic explanations or encourages rule discovery, may enhance awareness by prompting learners to notice linguistic regularities, thereby facilitating language learning (DeKeyser, 1995; Ruiz et al., 2025; Schmidt, 1990). However, Lichtman (2013) argued that this assumption may reflect differences in learning environments rather than inherent cognitive limitations, as older learners typically receive more explicit instruction, whereas younger learners are more often exposed to whole-language activities such as songs and stories.

There is a broad consensus that instruction supports L2 development (Norris & Ortega, 2000), yet children under 12 remain underrepresented in instructional studies, which have largely focused on adolescents and adults (Roehr-Brackin, 2024). A recent meta-analysis of statistical learning studies highlights this gap: out of 175 studies on auditory statistical learning of language, 105 focused on adults (mean age = 25.15 years) and 46 on infants (mean age = 12.33 months), while only 24 studies included young children, with a mean age of 7.83 years (Isbilen & Christiansen, 2022). Children aged approximately 2 to 7 years are typically considered distinct from older children in the context of L2 learning, as the development of literacy and cognitive skills in older children contributes to the emergence of metalinguistic awareness and more advanced problem-solving abilities (Philp, 2008).

Studies with children have demonstrated that explicit instruction can positively impact both vocabulary (Yousefi & Biria, 2018) and grammar learning (Lichtman, 2016; Pawlak, 2021; Spit et al., 2022b) in children. Yet, language learning, and in particular response to instruction, seems to vary with age. Some studies have shown that older children demonstrate advantages in non-native language (L2) learning (e.g., Snow & Hoefnagel-Höhle, 1978; Snedeker et al., 2012), both in laboratory settings and in real-life immersion contexts, often displaying a steeper initial learning trajectory (e.g., Jia & Fuse, 2007). Given that age captures a range of co-developing factors, such as cognitive maturation, literacy, schooling, and learning experience (Birdsong, 2018; Flege, 2019; Unsworth, 2016), it is plausible that older children gain an advantage through, for example, maturation of memory capacities, their ability to engage in explicit learning strategies and transfer their first language literacy skills (Hartshorne, 2022; Lightbown, 2003). These suggest that the effectiveness of explicit instruction may depend on age (DeKeyser, 2012). DeKeyser (2013) further emphasized the need for research designs with tight control over the quality and quantity of input, such as those using artificial but complex languages. The present study takes up this challenge by employing a rich, yet highly controlled, artificial language to investigate how age-treatment interactions influence the learning of both vocabulary and grammar within a CSL learning paradigm. We targeted an under-represented age group of 8 to 13 years, spanning the developmental window during which a critical period for language learning has been proposed (Hartshorne et al., 2018), also marking a stage where the maturation of metacognitive abilities may begin to qualitatively influence language learning processes.

The present study

In this study, we investigated the interplay between age and explicit instruction on language structure in school-aged children's cross-situational statistical learning of vocabulary and grammar. We employed a CSL paradigm designed to simulate an immersive language environment, with participants either receiving explicit instruction about the language's structure prior to the learning phase or engaging in the learning phase without such explicit instruction.

Conceptually, this study was designed to address key gaps at the intersection of CSL and SLA, particularly regarding when and how, across middle childhood through early adolescence, explicit knowledge gained through instruction begins to influence L2 learning. Methodologically, through adopting a laboratory-based experimental paradigm, the study enables the examination of the widely debated topics (i.e., age effect and role of explicit instruction) in SLA research under highly controlled environments.

The study addressed the following research questions.

RQ1: How does cross-situational statistical learning of vocabulary and grammar change across children's development?

We predicted that CSL would improve with age, given that developmental increases in attention and memory (Vlach & DeBrock, 2017), as well as in statistical learning abilities (Arciuli & Simpson, 2011), are well-documented. However, we anticipated that this improvement might differ across linguistic features. Specifically, we expected that vocabulary learning would show more age-related variation than syntax learning (e.g., sensitivity to word order), as procedural memory, which is typically associated with syntactic learning, matures earlier than declarative memory, which in turn supports vocabulary learning (Ullman, 2004).

RQ2: To what extent does explicit instruction about the syntactic structure of the language affect children's learning of L2 vocabulary and grammar through immersive cross-situational statistical learning, and how does this impact vary across different age groups?

We predicted that explicit instruction would enhance learning outcomes (Lichtman, 2012), particularly for the aspects of the language that are explicitly taught, in this case, word order. However, given the interactive nature of vocabulary and grammar learning (e.g., Gleitman & Gleitman, 1992), we also considered "spill-over" effects, whereby instruction on grammar might indirectly support vocabulary learning. Furthermore, we expected that the effectiveness of explicit instruction might vary with age, as older children may be more capable of benefiting from metalinguistic information due to their developing cognitive skills.

RQ3: To what extent do children develop explicit knowledge of the language, and how is this related to instruction and learning outcomes?

We examined whether children who received explicit instruction about the syntactic structure of the language were more likely to verbalize their syntactic knowledge. If so, we aimed to determine whether awareness of syntactic information had an effect on overall L2 learning. We predicted that explicit awareness would be more common among children who received instruction and who performed well on the task. Furthermore, we expected this awareness to be specifically related to the instructed features of the language, namely the verb-final word order and verb meanings rather than to vocabulary or other grammatical elements that were not explicitly taught.

Methods

Participants

One hundred and fifty children aged 8 to 13 years participated in the study, with 50 participants in each of three age groups: 8-9, 10-11, and 12-13 years. Participants were recruited through primary school teachers from two schools in Northern China. All were native speakers of Mandarin who had been learning English as a second language for one to three years and had no prior experience with verb-final languages. Participants were pseudo-randomly assigned[2] to one of two instruction conditions: an implicit group or an explicit group. Power analyses, based on the effect size reported in Monaghan et al. (2021)[3], indicated that a sample size of 25 participants per condition per age group would provide a statistical power of 0.88 to detect learning effects in the artificial language task. This resulted in six experimental groups, summarized in Table 1.

[Insert Table 1 approximately here]

Informed consent was obtained from both parents and children prior to participation. The study was approved by the Ethics Review Panel of the Faculty of Arts and Social Sciences at Lancaster University and the analysis was preregistered on the Open Science Framework (OSF, https://osf.io/9gkbz/overview?view_only=715430c90ad84228a61490d834162ce9).

