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EMPIRICAL STUDY

Primed From the Start: Syntactic Priming During the First Days of Language Learning

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New linguistic information must be integrated into our existing language system. Using a novel experimental task that incorporates a syntactic priming paradigm into artificial language learning, we investigated how new grammatical regularities and words are learned. This innovation allowed us to control the language input the learner received, while the syntactic priming paradigm provided insight into the nature of the underlying syntactic processing machinery. The results of the present study pointed to facilitatory syntactic processing effects within the first days of learning: Syntactic and lexical priming effects revealed participants' sensitivity to both novel words and word orders. This suggested that novel syntactic structures and their meaning (form–function mapping) can be acquired rapidly through incidental learning. More generally, our study indicated similar mechanisms for learning and processing in both artificial and natural languages, with implications for the relationship between first and second language learning.

Keywords miniature language; artificial language; syntactic priming; second language learning; lexical priming; comprehension

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Introduction

For language learners immersed in a new language environment, the language does not come prepackaged in helpful bits and pieces. Rather, being exposed to the language means handling its various aspects, including new words and new grammatical regularities, all at the same time. Not only do language learners have to learn the meaning of the individual words, they also have to figure out how the structure of sentences maps onto meaning, as in “who did what to whom.” Thus, learners need to acquire the mapping between form and function and build corresponding memory representations. The question is, however, whether the mechanisms by which this mapping between form and function is learned differ between first (L1) and second (L2) language learning and, thus, whether the processing of a L2 is fundamentally different if it is learned after puberty (e.g., for arguments supporting different mechanisms, see Chomsky, 1965, and Clahsen & Felser, 2006; for arguments supporting same mechanisms, see Arnon & Christiansen, 2017, and Christiansen & Chater, 2016). The notion that there is substantial overlap between L1 and L2 processing as well as between L1 and L2 learning mechanisms is supported by findings indicating that the same brain regions are recruited for L1 and L2 processing (Indefrey, 2006; Weber & Indefrey, 2009) and that nativelike brain signatures of syntactic processing, even in miniature languages, emerge very quickly (Christiansen, Conway, & Onnis, 2012; Morgan-Short, Steinhauer, Sanz, & Ullman, 2011). Thus, it appears that a L2 is processed by the same broad neural networks also employed for the L1.

In the current study, we sought to further elucidate the mechanisms of L2 learning in the context of syntactic processing. Specifically, we investigated syntactic priming effects when learning a new L2 to determine whether such priming follows the same patterns as observed during L1 learning and processing. As discussed below, we further aimed to theoretically link syntactic priming effects to implicit learning as a possible mechanism for L1 and L2 learning. To this end, we probed syntactic priming effects during the first days of language learning. We hypothesized that syntactic priming is an implicit language learning mechanism (Chang, Dell, & Bock, 2006; Chang, Dell, Bock, & Griffin, 2000) whereby the repetition of syntactic structure helps the form–function mapping, potentially through error-based learning. Moreover, we explored how different factors, such as structure frequency and lexical information, influence syntactic priming as the language is being learned. These factors are known to both affect and interact in L1 processing; therefore, we manipulated both structure frequency and lexical information to better understand their potential role in syntactic learning. In doing so, we created an environment in

which multiple aspects of a language were learned and multiple variables were manipulated at the same time. This environment allowed us to come closer to a real-life learning situation while keeping full experimental control.

We used miniature artificial languages (Newman-Norlund, Frey, Petitto, & Grafton, 2006; Opitz & Friederici, 2004; Perek & Goldberg, 2015; Wonnacott, Newport, & Tanenhaus, 2008), as they are an ideal testbed to investigate language learning. In a miniature artificial language, the input that the learner receives, such as the distribution of words and structures in the language, can be fully controlled while retaining the same building blocks as in a natural language. Here, we combined an artificial language learning paradigm with a syntactic priming paradigm to study syntactic processing online during language learning. Given the hypothesized role of syntactic priming as a language learning mechanism, we predicted that nativelike syntactic priming effects would occur after minimal exposure to novel syntactic structures.

Background Literature

Syntactic Priming

Syntactic priming provides evidence that participants are sensitive to specific syntactic constructions; therefore, it can be used as a tool to investigate syntactic processing. Syntactic priming reflects the facilitation of syntactic processing based on the repetition of syntactic structures (for reviews, see Ferreira & Bock, 2006, and Pickering & Ferreira, 2008). It is one of many kinds of priming that are observed in language processing and, more generally, cognition; for example, in addition to syntactic priming, priming effects in language processing have also been shown for the repetition of specific word forms and semantic information (Dehaene et al., 2001; Neely, 1991; Rugg, 1985). Typically, repeated exposure to certain stimuli or stimulus features will lead to behavioral priming effects (in the form of improved performance and facilitated processing of the primed information) and will also produce a neural signature of priming—repetition suppression effects (Grill-Spector, Henson, & Martin, 2006; Gupta & Cohen, 2002; Henson & Rugg, 2003; Tulving & Schacter, 1990; Wiggs & Martin, 1998). Syntactic priming effects are found in production, using response choice (Bock, 1986) and response onset time as measures (Segaert, Menenti, Weber, & Hagoort, 2011; Smith & Wheeldon, 2001). They are also found, albeit somewhat less consistently, in language comprehension (Tooley & Traxler, 2010), using picture choice (Branigan, Pickering, & McLean, 2005) and reading time as measures (Weber & Indefrey, 2009). Moreover, syntactic priming effects have been detected for known structures in L1 and L2 processing in adults (Hartsuiker, Pickering, & Veltkamp, 2004; Weber & Indefrey, 2009)