Materials

Artificial language

Vocabulary. The artificial language used in this study was adapted from Rebuschat et al. (2021) and consisted of 12 pseudowords: 10 bisyllabic content words (comprising six nouns and four verbs) and two monosyllabic grammatical case markers, which indicated whether the preceding noun referred to the subject or the object of the sentence (for the full list of stimuli, see Appendix S1). In this artificial language, a noun followed by a post-nominal case marker formed a noun phrase (NP). The case markers were included to indicate the thematic role of each noun phrase and thereby permit flexible ordering of subject and object noun phrases while preserving sentence meaning. They therefore increased the structural complexity of the language and provided learners with a cue to agent-patient relations. However, because the explicit instruction targeted verb-final word order rather than the meanings of the case markers, marker learning should be interpreted as a separate outcome rather than as a direct measure of instruction on the taught rule. All words were read and recorded individually by a female native speaker of English in a monotone voice.

Grammar. The word order of the artificial language was modeled on Japanese grammar, featuring a verb-final structure with variable word order. Specifically, the positions of the subject and object noun phrases (NPs) were flexible, but the verb always appeared at the end of the sentence. Thus, sentences followed either a subject–object–verb (SOV) or object–subject–verb (OSV) word order.

A total of 72 unique sentences were generated and distributed across six training blocks, with each block containing 12 sentences. Sentence stimuli were presented using E-Prime, with a 250 ms pause between each word. To assess participants' sensitivity to word order, we also constructed six ungrammatical word sequences that violated the verb-final syntax of the artificial language by altering the verb’s position: three followed VSO or VOS word orders, and three followed SVO or OVS word orders. In addition, six novel grammatical sentences that conformed to the language’s syntax but were not used during training were created. These grammatical and ungrammatical test sentences were used in the post-training phase to evaluate learners’ syntactic knowledge.

An example sentence is provided in (1).

(1) cheelow tha bimdah noo dingep.
Animal$_1$ SUBJECT Animal$_2$ OBJECT pushes.
‘Animal$_1$ pushes animal$_2$’.

Half of the sentences followed SOV word order, and the other half followed OSV. Vocabulary frequency, subject–object assignments, and word order were balanced across the six training blocks to ensure equal distribution of linguistic features.

Visual referents. Six cartoon animals (cow, chicken, turtle, zebra, elephant, owl) served as the referents for the nouns in the artificial language (for images, see Appendix S2). These animal characters were shown performing one of four actions (hiding, jumping, lifting, pushing) which served as the referents for the verbs in the animated scenes. The mappings between the pseudowords and the animal characters or actions were randomly assigned across several versions of the study to minimize potential biases arising from systematic associations between specific speech sounds and referents (Rebuschat et al., 2021).

Procedure

Data collection took place at the children's schools using two experimental platforms: E-Prime 2.0 was used for the 8–9 age group, and Gorilla was used for the 10–11 and 12–13 age groups. The task structure, stimuli, timing, and response format were kept as consistent as possible across platforms. Children were invited to a designated classroom equipped with laptops or desktop computers and noise-cancelling headphones. Testing was conducted in groups, with the number of participants per session varying based on the school timetable (up to a maximum of 25 children at a time). Children within each experimental condition and age group were always tested together. Instructions were provided to children as a group, but then testing was completed individually on computers without interaction among the children.

Cross-situational learning task

Participants were first informed that they would be learning an alien language spoken by "friends from a distant planet" and were instructed to make choices as quickly as possible based on their intuition during the experiment. Children assigned to the explicit instruction condition then received information about the verb-final word order in the alien language. The instruction, translated from Chinese, was as follows: "In Chinese, if we want to say 'The dog pushes the pig.', we say the animal who does this action first, the dog in this case; and then we say the action word, pushes in this case, and we finally say the animal who is being pushed, the pig in this case. But in the alien language, aliens say the two animals first, and the action word always goes to the end of the sentence: the dog the pig pushes, or the pig the dog pushes. Remember, the action word is always at the end of the sentence. But the two animals' positions varied". While listening to this instruction, children were shown an image of the animal characters (a dog pushing a pig) to support comprehension. Participants' understanding and memory of the grammatical rule were checked right after the instruction, by asking them to repeat the rule. Once they could accurately repeat the rule, they proceeded to the CSL task.

Each trial in the CSL task presented two dynamic scenes side by side on a computer screen. Each scene featured two cartoon animal characters performing different actions. While the scenes were displayed, children heard a sentence in the artificial language that corresponded to one of the two scenes. The audio was played only once, and children could respond only after the sentence had finished playing. The animations continued looping until the child provided a response by pressing a key on the keyboard corresponding to their selected scene. The experiment then proceeded immediately to the next trial. Children were instructed to match the sentence to the scene it described as quickly and accurately as possible. Correct responses were rewarded with an increase in an on-screen coin counter accompanied by a coin sound effect. Figure 1 illustrates an example of a training trial.

Before the training began, children completed two practice trials designed to familiarize them with the task. In each practice trial, they observed two animated scenes while listening to a sentence in the artificial language, which matched one of the scenes. The animal characters and pseudowords used in the practice trials were not included in the main study.

Training trials The CSL task consisted of six training blocks, followed by a grammaticality judgment task in a final test block (Block 7). Blocks 1, 2, 4, and 5 included only training trials, while Blocks 3 and 6 interleaved training and vocabulary test trials to assess learning progress throughout the task. There were 72 training trials in total, distributed evenly across the six training blocks (12 trials per block). Each trial presented two animated scenes that varied in the animal characters, the actions being performed, and the assignment of agent and patient roles to the animals.

Vocabulary test trials Vocabulary test trials were used to assess participants' learning of nouns, verbs, and grammatical markers, and were interspersed within training Blocks 3 and 6. To minimize participants' awareness of being tested, these test trials were visually identical to training trials from the learner's perspective. In each trial, participants listened to a sentence and viewed two animated scenes, with the target and distractor scenes differing only in the feature being tested. In noun test trials, the scenes differed in one of the animal characters; in verb test trials, the distinction lay in the action being performed; and in marker test trials, the scenes differed in the assignment of agent and patient roles, achieved by reversing the roles of the two animal characters.

[Insert Figure 1 approximately here]

Grammaticality judgment task

The learning of word order was assessed using a grammaticality judgment task (GJT, Block 7), which was administered immediately after the six cross-situational training blocks. In these syntax test trials, only one animated scene was presented alongside an auditory sentence in the artificial language. Participants were instructed to judge whether the sentence, spoken by “an alien from another planet who is also learning this alien language,” sounded good or funny, based on the sentences they had heard during training.

Before the task began, the distinction between good and funny was explained clearly to ensure all children shared the same judgment criteria. Children were asked to press a key labeled with a sticker marked good if they believed the sentence conformed to the alien language, or a key labeled funny if the sentence sounded incorrect. Of the 12 sentences presented, half (6) contained syntactic violations, while the other half were grammatically consistent with the artificial language.

Retrospective verbal reports

Finally, all children completed a series of debriefing questions designed to probe their explicit knowledge of the language. These questions assessed their understanding of the function of the marker words, as well as their knowledge of the typical positions of nouns and verbs within the sentence structure.

Statistical Analysis

For both training and test trials of the CSL task, accuracy was treated as a binary outcome, with responses categorized as either correct or incorrect. Generalized linear logistic mixed-effects modeling (Baayen et al., 2008) was then conducted for statistical analysis. To address RQ1 (developmental effects of CSL) and RQ2 (effect of instruction on learning), we constructed mixed-effects models starting with the null model (containing random effects of participant and item with intercepts and slopes for each fixed effect) to models where we incrementally added fixed effects (i.e., block, age group, condition, then two-way, and finally the three-way interaction) with log-likelihood tests on model fit. The variables age and condition were entered into the models as categorical variables with three (8-9, 10-11 and 12-13) and two (implicit and explicit) levels, respectively. For age, 8-9 age group served as the initial reference group. To test all three age groups simultaneously, in addition to the comparison only to the reference level as ascertained using the log-likelihood model comparison, we also used a type 3 Anova comparison of models that included group as a fixed effect. For condition, the implicit group was reference group. Block was entered as a continuous variable coded sequentially from 1 to 6 to index learning progression and was not centered or scaled. We ran separate models for the training trials, the noun, the verb, the marker words, and the syntax test trials.

To address RQ3, which examined (a) the extent to which children developed explicit knowledge of the language and (b) how such awareness related to learning outcomes, we first constructed logistic regression models with awareness as the binary outcome, with age group (reference = 8-9 years) and condition (reference = implicit) as categorical predictors for the retrospective verbal reports. Then, awareness was added as a fixed effect into the best fitting logistic mixed-effects models of training trials, vocabulary test trials and syntax test trials respectively and comparing model fit using likelihood ratio tests and type 3 Anova comparisons.

To clarify how the statistical analyses map onto the research questions, we specify here the statistical results that would constitute support for each RQs. For RQ1, evidence would be indicated by significant effects involving age in the training and test phases. For RQ2, evidence would be indicated by significant effects involving condition, particularly a main effect of condition, a two-way interaction between age and condition, or, in the training phase, a three-way interaction among block, age, and condition. For RQ3, evidence would be indicated by significant effects of age, condition, and their interaction on awareness, as well as by improvements in model fit when awareness is added as a predictor of training and test performance.

The analysis plan was preregistered on the Open Science Framework: https://osf.io/9gkbz/overview?view_only=715430c90ad84228a61490d834162ce9. Deviations from, or additions to, the preregistered analyses are identified as exploratory.

Results

We first report descriptive results, and then turn to mixed-effects modeling for analyses of whether block, age or experimental condition predicted learning outcomes, and whether these effects interacted.

Performance during training trials of the CSL task

Performance on the training trials of the CSL task is summarized in Figure 2. Detailed descriptive statistics are reported in Table S-1.

[Insert Figure 2 approximately here]

To address RQ1 (developmental trajectory effects) and RQ2 (instructional effects) on overall learning, we investigated whether block, age, explicit instruction, as well as their interactions affected CSL learning trajectories. In line with our analysis preregistration, we conducted binary logistic mixed-effects modelling (for the full model-building procedure, see Supporting Information, Appendix S3). The best-fitting model showed a significant three-way interaction among block, age and condition ($\chi^2(3) = 12.86$, $p = .005$). Table 2 presents the best-fitting model summary. Figure 2 shows how these learning trajectories differed across age groups and conditions as learning proceeded (from block 1 to 6). Post hoc comparisons revealed that there was a significant difference for those in the explicit instruction group in the effect of block for 12-13-year-olds compared to 8-9-year-olds ($z = 4.50$, $p < .001$) and 10-11-year-olds ($z = 4.34$, $p < .001$), who did not differ from one another (z = 0.25, $p = .965$). There were no differences in effect of block by age for those in the implicit group (all $z <= 1.99$, $p >= .115$). Thus, instruction enhanced learning for the 12-13 age group more than the other age groups, and this improvement increased as training proceeded.

[Insert Table 2 approximately here]

Performance on vocabulary test trials of the CSL task

The vocabulary test trials were used to measure the learning of nouns, verbs, and marker words. Detailed descriptive statistics, including comparisons against chance level, are provided in Table S-2. For nouns, significant learning was observed only in the 10-11-year-old group under the explicit instruction condition. For verbs, significant learning emerged in the 12-13-year-old group across both the implicit and explicit instruction conditions, while no significant effects were found in the younger age groups. For marker word learning, no significant learning effects were found.

[Insert Figure 3 approximately here]

To address RQ1 and RQ2, we examined whether block, age, condition, and their interactions predicted CSL vocabulary learning. In line with our analysis preregistration, generalized linear mixed-effects modeling was conducted (see Table S-3 for best fitting models summary and formula for vocabulary tests).

For noun learning, the null model was the best-fitting model as adding block, age, condition and their interactions did not improve model fit. For verb learning, the final model was also the null model, indicating no reliable main or interaction effects of age and instruction. However, this was for when only a simple effect of age was considered in the model (comparing the youngest age group to the other two age groups). When all three groups were considered simultaneously, the effect of age interacting with condition was significant, with similar results to the overall training results: 12-13-year-olds in the explicit instruction condition outperformed 8-9-year-olds (z = 3.71, *p* = .006) and 10-11-year-olds (z = 4.37, *p* < .001), but did not differ from one another (z = 0.80, *p* = .704), and there were no differences by age for the implicit condition (all z <= 0.40, *p* >= .914). However, this pattern should be interpreted cautiously given that inclusion of the interaction terms did not significantly improve overall model fit.