and in children's language comprehension (Thothathiri & Snedeker, 2008) and production (Branigan & Messenger, 2016; Messenger, Branigan, McLean, & Sorace, 2012; Rowland, Chang, Ambridge, Pine, & Lieven, 2012). In addition, novel constructions like "this table needs cleaned" (Kaschak & Glenberg, 2004) can also be primed.

Two previous artificial language learning studies have looked at syntactic priming. Fehér, Wonnacott, and Smith (2016) showed abstract structural priming in production within a communicative context after learning an artificial language with novel word orders. Whereas Fehér et al. used a combination of an artificial language and a syntactic priming paradigm as a tool to investigate language change, we employed this methodological combination to investigate mechanisms of language learning. We previously reported a functional magnetic resonance imaging (fMRI) study using a very similar paradigm to the one used here (Weber, Christiansen, Petersson, Indefrey, & Hagoort, 2016) and showed that novel word orders can be primed 1 day after the first exposure to a miniature language, using both picture choice and neural repetition suppression/enhancement measures. This suggests that novel syntactic representations can be built up very quickly and investigated through syntactic priming during learning. Crucially, though, these two artificial language studies did not investigate the effects during the first moments of learners' exposure to novel grammatical regularities. Moreover, the behavioral measures used in these studies were restricted to picture and language production choices. In the current study, we investigated these effects in comprehension, using both picture choice and reading-aloud time as measures. While the picture choice indicated whether syntactic priming facilitates the interpretation of "who did what to whom," the reading-aloud time provided a more direct measure of whether the online processing system is sensitive to the processing of grammatical structures in context.

Syntactic Priming as Implicit Learning

During learning, syntactic priming can be interpreted as an indication of when the processing system has accommodated novel structures, because the priming effect shows that the novel grammatical regularity must have a mental representation. Building on implicit learning theory, some accounts of syntactic priming have proposed that it might even be a mechanism for language learning (Chang et al., 2000). The repetition of syntactic structures might help in the mapping of meaning onto form (Ferreira & Bock, 2006) by reducing the error signal that is generated when the input does not match the expected syntactic structure. Thus, syntactic priming effects might be particularly strong during

learning. From this line of thought follows an additional prediction known as the inverse preference effect: Priming effects should be stronger for infrequent structures because these benefit most from repetition (Ferreira & Bock, 2006), as an unexpected structure leads to a larger error signal (Chang, Janciuskas, & Fitz, 2012). In both language comprehension (Fine, Jaeger, Farmer, & Qian, 2013) and production (Jaeger & Snider, 2013; Segaert et al., 2011), studies have shown that syntactic priming is sensitive to expectation modulations, such as the frequency of occurrence of a particular structure. This is in line with accounts of error-based implicit learning and with the inverse preference effect. Unexpected information leads to a larger prediction error and, hence, a larger learning signal.

As mentioned previously, syntactic priming effects are also found in children's language learning (Branigan & Messenger, 2016; Messenger et al., 2012; Thothathiri & Snedeker, 2008), from as early as 3 years of age (Rowland et al., 2012). Thus, syntactic priming might be a learning mechanism for syntactic structures that is present throughout life, driving the acquisition of grammatical structures in the L1 and the L2 and facilitating the processing of known syntactic structures. However, in both adults and children, syntactic priming effects have mainly been studied using syntactic structures with which the participants had at least some experience. To link these priming effects to learning, a key aim of this study is, therefore, to show that these effects are present from the very beginning of learning a new syntactic structure.

Lexical Influences on Syntactic Learning

In its original form, the implicit learning theory of structural priming is a purely structural account, independent of lexical representations. Other theories, such as the residual activation account (Pickering & Branigan, 1998), link syntactic priming to the activation of syntactic frames that are tied to lexical representations. This implies that syntactic processing is lexically guided (Jackendoff, 2002; MacDonald, Pearlmutter, & Seidenberg, 1994) and that verb repetition, therefore, will boost syntactic priming effects (Pickering & Branigan, 1998). However, syntactic priming is also found with novel or morphologically anomalous verbs (Ivanova, Pickering, Branigan, McLean, & Costa, 2012), indicating that it has at least some lexically independent components.