Similarly, regarding marker learning, the final model was the null model, as none of the main effects or interactions improved model fit significantly. As with the verb learning, when all three groups were considered simultaneously, differences were observed for age across both conditions when comparing 10-11-year-olds and 8-9-year-olds (*z* = 3.11, *p* = .005), but the other age groups did not differ (*z* <= 1.71, *p* >= .201). Again, as including age as a simple effect did not significantly improve overall model fit, the comparisons should therefore be interpreted with caution.

Performance on syntax test trials

Participants' learning of syntax (i.e., word order) was assessed by the grammaticality judgment task. Significant learning was observed in both implicit and explicit instruction conditions for the 8-9 and 12-13 age groups, and marginal effects were detected for the 10-

11-year-old group (for the detailed descriptive statistics including comparisons against chance level, see Table S-4 in Appendix S4).

To answer RQ1 and RQ2 with respect to syntax learning, we examined whether age, condition, and their interaction predicted GJT performance. The best-fitting model included age, $\chi^2(2) = 13.19$, $p < .001$, and the interaction between age and condition ($\chi^2(2) = 7.55$, $p = .023$). For the instruction condition, 12-13-year-olds performed more accurately than 8-9-year-olds ($z = 4.65$, $p < .001$) and 10-11-year-olds ($z = 3.98$, $p < .001$), who did not differ from one another ($z = 0.02$, $p = 1.0$), but there were no differences among age groups for the implicit condition (all $z <= 1.60$, $p >= .245$). Adding condition did not improve model fit ($\chi^2(1) = 1.10$, $p = .293$). See Table S-5 for best-fitting model summary.

[Insert Figure 4 approximately here]

In summary, we observed a non-linear developmental trajectory of CSL learning. 12-13-year-old children benefited more from explicit instruction during training and outperformed younger peers in syntax learning in this condition.

Retrospective verbal reports

Responses to the debriefing questions concerning participants' knowledge of the syntax (i.e., the verb-final word order knowledge) of the artificial language were coded into two categories according to their awareness (Lichtman, 2016). Participants were coded as

“Noticing” if they provided responses indicating that verbs are placed at the sentence final position. Participants whose responses did not include this description were coded as “No report”. Cohen’s κ indicated high inter-rater reliability (κ = 0.973; 98.7% agreement). The proportion of children in each category, across the implicit and explicit instruction groups, is presented in Figure 5.

[Insert Figure 5 approximately here]

To answer RQ3 (development of awareness), we first examined whether the development of explicit knowledge of the language syntax (i.e., verb-final word order) could be predicted by age, condition, and their interaction. Binary logistic regression models indicated that the final model included age, condition and their interaction. Condition was significant, $\chi^2(1) = 22.69$, $p < .001$, as was the interaction between condition and age group, $\chi^2(2) = 12.86$, $p = .002$. This was due to greater awareness for the youngest children in the instruction condition than the implicit condition, $z = 4.07$, $p < .001$, with levels of awareness not different for the other age groups ($z <= 1.96$, $p >=0.050$).

Next, we examined whether the development of the explicit knowledge predicted CSL learning outcomes as covered in RQ3. Specifically, we examined whether awareness significantly affected accuracy in both training and test trials, beyond the effects of age and condition already included in the mixed-effects analyses. For training trials, adding awareness did not improve the model fit of the best-fitting model (i.e., the model shown in

Table 2; $\chi^2(1) = 0.23$, $p = .629$). For the vocabulary test trials, awareness had a significant effect on verb learning ($\chi^2(1) = 8.95$, $p = .003$), but no significant effects were found for noun learning ($\chi^2(1) = 0.0$, $p = 1.0$), marker learning ($\chi^2(1) = 1.12$, $p = .290$), or syntax test trials ($\chi^2(1) = 0.05$, $p = .829$.

In sum, awareness of verb-final word order was influenced by instruction and its interaction with age group. This pattern was not a simple age-related increase: explicit instruction increased reported awareness most clearly among the youngest children, while differences among the older groups were less pronounced. In addition, awareness predicted verb learning. For nouns, marker words, and syntax, however, we found no evidence that awareness related to performance. These suggest that the effect of awareness may depend on learning tasks.

Discussion

It is widely assumed that children and adults acquire language through fundamentally different mechanisms: children primarily rely on implicit learning, while adults tend to engage more with explicit strategies (Lichtman, 2013). The aim of this study was to investigate when and how, over the course of development, learners begin to benefit from explicit instruction to support language learning, and whether this might affect acquiring words and relations among words differently. Our findings revealed that the effectiveness of explicit instruction varies across developmental stages.

Developmental trajectories in statistical learning of language

Our first research question examined how cross-situational statistical learning develops across childhood and early adolescence. As predicted, we observed a significant effect of age in the learning of syntax (i.e., word order knowledge) in a CSL paradigm, indicating that older children were more capable of extracting language structure through tracking input statistics. This finding aligns with Arciuli and Simpson’s (2011) evidence of increasing statistical learning ability between the ages of 5 and 12, and is also consistent with Savarino et al.’s (2025) report that younger children (7-11 years) showed difficulty acquiring morphophonological rules. Our results challenge the view that statistical learning is age-invariant (e.g., Saffran et al., 1997; Moreau et al., 2022). Our results also correspond with the maturation of cognitive skills (e.g., working memory) that typically emerge around the age of eight and beyond (e.g., Vuontela et al., 2003), and which are likely to support more successful language learning.

The developmental trajectory observed in our study was nonlinear. While syntax learning remained relatively stable between the ages of 8 and 11, a significant improvement emerged in the 12-13 age group. This pattern is less consistent with the Critical Period Hypothesis, which posits that younger learners have an advantage in acquiring a L2 through implicit mechanisms (Johnson & Newport, 1989; Hartshorne et al., 2018), and more in line with alternative accounts suggesting a “the-older-the-better” trend during childhood and adolescence (Muñoz, 2006; Snedeker et al., 2012; Snow & Hoefnagel-Höhle, 1978).

Nevertheless, there was an exception to the overall “the-older-the-better” trend observed in the current data. Notably, 10-11-year-olds showed better learning of marker words than the younger children (8-9), though this was a small effect and was not significant in terms of a simple main effect of condition in the model results. It was only significant when all three age groups were compared simultaneously. This effect of the marker words, which indicate agent and patient roles of words in the language, is complex and hard to learn even for adults (e.g., Monaghan et al., 2021), so sensitivity to these markers is surprising and impressive in the children. Within the implicit condition, we also observed relatively higher rates of noticing in the 10-11 group, suggesting that even without explicit instruction, children at this age may be better at abstracting sentence structure through navigating sentence-scene correspondences. Although some studies have reported a similar pattern in morphosyntax development, such as an advantage for 11-year-olds on several morphophonological indices followed by a dip at mid-adolescence (e.g., Reed et al., 1998), there is currently limited work that specifically explains a learning peak at this developmental stage, particularly within cross-situational learning paradigms. The present findings may therefore reflect a potential developmental transition in sensitivity to morphosyntactic cues; however, this interpretation should be treated cautiously and warrants further investigation in future research focusing more directly on this age group.

Our findings further suggested a qualitative difference between vocabulary and syntax learning across development. Syntax learning appeared more consistent across age groups, with even the youngest children (aged around 8) demonstrating successful learning of syntactic structure. By contrast, the youngest learners failed to learn word-referent mappings, and the successful learning of marker words and verbs was only observed in older learners (aged 10-11 and 12-13, respectively). Though we did not directly compare vocabulary and syntax learning, because of the different ways in which these measures are analysed, this pattern could suggest a developmental shift in vocabulary learning during middle childhood to early adolescence. These results reflect those of Zhang et al. (2025), who found that 8 year olds were able to acquire word order knowledge but struggled with vocabulary learning.

The observed advantage in word learning for older children may be linked to developmental improvements in memory skills. Procedural memory, which supports syntax learning, reaches maturity earlier than declarative memory (Ullman, 2004). Declarative memory, associated with vocabulary learning, continues to develop through adolescence, the age range targeted in our study, spanning the transition from childhood to adolescence.

Walker et al. (2020), in a study with adults using a similar language learning task, found that declarative memory related most closely to verb learning, whereas procedural memory related more to learning of nouns and marker words. This association between declarative memory and verb learning may be consistent with the current finding that verb learning, rather than noun learning was more successful for the older children, whose declarative memory may have been more developed. Verbs tended to be learned more effectively from the language, potentially because their position was always at the end of the sentence, thus meaning that they are more likely to engage with explicit, declarative memory systems. However, it does not explain why the 10-11 year old children were more successful at acquiring the marker words, and it remains an open question as to whether similar effects would be observed if nouns appeared in more fixed positions in the language.

However, the current study did not collect data on learners' individual differences in cognitive abilities, which limits the extent to which our interpretation can be empirically supported. Nevertheless, we highlight this as an important direction for future work: investigating how the development of cognitive abilities shapes the effectiveness of instruction, particularly during the transition from middle childhood to early adolescence.

Effects of explicit instruction and developmental differences

Our second research question explored the extent to which explicit instruction about syntactic structure influenced children's learning of L2 vocabulary and grammar. As predicted, we found that explicit instruction enhanced L2 learning performance. This finding supports recent evidence (e.g., Lichtman, 2016) that challenges the long-held assumption that children acquire language primarily through implicit mechanisms (Lichtman, 2013). Our paradigm extends this line of research by demonstrating that children can benefit from explicit instruction even when required to acquire vocabulary and grammar simultaneously in an immersive learning context.

However, contrary to our initial prediction, the benefits of explicit instruction were not uniform across age groups. Children aged 12-13 years showed responsiveness to explicit instruction, leading to better performance on both vocabulary and grammar learning tasks. A similar shift was noted in Lichtman (2013), where learners around age 12 exhibited a sudden improvement in learning outcomes, coinciding with the introduction of explicit instruction in their school curriculum. While Lichtman attributed this shift solely to instructional exposure, we propose that cognitive maturation may also play a central role. This developmental shift in sensitivity to explicit instruction can be interpreted in relation to the two mechanisms: hypothesis-testing and associative learning. If CSL were purely an associative process which relies on the gradual accumulation of co-occurrence statistics, we would expect instruction to have a limited impact on learning. However, our finding that the 12-13-year-olds benefited from explicit cues suggests that CSL may increasingly recruit hypothesis-testing processes as children mature. This aligns with the suggestion that older learners or more expert learners "appear to be hypothesis testers" (Yu et al., 2007, p. 742).

Our results also conform with Chen et al.'s (2017) argument that the simultaneous learning of multiple linguistic components from CSL may be affected by learners' (selective) attention and cognitive capacities. Although children struggled to acquire vocabulary and grammar simultaneously through CSL, performance improved when explicit instruction directed their attention to specific linguistic features and promoted their awareness of the underlying rules (West et al., 2021). It is thus a possibility that developing attentional resources, rather than procedural memory skills, may contribute to statistical learning ability relative for language learning.

The interaction between age and instruction that we found in our study is also consistent with increasing capacity for explicit learning strategies as cognitive abilities mature, such as working memory (Ellis, 2002). The effectiveness of explicit feedback (Yilmaz, 2013) and explicit instruction (Suzuki & DeKeyser, 2017) is moderated by working memory, which itself develops significantly between ages 6 and 13 (Vuontela et al., 2003). Distinguishing attention from memory skills in future studies can highlight which may be most critical in language learning.

Relatedly, our study also responds to Roehr-Brackin's (2024) call for research into whether explicit learning can facilitate implicit learning, the process during which learning proceeds without conscious awareness. The CSL paradigm adopted in the current study provides an appropriate context for this question because it is widely considered to rely on implicit statistical learning, in which learners extract distributional regularities merely from the co-occurrences in the input, often without awareness (e.g., Kachergis et al., 2010). By embedding explicit instruction within this immersive CSL context, we show that instruction can enhance learning under specific conditions. Previous studies with adults have suggested a potential benefit of instruction in cross-situational learning (Kachergis et al., 2014; Monaghan et al., 2019), but the outcomes appear to depend on the linguistic feature being targeted (Monaghan et al., 2021). In contrast, our study showed that explicit instruction on sentence structure, specifically, verb-final word order, significantly enhanced learning, suggesting that the focus of instruction matters greatly in determining its impact on L2 learning.