Even if there is lexically independent syntactic processing in a learned language, syntactic priming linked to verb repetition might be helpful during language acquisition because lexical repetition might provide an additional boost to the mapping process between form and meaning. This could be because of a strong lexical contribution or even because of lexical specificity

of the mechanism responsible for building syntactic structure at the beginning of learning (Savage, Lieven, Theakston, & Tomasello, 2003; Tomasello, 2000). However, in L1 acquisition, many syntactic priming studies have found verb-independent priming effects (Branigan & McLean, 2016; Huttenlocher, Vasilyeva, & Shimpi, 2004; Messenger et al., 2012; Peter, Chang, Pine, Blything, & Rowland, 2015; Rowland et al., 2012), indicating that there is at least some independence of syntactic learning from a lexical boost to priming (Branigan & McLean, 2016; Rowland et al., 2012).

The Current Study

In this study, participants were exposed to a novel language, which they learned in four sessions over the course of 9 days. They read sentences with novel lexical items occurring in novel transitive word orders. Participants could infer the meaning of these sentences from accompanying pictures. This allowed them to map the subject (S), object (O), and verb (V) of the transitive sentences, respectively, onto the agent, patient, and action that they saw in the pictures. To make lexical learning as easy as possible, the novel language had the same mapping of persons to nouns and actions to verbs as in participants' L1. The experimental manipulation involved both sentence structure and lexical repetition. To test for the inverse preference effect, we added a frequency manipulation on the first day of exposure to the sentences. Priming effects were investigated using a picture-choice task as a measure of how well participants understood the meaning of the sentences. In addition, the effects of priming on reading-aloud times were measured, which provided a processing-based measure of online processing during learning. We chose reading-aloud times instead of standard (silent) reading (measured via button presses) to keep the exposure to the sentences the same for all participants during learning.

We asked whether we would detect syntactic priming effects in the responses from the picture-choice task in the form of increased performance after priming as well as in the processing-based measure of reading-aloud times in the form of faster reading-aloud times after priming. These findings would be in line with priming effects in L1 acquisition and in L1 and L2 processing. If novel syntactic structures are quickly integrated into the language-processing system, we expected the priming effects to known and novel structures to resemble each other early on. We were particularly interested in whether syntactic priming effects would occur on the first day and during the first hour of exposure to novel syntactic regularities. This would point to a link between syntactic priming and syntactic learning, facilitating the mapping of syntactic form onto

function (meaning). We predicted that potential effects on reading-aloud times would get larger across days, as processing is further facilitated over the course of learning, but that picture-choice performance would reach ceiling levels over time once participants have become proficient comprehenders of the new language. In addition, we also expected lexical repetition of verbs to result in priming effects, which would reflect the learning and integration of novel lexical information.

We also investigated whether syntactic processing during the early stages of learning is lexically bound, lexically mediated, or lexically independent. More specifically, if syntactic learning is helped by lexical–syntactic information, then we should find a lexical mediation to syntactic priming effects from the first day of exposure. If, however, more abstract syntactic structures can be learned independently, syntactic priming effects might only become lexically mediated over time, if at all. We therefore tracked syntactic priming effects during learning over multiple days. Furthermore, in line with the inverse preference effect in syntactic priming and its potential link to error-based learning, we expected stronger priming effects for the more infrequent syntactic structures than for the more frequent syntactic structures. However, as some minimal exposure to a structure might be necessary to produce a priming response, it might also be the case that the more frequent structure would initially show the stronger effect.

Method

Participants

Twenty-seven university students, all native speakers of Dutch (21 female, 6 male; age range = 18–30) were tested; one participant was subsequently excluded from the analysis because the sound files were not properly recorded. Three additional participants started the experiment but did not complete all days. All participants had normal or corrected to normal vision. The participants received course credits or money for their participation. All participants gave informed consent prior to participating.

Materials

The artificial language consisted of 36 transitive verbs, 10 intransitive verbs, and 4 nouns (example words and sentences can be seen in Figure 1 and in Appendix S1 in the Supporting Information online). There were four different types of sentence structures in this language. Two were novel transitive word orders that are not permissible for Dutch transitive sentences. These word

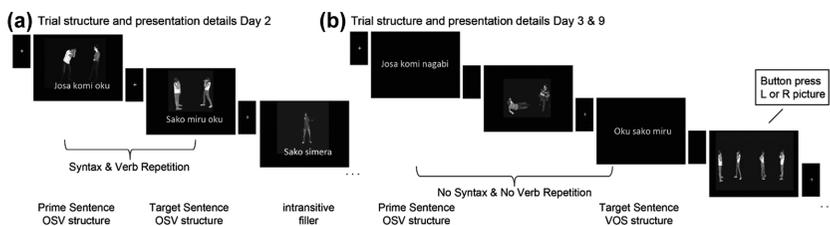


Figure 1 Trial structure on Day 2 (left panel). A sentence–picture pairing started with a fixation cross followed by a screen displaying both the picture and the sentence simultaneously. An example of a trial is shown where both syntax and verb are repeated between prime and target (OSV sentence structure; the verb is *oku*, “to photograph”). Trial structure on Day 3 and Day 9 (right panel). A sentence–picture pairing started with a fixation cross followed by the sentence. After a blank image, a picture was presented. On target trials two pictures were presented simultaneously, and participants had to choose the one corresponding to the preceding sentence. An example of a trial is shown where neither the syntax (prime OSV, target VOS structure) nor the verb is repeated (prime *nagabi*, “to draw,” target *oku*, “to photograph”).

orders were VOS and OSV. A third transitive word order was SVO, the active word order in Dutch and thus known to the participants. The fourth sentence structure was an intransitive SV word order, also present in Dutch, and used in filler sentences. All subjects and objects were animate (man, woman, girl, boy).