The instruction we provided closely related to the syntax learning that we tested in the GJT, i.e., sensitivity to the word order. Learners could perform well on this task if they became aware of the identity and position of the verb at the end of the sentence. Future studies could extend this approach by examining other syntactic structures, such as subject-verb agreement and number marking. For instance, learners might be guided to attend to number or role distinctions in the input without being explicitly told the grammatical rule. Researchers could then examine whether such guidance supports transfer to structurally related but untaught constructions, thereby testing whether instruction facilitates broader grammatical abstraction rather than feature-specific learning.

Nevertheless, our findings contribute to broader debates on the interface between explicit and implicit learning in terms of developmental effects and whether there is any possibility at all of interactions between explicit and implicit knowledge (Ellis, 2015). Our findings suggest that explicit instruction can influence learning performance in a CSL context, particularly among older children. However, because the present measures do not provide a direct separation of implicit and explicit knowledge, these findings should be interpreted as evidence that explicit information can shape performance during statistically structured language learning, rather than as definitive evidence about the mechanisms by which explicit and implicit knowledge interact.

The role of awareness in vocabulary and syntax learning

Our third research question examined the relationship between awareness of language structure and L2 learning outcomes. As predicted, children as young as eight years old demonstrated an ability to verbalize the syntactic rule (i.e., word order) after receiving explicit instruction, and greater awareness was associated with better performance in verb learning, consistent with broader evidence that awareness can shape language-learning outcomes (e.g., Zhao et al., 2021). These findings align with those of Lichtman (2016), who found that children aged 5-7 in an explicit instruction condition developed greater awareness of the structural features of a mini-language.

Notably, the present study found that awareness emerged as the only global predictor of verb learning. This finding indicated that the key predictor of successful verb learning was not merely the receipt of instruction, but rather the learner's awareness of the instructional target, underscoring the role of awareness in children's statistical learning of vocabulary. This aligns with findings from Ruiz et al. (2025), who also reported that awareness, but not memory capacity or instruction type, best predicted vocabulary learning outcomes in adult learners under similar experimental conditions. These findings highlight the importance of considering awareness not only in research but also in practical L2 classroom instruction.

Practical implications

Our findings offer tentative practical insights for designing age-appropriate L2 instruction. As DeKeyser and Larson-Hall (2005) argued, the widely held belief that "earlier is better" does not apply uniformly across all L2 learning contexts. In formal educational settings, such as classroom-based L2 instruction, our findings support a more nuanced interpretation of the critical period hypothesis. Rather than assuming that younger learners always benefit more, we emphasize the importance of aligning explicit instruction with learners’ cognitive and developmental readiness. The effectiveness of instruction, in this view, may depend not only on what is taught, but when and to whom it is taught.

Moreover, the finding that metalinguistic awareness predicted verb learning suggests that learners’ conscious understanding of grammatical regularities may play a role in supporting learning under certain conditions. Explicit instruction may therefore be particularly useful when paired with opportunities for learners to reflect on, articulate, and apply the rules they have been taught.

However, we note that the effects observed here were obtained under highly-controlled lab-based environment, and thus future research examining longer-term learning and more ecologically valid instructional contexts will be important for determining how these findings may translate to educational practice. With these limitations in mind, the present results suggest that aligning pedagogical approaches (e.g., explicit instruction) with learners’ developmental readiness and promoting metalinguistic awareness can help create more effective, age-sensitive L2 learning environments.

Limitations and future directions

The present study provides support for a maturational account of L2 learning in children aged 8 to 13. However, we did not directly examine the role of individual cognitive abilities (such as memory) in the learning process. Prior research by Vlach and DeBrock (2017) suggests that memory abilities, rather than age, are the strongest predictors of vocabulary learning in younger children (ages 2 to 5). Future research should aim to disentangle the effects of procedural, declarative, and working memory from chronological age, and examine how these memory systems interact with explicit instruction in additional language learning (Ruiz et al., 2019).

A second limitation concerns our reliance on offline testing measures. Incorporating a combination of online and offline methodologies could yield a more comprehensive understanding of the learning process. For example, Spit et al. (2022b) found that the effect of instruction on grammatical marker learning was detectable only through eye-tracking data, not through standard accuracy measures. Future studies should therefore consider integrating online processing-based measures (e.g., eye-tracking, reaction times) to capture more subtle, implicit learning effects, alongside offline explicit assessments (e.g., untimed grammaticality judgment tasks), which allow learners to reflect on and apply their explicit knowledge (R. Ellis, 2005). Furthermore, the syntax learning in the current study was assessed with only a single grammaticality judgment task. While this provided evidence of children's explicit knowledge of the word order rule, it offers a relatively narrow perspective on syntactic competence. Complementary tasks, such as sentence-picture matching, would help triangulate syntactic knowledge in a more ecologically robust way and provide stronger evidence about the depth and durability of syntactic learning.

Although participants' understanding and memory of the grammatical rule was checked immediately after instruction through a recall test, this procedure does not constitute a standardized assessment, and thus could limit our finding regarding effect of instruction and awareness. Future research would benefit from implementing standardized rule knowledge check both before and during exposure, though we recognize that such checks during the task may risk interfering with the learning process.

Another concern is the absence of direct measures of task motivation, which can affect learner's attention during the task. Although the coin-based reward structure was designed to maintain attention and encourage active participation, we cannot determine whether it was equally motivating across different age groups. Future research should therefore consider incorporating measures of motivation (e.g., self-reports) alongside online methods such as eye-tracking, which can capture real-time attention allocation during learning. This multimethod approach would offer a fuller picture of how, when, and for whom explicit instruction facilitates L2 learning.

A further limitation is that testing platform was partially confounded with age group, as the youngest children completed the task in E-Prime whereas the two older groups completed it in Gorilla. Although the task structure, stimuli, and response format were matched across platforms, future work should use a single platform across age groups to rule out platform-related influences.