Lexical items were novel with an easy-to-produce syllabic structure (e.g., *basi*, *kisu*, *epaki*, *hakaro*). A list of lexical items was rated by six Dutch native speakers, and those that resembled Dutch or otherwise meaningful words were removed. The assignment of meaning to the different words was counterbalanced across subjects (using eight different word-referent assignment lists), as was the selection of which of the new word orders was the frequent structure on Day 2. Day 1 was an introductory day when participants learned the four nouns (see below). On Day 2, the experimental lists contained 20 trials (prime–target pairs) for the frequent word order condition and 10 each for the infrequent and known word orders (per verb and syntactic priming condition). The lists for Days 3 and 9 contained 20 trials per condition.

The sentences described events depicted in black and white photographs. There were eight possible depictions of each event. These were created using two sets of actor pairs (girl/boy and woman/man), where the agent was either the male or the female actor and where the agent was either located to the left or to the right in the picture.

Procedure

Participants took part in the experiment on four different days (Day 1, Day 2, Day 3, and Day 9). They were told that they were going to learn a new language called “Alienese.” The experiment was run using Presentation[®] software (Neurobehavioral Systems, 2018). Participants sat in front of a desktop computer. Words and sentences were presented in 22-point, white, Arial font on a black background.

Vocabulary Teaching

On Day 1, participants learned the four nouns—the words for man, woman, boy, and girl—by means of a picture–word matching paradigm. First, each word was presented six times with a matching picture, with all nouns intermixed. To verify the learning, the pictures were then presented with the four possible nouns, and participants had to choose the matching noun by a button press. They had learned all four nouns by the end of this noun-learning session (after six more repetitions of each noun). For one participant, the whole procedure was repeated again, as she was not 100% correct after the first round of exposure. The verbs were not taught explicitly; they were learned during exposure to the sentences on the subsequent days.

Training Session

On Day 2, participants took part in a sentence training session, which took around 50 minutes (including a short break). Eighty percent of the sentences were experimental items, and 20% were filler sentences (intransitives). In total, including filler sentences, Word Order 1, which was counterbalanced across participants (for half of the participants, Word Order 1 was VOS, for the other half it was OSV), occurred 40% of the time. The other three word orders (Word Order 2, known word order SVO, and intransitive word order SV), each occurred 20% of the time. By having one of the word orders appear twice as often as each of the other syntactic structures (including fillers), we could study the potential effects of structural frequency on syntactic priming during the initial phase of learning.

Participants were asked to read the sentences aloud, and we recorded their responses. Pictures and sentences were displayed simultaneously: The picture was presented in the middle of the screen, and the sentence was presented in the middle of the bottom half of the screen overlapping the picture. A picture–sentence trial would start with a fixation cross displayed for 2 seconds followed by the sentence and picture, which were displayed simultaneously for 4 seconds. To mirror the manipulation of the following days, we

included lexical and syntactic priming manipulations. Both verbs and word orders were repeated in half of the cases, orthogonally to each other. The nouns were never repeated in subsequent sentences. Sentences containing the woman and the man alternated with those containing the boy and the girl; each sentence structure would thus occur with both noun combinations. Verbs were randomly assigned to a trial, and each transitive verb would occur in all transitive structures.

Experimental Sessions

On Days 3 and 9, participants took part in the experimental sessions, which lasted about 1.5 hours (including three short breaks). Here, all word orders occurred equally often. On these days, the picture was displayed after the sentence (see Figure 1). A fixation cross was displayed for an average of 1.7 seconds, followed by the sentence for 2 seconds, then a blank screen for 1 second, and then a picture describing the sentence for 3 seconds (or for 4 seconds if it was a target with two pictures). The limited temporal jitter was introduced between the fixation cross and the blank screen because we wanted to test the paradigm for an fMRI version of this study.

In addition to reading aloud, participants also had to perform a comprehension task. After a target sentence, they were presented with two pictures. Both pictures depicted the same action with the same actors, but the roles of the actors (agent and patient) were reversed. Participants were asked to decide which of the pictures matched the preceding sentence by pressing one of two buttons with their left and right index fingers. In all three sessions (Days 2, 3, and 9), the priming manipulations were the same and involved immediate repetition (or nonrepetition)—between prime and target—of syntactic structure, the verb, or both. At the end of the sessions on Days 2, 3, and 9, participants received a paper-based questionnaire with all 46 Alienese verbs. They were asked to translate these verbs into Dutch.

Data Analysis

The onset times were measured online using a voice key and saved in a logfile. Speech offset values were determined by applying a semiautomatic method in Praat (Boersma & Weenink, 2015) to the recorded sound files. A script determined speech offset times based on loudness. Participant-specific parameters for this calculation were determined using random spot checks. Following this, onset and offset times that were more than three standard deviations different from the mean were manually checked for errors. This procedure was done

twice in a row. Where identified, sound files that contained coughs, hesitations, and repairs were removed from the analysis. In total, 11.9% of trials were removed from the analysis following these steps; these trials were also removed from the analysis of picture choices.

We analyzed the picture choices using mixed-effects logit models (Barr, Levy, Scheepers, & Tily, 2013; Jaeger, 2008; Pinheiro & Bates, 2000) and the overall reading-aloud times on Days 2, 3, and 9 (from the start of sentence presentation to reading offset) using a mixed-effects model with random effects for subjects and items in R (R Core Team, 2016). The model for the overall reading-aloud times on Days 2, 3, and 9 included fixed effects for day (Days 2, 3, 9), type of sentence (frequent, infrequent, known), verb (verb repeated, unrepeated), and syntax (syntax repeated, unrepeated) and allowed interactions between all of these. The random effects structure included a random intercept for subjects and items, and random slopes for day and type of sentence for subjects, as well as for items.

Because we were specifically interested in determining whether syntactic and verb priming effects would already be strongly present on the first day of learning, thus indicating their importance for learning form–function mappings, we ran a separate model for this day only. The model targeting the overall reading-aloud times on Day 2 included fixed effects for type of sentence (frequent, infrequent, known), verb (verb repeated, unrepeated), and syntax (syntax repeated, unrepeated) and allowed interactions between all of these. The random-effects structure included a random intercept for subjects and items and no random slopes (as the model including the random slope with the highest variance did not converge).

For the picture choices, following (Barr et al., 2013), we used a model with the maximal effect structure that was still converging. When a model did not converge, we removed random slopes for factors with the lowest variance first. For contrast specifications, Helmert coding was used (for two levels, this was equivalent to deviation coding), where each level of a categorical variable is compared to the mean of the subsequent levels. This coding was adopted to ensure that for the factor type of sentence we could address two key questions related to our predictions: (a) whether the effects for known structures were different from those for novel structures and (b) whether there was a difference between frequent and infrequent novel structures. In the text, we only report effects for the contrasts of interest. The model for the picture choices included fixed effects for day (Days 3, 9), type of sentence (frequent, infrequent, known), verb (verb repeated, unrepeated), and syntax (syntax repeated, unrepeated) and allowed interactions between all of these. The random-effects structure

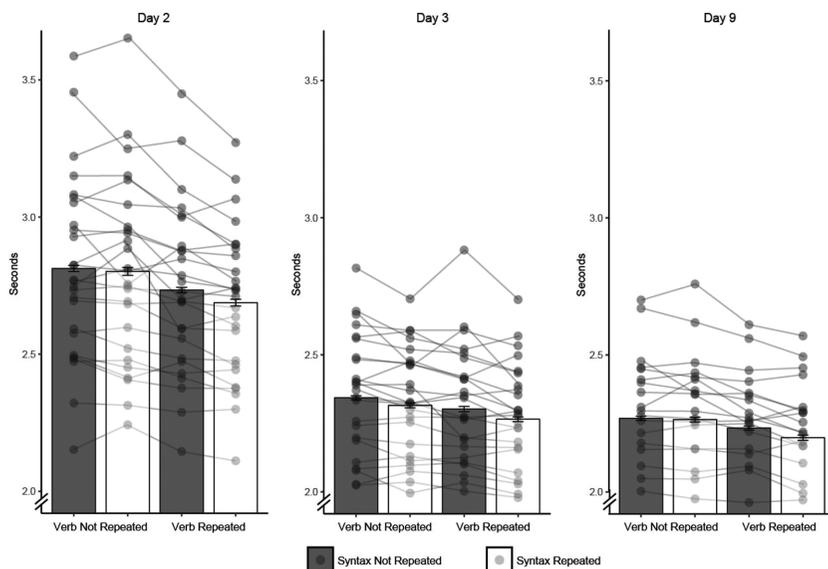


Figure 2 Overall read-aloud times (from text display onset to reading offset) on Days 2, 3, and 9 for the verb and syntax repetition conditions. The error bars show the standard error of the mean. Dots and lines represent individual participants' performance.

included a random intercept for subjects, items, and random slopes for type of sentence and day for subjects and item. The statistics for all fixed effects in all analyses are reported in Appendix S2.

Results

Verb Translation

Participants improved in translating the verbs from Alienese into Dutch from Day 2 to Day 9 ($M_{\text{Day 2}} = 27.98\%$, $M_{\text{Day 3}} = 48.96\%$, $M_{\text{Day 9}} = 64.76\%$).