Last but not least, while the artificial language paradigm allows for tight experimental control over linguistic and instructional input, we acknowledge that it differs from natural L2 learning, which may limit the ecological validity of our findings. We also acknowledge the potential for instructional contamination due to the group-based delivery of explicit instruction, as uncontrolled peer effects (e.g., observational learning) may have influenced the effect of the explicit instruction observed in the current study.

Conclusion

This study provides insights into developmental changes in children's receptivity to explicit instruction in second language (L2) learning across middle childhood and adolescence. The findings carry important methodological, theoretical, and practical implications. Methodologically, this study is the first to demonstrate how L2 instruction can be examined within a highly controlled yet immersive learning environment, combining ecological validity with experimental precision. Theoretically, our results suggest a possible developmental change around early adolescence in children's ability to benefit from explicit instruction in this CSL task. The study contributes to theoretical models of cross-situational learning by showing that explicit knowledge can support learning, particularly for older learners and for language features (such as vocabulary) that rely more heavily on declarative memory. We further propose that CSL may begin as an associative process but becomes increasingly strategic and metacognitively driven as learners approach puberty. Finally, our findings offer important practical insights for L2 instructional design, highlighting when and for which language features the explicit instruction is most effective.

Endnotes

1. The current study adopts the notion that instruction is a deliberate intervention that modifies learning mechanisms (e.g., attention) and/or the conditions under which learning takes place by directing attention to specific features or structures in the input (Ruiz et al., 2025).
2. The assignment was not fully randomized. For logistical reasons, participants were grouped by their schoolteacher prior to the lab sessions. To the best of our knowledge, there was no intentional grouping based on ability or background. Group sizes and age distributions were balanced across conditions, but individual-level randomization was not implemented.
3. We tested a medium-small effect size, slightly smaller than in Monaghan et al. (2021), with accuracy estimates in our simulation-based power analysis of 0.75 (explicit) and 0.60 (implicit), assuming lower learning success for younger children than adult participants. With 25 participants per condition per age group, this yielded an estimated power of 0.88 to detect a medium-sized effect.

Tables

Table 1 Number of participants by instruction type and age group.

Instruction Type	**Age Group (Years)**	**n**
Implicit	8–9	25
	10–11	25
	12–13	26
Explicit	8–9	25
	10–11	25
	12–13	24

Table 2

Best fitting model for accuracy in training trials, showing fixed effects

Fixed Effects	Estimate	SD Error	Z	*P*
(Intercept)	-0.200	0.110	-1.821	.069
block	0.055	0.036	1.540	.124
age10-11	0.129	0.171	0.755	.450
age12-13	0.198	0.169	1.171	.242
condition:instruction	0.342	0.166	2.062	.039*
block:age10-11	-0.009	0.054	-0.172	.863
block:age12-13	0.007	0.052	0.144	.886
age10-11:condition	-0.406	0.250	-1.626	.104

age12-13:condition	-0.517	0.240	-2.183	.029*
block:age8-9:conditioninstruction	-0.058	0.053	-1.083	.279
block:age10-11:conditioninstruction	0.039	0.052	0.741	.459
block:age12-13:conditioninstruction	0.200	0.054	3.729	<.001***

Number of observations: 10851, Participants: 150 , Item, 106. AIC = 14761.4, BIC = 15439.5, log-likelihood = -7287.7. R syntax: glmer(accuracy ~ block + age + condition + block:age + age:condition + block:age:condition + (1 + block| participant) + (1 + block * age * condition | item), family = "binomial").

Figures

Figure 1

Example of a training trial. Screenshots were captured at the beginning, middle, and end of the trial. In the left scene, an elephant (agent) is pushing an owl (patient), while in the right scene, a zebra (agent) is jumping over a cow (patient).

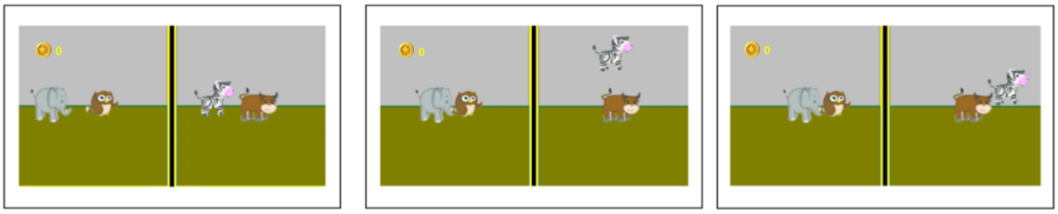


Figure 2

Performance on training trials of the CSL tasks by age group, across six blocks of exposure by learning conditions. Dotted lines at 0.5 represent chance performance. Error bars indicate standard error of the mean. The left panel shows performance in the implicit condition and the right shows performance in the explicit condition.

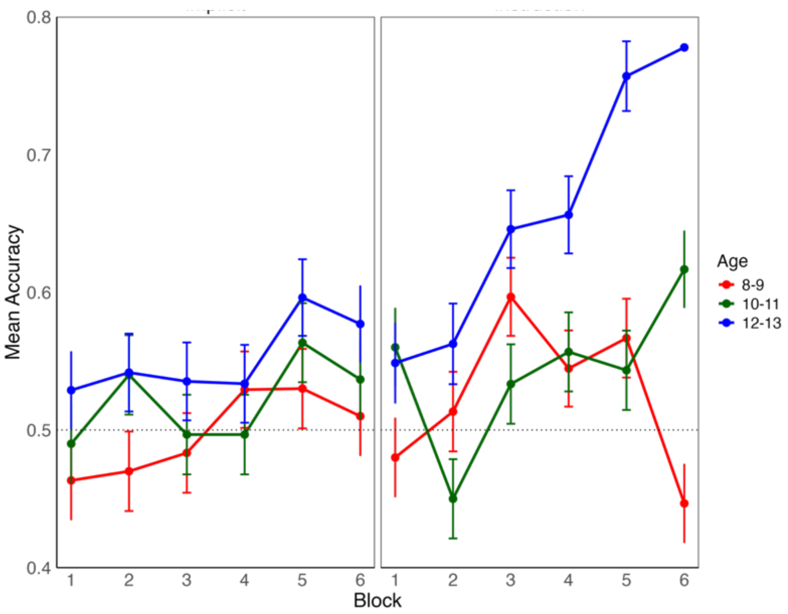
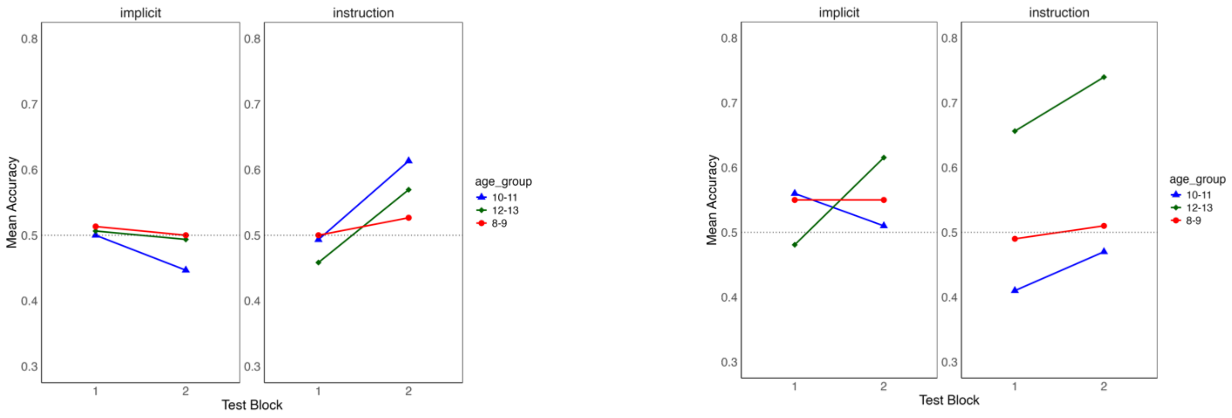