Overall Reading-Aloud Times

The results for overall reading-aloud times are illustrated in Figure 2. Participants were significantly faster if the verb was repeated, $\beta = -.06$, $SE = .01$, $t = -11.07$, $p < .001$. Participants were also significantly faster if the syntax was repeated, $\beta = -.03$, $SE = .01$, $t = -4.71$, $p < .001$. This effect did not differ across days, both $|t| < 1.00$. There was a significant interaction between verb and syntax, $\beta = -.02$, $SE = .01$, $t = -2.00$, $p = .045$: If the verb was repeated, there was a large syntactic repetition effect, $\beta = -.04$, $SE = .01$, $t = -4.90$, p

$< .001$, while there was a marginally significant syntactic repetition effect if the verb was not repeated, $\beta = -.02$, $SE = .01$, $t = -1.90$, $p = .06$. However, there was no difference between known and novel word orders for the verb by syntax interaction, $|t| < 1.00$. The two three-way interactions between day (Day 3 vs. Day 9 and Day 2 vs. Day 3 & 9), verb, and syntax were not significant, $t = 1.11$ and $|t| < 1.00$. The two interactions between type of sentence (frequent vs. infrequent and known vs. novel) and syntax were not significant, $|t| < 1.00$. Finally, there was also no further interaction involving day, $|t| < 1.00$.

Overall Reading-Aloud Times on Day 2

Participants were significantly faster if the verb was repeated, $\beta = -.04$, $SE = .01$, $t = -7.14$, $p < .001$. Participants were also significantly faster if the syntax was repeated between prime and target (see Figure 2), $\beta = -.01$, $SE = .01$, $t = -2.62$, $p = .009$. While numerically the syntactic repetition effect was larger in the case of verb repetition, the interaction between verb and syntax repetition was not significant, $t = -1.46$, neither were the two interactions between verb, syntax, and type of sentence (frequent vs. infrequent and known vs. novel), $|t| < 1.00$. Finally, the two interactions between type of sentence (frequent vs. infrequent and known vs. novel) and syntax were not significant, $|t| < 1.00$.

Picture Choices on Days 3 and 9

The results for picture choices are depicted in Figure 3. Participants were significantly better in making the correct choice if the verb was repeated, $\beta = .24$, $SE = .06$, $Z = 3.82$, $p < .001$. Participants were also significantly better in making the correct choice if the syntactic structure was repeated, $\beta = .38$, $SE = .07$, $Z = 5.43$, $p < .001$. The syntactic repetition effect decreased slightly on Day 9, $\beta = -.39$, $SE = .13$, $Z = -2.95$, $p < .001$. Verb repetition gave a boost to the syntactic repetition effect, but this effect was only marginally significant, $\beta = .23$, $SE = .13$, $Z = 1.83$, $p = .07$ (see Figure 3). If the verb was repeated, there was a large syntactic repetition effect, $\beta = .49$, $SE = .09$, $t = 5.10$, $p < .001$; nonetheless, there was still a significant syntactic repetition effect if the verb was not repeated, $\beta = .26$, $SE = .08$, $Z = 3.10$, $p = .002$.

The interaction effect between verb and syntax was larger on Day 3 than on Day 9, $\beta = -.52$, $SE = .25$, $Z = -2.06$, $p = .04$, as well as larger for the known compared to the novel structures, $\beta = .98$, $SE = .27$, $Z = 3.64$, $p < .001$. For the known structures, the verb by syntax interaction was significant, $\beta = .88$, $SE = .22$, $Z = 4.03$, $p < .001$, while for the novel structures, the interaction between verb and syntax was not significant, $|Z| < 1.00$. The syntactic repetition effect was slightly larger if the target sentences had a known sentence structure,

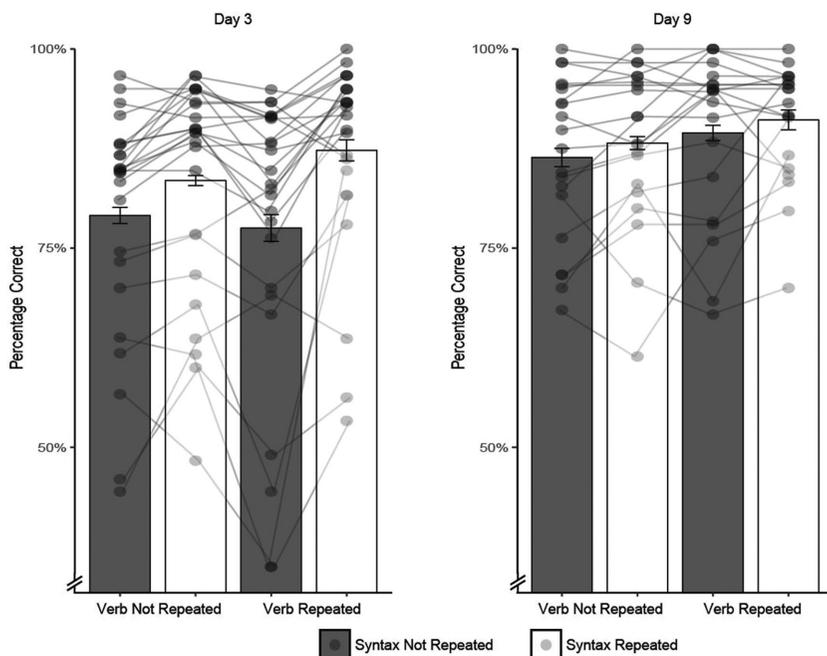


Figure 3 Picture choices for Day 3 and Day 9 for the verb and syntax repetition conditions. The error bars show the standard error of the mean. Dots and lines represent individual participants' performance.

$\beta = .36$, $SE = .14$, $Z = 2.56$, $p = .01$. Moreover, the syntactic repetition effect was larger for the frequent than for the infrequent structures, $\beta = .32$, $SE = .15$, $Z = 2.07$, $p = .04$. Given the interactions, we explored the syntactic repetition effect within each structure separately. The effect was significant for the known structure, $\beta = .63$, $SE = .11$, $Z = 5.76$, $p < .001$, and the frequent structure, $\beta = .41$, $SE = .11$, $Z = 3.83$, $p < .001$, but not for the infrequent structure, $|Z| < 1.00$.

Discussion

In this study, we showed that language learners can acquire novel word orders and new lexical items very quickly. Although the meaning was only provided in the form of pictures, participants were able to extract this information from the novel language. Both the meaning of the verbs and the syntactic structures were learned to a high level of proficiency (65% correct in verb translation, 89% correct in the picture-choice task on Day 9).

Effects of Verb and Syntactic Repetition

Both verb and syntactic priming effects were found for the overall reading-aloud times of the sentences. This measure of overall processing time might reflect the online efficiency of the language-processing system, which is facilitated by repetition (Christiansen & Chater, 2016). Our results show that language learners became sensitive to the underlying syntactic structures very quickly, within the first hour of exposure (i.e., the syntactic priming effect was significant from the first day of exposure to the sentences), even if those structures are not presented to the learner explicitly. Moreover, similarly to the results of our previous fMRI study using this paradigm in the scanner and looking at hemodynamic repetition effects (Weber et al., 2016), verb and syntactic priming effects were found for the picture-choice measure, indicating that the repetition of both lexical and syntactic information helps in understanding novel linguistic information. The picture-choice measure can be construed as reflecting the outcome of syntactic processing, as the picture choice is made after an interpretation is established. Lexical and syntactic repetitions seem to facilitate the mapping of form onto meaning, thus leading to an improved interpretation.

Mechanisms of Priming and Learning

Mechanistically, behavioral priming effects might be the result of neural repetition effects, as found in our previous fMRI study (Weber et al., 2016). The repetition of novel information might strengthen (a) the creation of a novel memory representation (Henson, Shallice, & Dolan, 2000), (b) the distributional pattern of a syntactic structure (i.e., the order of the grammatical roles), and/or (c) the mapping of structure onto thematic roles and their links to meaning. Alternatively, predictive coding theories (Friston, 2005) and error-based learning theories (Chang et al., 2006) can also account for priming effects. In such theories, prediction errors generated between an expected event (i.e., an expected syntactic structure) and the actual syntactic structure encountered are useful learning signals. Repetition of information then leads to reduction in prediction error, which manifests itself in priming or neural repetition effects (Auzsztulewicz & Friston, 2016). That syntactic priming effects are found from the start of exposure thus supports the idea that syntactic priming plays a role in language learning (Bock & Griffin, 2000; Chang et al., 2000; Ferreira & Bock, 2006) because it shows that it supports a form–function mapping and the building of a novel memory representation from the earliest moments of exposure to new language patterns.

However, the implicit learning account of syntactic priming also predicts that the infrequent structure should have shown a stronger syntactic priming

effect (Chang et al., 2012; Ferreira & Bock, 2006). We did not observe such an effect here; rather, syntactic priming effects in read-aloud times were similar for all structures (but see Weber et al., 2016, for differences in the neural signature of priming effects using a similar paradigm). Moreover, for the picture choices, a syntactic repetition effect was detected for both known and frequent structures but not the infrequent ones, indicating that at least a certain level of exposure has to be reached before structural priming can lead to a benefit in understanding the meaning of the sentences (McDonough & Fulga, 2015). The syntactic priming effect on the picture choices appeared to level off on Day 9. This is most likely due to a ceiling effect, as participants made very few mistakes on Day 9 (11%), leaving little room for improvement due to priming.

Lexical Influences on Syntactic Learning

In L1 processing, syntactic priming effects are sometimes boosted by verb repetition (Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Pickering & Branigan, 1998), hinting at a lexical mediation of some syntactic processing effects. During L1 acquisition in young children (3–4 year olds), there is some evidence of lexically bound syntactic priming effects (Savage et al., 2003) whereas other studies find verb-independent syntactic priming (Branigan & McLean, 2016; Huttenlocher et al., 2004; Messenger et al., 2012; Rowland et al., 2012), showing that syntactic structures can be learned independently of verb-specific information. Nevertheless, a lexical boost to the syntactic priming effect is often also found in children, both in comprehension and production (Branigan & McLean, 2016; Thothathiri & Snedeker, 2008), but it might only be found in older children (Rowland et al., 2012).