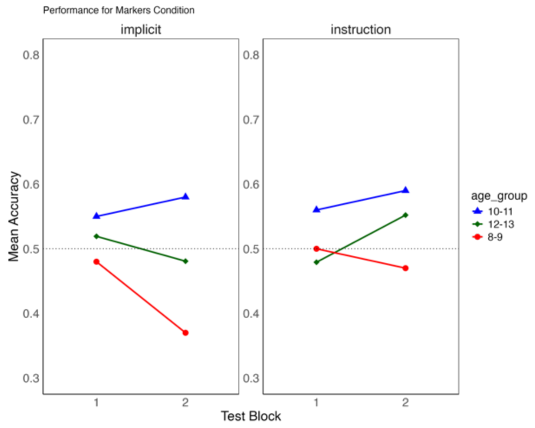
Figure 3

Mean accuracy on the vocabulary test trials of the CSL task by learning conditions. These trials only occurred in Blocks 3 and 6. Dotted lines at 0.5 represent chance performance. Error bars indicate standard error of the mean. The left panels show performance in the implicit condition and right ones show performance in the explicit condition.



A. Mean Accuracy for Noun Test

B. Mean Accuracy for Verb Test



C. Mean Accuracy for Marker Test

Figure 4

Performance on the grammaticality judgement task (i.e., syntax test trials) across age groups and instruction type.

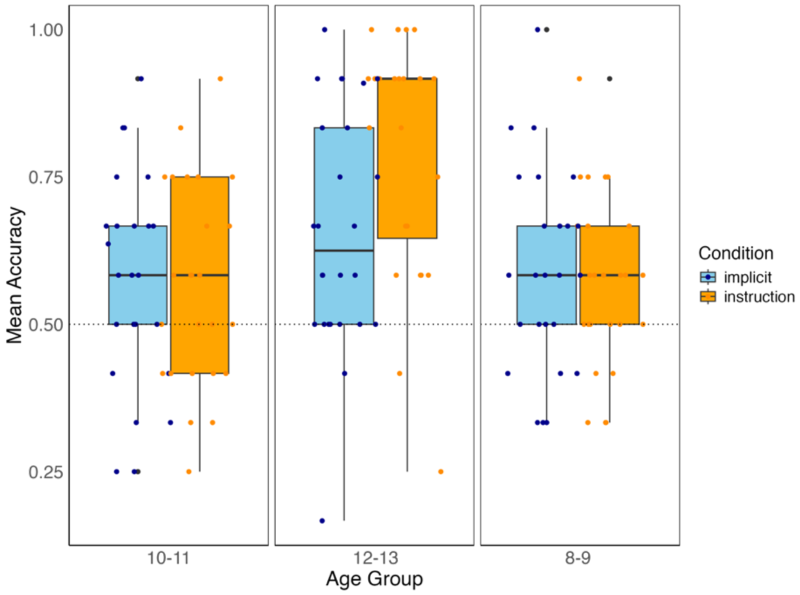
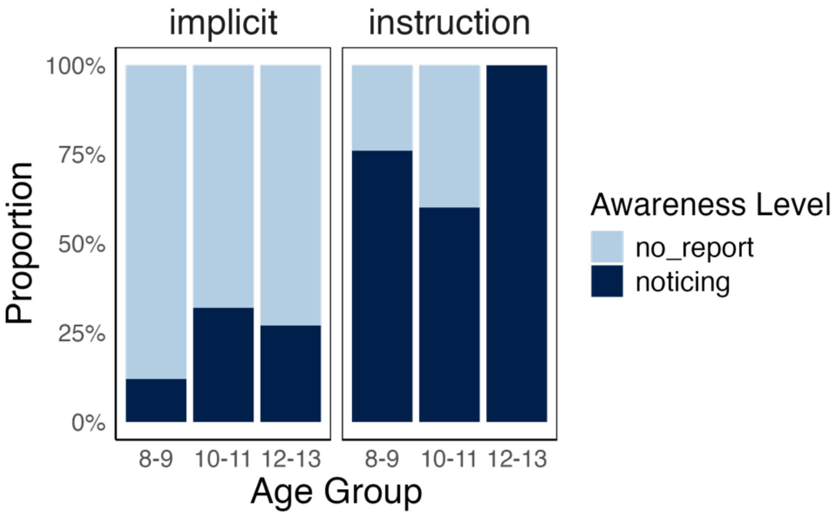


Figure 5

Proportion of children who were aware or unaware of the learning target, based on their retrospective verbal reports



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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1 Pseudoword lexicon used in the experiment
Appendix S2 Animal characters used in training and testing blocks.
Appendix S3 Model-building procedures for the training phase
Appendix S4 Supplementary Tables
Appendix S5 Exploratory analysis