In the present study, we found evidence of a verb boost to syntactic priming for known syntactic structures within a novel language on the picture-choice measure. However, no verb boost was detected for novel syntactic structures using this measure. On the other hand, the read-aloud measure revealed a verb boost to syntactic priming, which did not differ between novel and known syntactic structures. When looking at the first day of learning on its own, there was no verb boost, but there was a verb-independent syntactic priming effect. Thus, verb-independent syntactic priming effects for novel structures were found using both target measures starting on the first day of exposure to the sentences, suggesting that the structure may not be lexically bound in initial phases of experience with a new structure. Rather, it seems that some amount of generalization to other verbs occurs. This, in turn, implies that sensitivity to more general distributional regularities relating to the different word orders is established early in learning. This is thus in line with theories that link

syntactic priming effects to implicit learning mechanisms (Chang et al., 2006) but seemingly inconsistent with a strong account of lexically bound syntactic learning (Tomasello, 2000).

Taken together, these results indicate that the syntactic priming effects for novel structures in a miniature language display similar patterns very early on to those obtained during L1 learning and processing. Abstract syntactic priming effects were found from the start, while a verb boost was present after some exposure to the artificial language. More generally, the syntactic priming effects for novel structures revealed through both the picture-choice and read-aloud measures show that these effects can be employed as a tool to investigate syntactic processing during language learning using a miniature artificial language.

Limitations and Future Directions

This study is an initial foray into investigating syntactic priming effects as a learning mechanism during the first hours of language learning. Consequently, this initial design has certain limitations that should be considered in future research. As a processing-based measure, we used reading-aloud times to be able to control the timing of the input during learning. However, in the future, finer-grained measures, such as word-by-word self-paced reading times or a combination of comprehension and production measures could be used. Moreover, it may also be of value to link the strength of syntactic priming effects during learning to the learning outcomes by employing more nuanced behavioral measures of learning (e.g., in this study, many participants performed at ceiling on the picture-choice task on Day 9). Furthermore, the reading-based nature of our design (with the reading-aloud task) does not resemble learning situations typical of L1 acquisition or immersion-based L2 learning. Thus, in future research, it may be useful to adapt our experimental paradigm to a more speech-based format.

Conclusion

In sum, syntactic priming effects appeared early during the learning of novel syntactic structures and revealed an early sensitivity to these structures. The speed at which novel word orders can be extracted by adult learners from the input suggests a general sensitivity to sequence structure that is not fixed for life by learners' long-term experience with the dominant L1. Moreover, these findings suggest that similar mechanisms are in place for L1 and L2 acquisition

and that artificial language learning paradigms can be used to study both kinds of learning processes.

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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. Sample Lexical Items.

Appendix S2. Summary of Statistical Results.

Appendix: Accessible Summary (also publicly available at <https://oasis-database.org>)

The First Days of Learning New Words and Grammar

What This Research Was About And Why It Is Important

Learning a new language is a difficult task. For example, it requires learners to memorize new words, to understand how to put those words together in a grammatically correct way, and to combine them with what they already know about the language. In this study, the researchers simulated the very first days of language learning as native speakers of Dutch learned “Alienese”—an artificial mini language. Because the language was constructed by the researchers, participants had no familiarity with it, so the researchers could examine how a new language is learned within the first few days. The researchers showed that new words, new grammar patterns, and their meaning can be learned rapidly by reading short sentences and choosing the image that best depicts their meanings, without participants intentionally trying to memorize the material.

What the Researchers Did

- The researchers tested 27 native speakers of Dutch, all university students.
- They created a mini language containing several words, such as *josa* “woman,” *komi* “man,” and *oku* “to photograph.”
- These words could be combined in a particular order, which either did or did not follow a typical order of words in Dutch. For instance, both sentences *Komi oku josa* (literally, man photograph woman) and *Josa komi oku* (literally, woman man photograph) had the same meaning “The man photographs the woman.” However, only the first sentence is similar to Dutch because it has the same order of words as Dutch.
- On Day 1, participants learned the nouns (e.g., *josa*) and then were tested to make sure that they knew their meanings.
- Participants then read short (three-word) sentences with familiar and unfamiliar word orders accompanied by pictures of their meaning. Participants had to read each sentence aloud and then choose the correct image from several alternatives. This task lasted for 50–90 minutes and was repeated three more times, on Days 2, 3, and five days later on Day 9.
- The researchers were interested in how experiencing repeated language (repeated words or repeated order of words across different sentences) influenced participants’ performance. If experiencing repetition is helpful, then participants should be faster at reading sentences and at choosing the correct meaning when they had experienced the language repeatedly earlier.

What the Researchers Found

- Participants learned novel words and the order in which they were presented quickly over the course of several days.
- Participants were faster at reading sentences and more accurate in choosing the correct image when words had been experienced repeatedly.
- Participants were also faster at reading sentences and choosing the correct image when the order of words in them had been repeated. This indicated that participants learned something about the order of elements in Aliense— they learned something about its grammar.
- When both words and word orders were repeated, participants were even faster in reading the sentences. This suggested that participants learned something both about words and about how to string them into a sentence.

Things to Consider

- A mini language can be learned quickly by performing a simple reading and picture-choice task, without intentionally memorizing the material.
- The repetition of words and grammar (in this case, order in which words are organized in a sentence) might help learners make sense of the patterns in language; this repetition-driven learning probably supports the learning of language from the first minutes of exposure to it.
- Using an artificial mini language allows researchers to simulate early stages of language learning because it allows them to control what learners see and hear when learning begins.

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